Università Politecnica delle Marche
Scuola di Dottorato di Ricerca in Scienze dell'Ingegneria
Curriculum in Ingegneria Civile, Ambientale, Edile ed Architettura
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Applications of innovative materials, GFRP and structural adhesives, for the curtain wall: technological and performance verification.

Ph.D. Dissertation of:
Vanessa Terlizzi

Advisor:
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XVI Ciclo – new series

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Via Brecce Bianche — 60131 - Ancona, Italy

In breve

L'obiettivo del presente lavoro è verificare l'applicabilità di materiali innovativi, quali compositi (GFRP - Glass Fibre Reinforced Polymer) e colle strutturali, per la realizzazione di facciate continue ad alte prestazioni meccaniche e termiche e a basso impatto ambientale.

Tale obiettivo è stato verificato anche tramite l'applicazione del principio della "*Semplificazione tecnologica"* che rappresenta il filo conduttore alla base dello studio e delle sperimentazioni svolte dal gruppo di ricerca, coordinato dal Prof. P.Munafò, che ha sviluppato il brevetto "Sistema per la realizzazione di facciate di edifici" (n. 102015000087569) di cui il Professore è inventore. Con tale filosofia di approccio è possibile realizzare componenti edilizi altamente prestazionali e semplici nella loro concezione essendo costituiti con un numero limitato di pezzi implicando così un minor consumo di energia nella produzione, assemblaggio, manutenzione e smaltimento del prodotto, classificandolo quindi come eco-sostenibile.

In questa tesi viene verificata la fattibilità di un sistema costruttivo per la realizzazione di facciate continue per edifici studiando preventivamente, con test sperimentali e analisi sul ciclo di vita dei componenti, le prestazioni meccaniche dei profili in GFRP e degli adesivi strutturali in condizioni di invecchiamento accelerato (durabilità) e non, e l'interazione del componente edilizio con l'ambiente, dalla produzione alla dismissione finale (LCA - Life Cycle Assessment).

I metodi principalmente usati in questo studio sono di tipo sperimentale al fine di testare le proprietà meccaniche dei materiali, in condizioni ambientali e dopo invecchiamento (accelerato in camera climatica ad elevata umidità e temperatura (ISO 6270-2) e sotto esposizione ai raggi UV (ASTM D904-99)). In seguito ai singoli test di invecchiamento precedentemente citati, sono stati condotti ulteriori sperimentazioni riguardanti il trattamento di campioni a condizioni di invecchiamento combinato (camera climatica ed esposizione ai raggi UV - Tcc+Tuv - e viceversa - Tuv+Tcc -). Al fine di validare i risultati ottenuti dalle sperimentazioni effettuate sono stati eseguiti test numerici e analitici.

Il risultato più significativo è dato proprio dalla validazione dell'idea brevettuale dimostrando la possibilità di industrializzare componenti (facciate continue) che utilizzano tale materiale composito (pultruso - GFRP), mediante l'accoppiamento a materiali come l'acciaio che possono conferire al componente alte prestazioni meccaniche, soprattutto per quanto riguarda il contenimento delle deformazioni sotto carico. Le soluzioni tecniche studiate inoltre evitano il problema della rottura fragile delle giunzioni bullonate che è uno dei problemi che riguardano le giunzioni di questo tipo su profili in pultruso. La deformabilità e la rottura fragile delle giunzioni bullonate dei profili in pultruso ne hanno limitato l'utilizzo nel settore dell'ingegneria edile per la realizzazione di facciate continue specie di grandi dimensioni.

A tal fine l'attività di ricerca è stata prevalentemente incentrata a verificare la possibilità di inserire nei montati in pultruso di tali facciate, una lamina d'acciaio incollata per contenere la deformazione e per migliorare la qualità della giunzione bullonata in modo da evitare rotture di tipo fragile raggiunto il carico di collasso. Le risultanze dei test sperimentali condotti dimostrano le buone performance del sistema ibrido GFRP-acciaio anche in seguito all'esposizione a differenti condizioni di invecchiamento artificiale e verificano la fattibilità di realizzazione di una facciata continua ad alte prestazioni meccaniche e termiche.

Abstract

The *aim* of this work is to demonstrate the applicability of innovative materials, such as Glass Fibre Reinforced Polymer (GFRP) industrialized components (profiles), structural adhesives, for the realization of curtain walls with high mechanical and thermal performances and low environmental impact.

This objective with the “Technological Simplification” principle is verified. This latter is the guiding principle to the base of the search and experimental tests carried out by the research group. The teamwork coordinator and patent inventor is Prof P.Munafò, with him I developed a “System for the realization of building façade” (n. 102015000087569).
The “Technological Simplification” principle allows the building components realization with high performance and easy to assemble, by using a limited number of pieces. All this involves lower energy consumption in the production, assembly, maintenance and disposal phases. For this reason, the construction element can be considered environmentally sustainable.

In this thesis, the feasibility of the constructive system for the realization of building façade, through the experimental tests and component life cycle analysis, is verified. The components and materials properties both in laboratory conditions and after different types of ageing conditions (durability) are tested. The interaction between building components and environment, from the production to ultimate disposal (LCA - Life Cycle Assessment) are analysed.

The *methods* used were mostly of the experimental type. The material mechanical properties both in environmental conditions and in different types of ageing conditions were analysed, such as continuous condensation (ISO 6270-2) and UV irradiation (ASTM D904–99). Additional test with combined artificial ageing (climatic chamber and exposure to UV radiation - Tcc+Tuv – and the other way around - Tuv+Tcc) were tested.
The numerical and analytical studies were carried out, with the objective to check and validate the results obtained through experimental tests.

The *main outcome was the validation of the patents basic ideas*, which is a key point in the industrialization process of the construction elements (Structural Member). The aim of this work is to demonstrate the feasibility of the use of pultruded Glass Fiber Reinforced Polymers (GFRP) profiles, adhesively joined with other materials (i.e. steel), in the construction sector. The objective is both to reduce the GFRP profiles deformation under loading conditions, and to avoid the brittle fractures that could occur in bolted joints. In the building engineering field, in fact, these issues (deformations and brittle fractures) prevent the use of pultruded materials. In the research activity, the possibility to adhesively join a steel laminate on the pultruded profile mullion for curtain walls was verified. The containment of the deformations and the prevention of brittle fractures in the bolted joint were checked, in order to verify the pultruded curtain wall feasibility, both constructively and for its structural and energy performances.

Experimental results, in fact, demonstrated that the use of GFRP profiles, bonded with structural adhesives and combined with steel, is successful on curtain walls, even when they are exposed to adverse environmental conditions. The feasibility of the curtain wall implementation with high performance is verified.

Abstract

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Chapter 1

Overall introduction

1.1. Objectives

The aim of the Ph.D. research is **to assess the applicability** of pultruded Glass Fiber Reinforced Polymers (GFRP) profiles, adhesively joined with other materials (i.e. steel), for the realization of curtain walls with high mechanical and thermal performances and low environmental impact. Furthermore, the study from the design phase to the industrialization process to transfer these innovative elements to the construction market is carried out.
In the recent years, the working group has designed and patented the *Structural Member* for curtain walls (patent application n. 102015000087569). The guiding principle is mainly the "*Technological Simplification*" a method to realize high-performance and easy to assemble components, by using innovative materials in a limited number of pieces. This principle led to low energy consumption in the production, assembly, maintenance and disposal processes, becoming the new concept of "environmental sustainability" [1].

The aim of this work is to demonstrate the feasibility of the ideas behind the patented *Structural Member*, both constructively and for its structural and energy performances. Especially, the possibility to adhesively join a steel laminate on the pultruded profile mullion for curtain walls in order to contain the deformations (under loading condition) and the prevention of brittle fractures in the bolted joint is discussed also considering the durability of construction element.

The main aspects of this work concern the mechanical performance of the hybrid system, GFRP-steel, and of the structural adhesives for the realization of the mullion for curtain walls; the energy performance through LCA process (UNI EN ISO 14040) for to analyse the curtain wall life cycle and its environmental impact for a period of 30 years. This report is structured as follows:

- *(i)* State of the art about the curtain wall (construction element, patent, literature review);
- *(ii)* Structural Member patent, description and product information;
- *(iii)* An experimental and analytical study regarded the comparison of different epoxy adhesives used in GFRP-steel profiles conjunctions: the objective was to verify the compatibility of the two materials and the steel contribute to the stiffness increase of GFRP profiles. The verification of the hybridization method was conducted through several mechanical tests and the effects of different aging conditions were observed;
- *(iv)* Mechanical and thermal performance verification of the curtain wall made in pultruded profiles;
- *(v)* Market analysis;
- *(vi)* Conclusion.

1.2. Literature review

In recent years, in civil engineering, increasing attention has been focused on technologies and innovative materials that allow achieving both excellent mechanical performance and maximum energy efficiency. Furthermore, increasing interest has also been pointed towards technological simplification. The reduction of the number of components leads to numerous advantages: the ease of installation, the saving of production time and the decrease of environmental impacts, thanks to the reduction of production processes and the relative CO2 emissions [1]

Over the past two decades, glass fiber reinforced polymer (GFRP) pultruded profiles are becoming a valuable alternative in many civil engineering fields as in structures of building and bridges, in both new construction and rehabilitation [2], electricity transmission tower [3], and windows frames [4], [5].

- *GFRP characteristics*

In literature, many studies were carried out to investigate the different *mechanical properties* of composite material in un-aged conditions, both on small samples: flexural [6], [7], torsional [8], tensile [9] and compressive [10] characteristics, and on full-scale components: connections [11], profiles [12] or panels [13]. Further experiments were performed to compare profiles with different types of the matrix [14], [15], demonstrating that the vinyl ester resin has better mechanical properties than the polyester one.
With regard to the *durability*, different aged conditions were carried out in various experimental studies: the exposure to UV radiations on the GFRP profiles, led to very small changes in the mechanical properties[15]–[17], while the "hot-wet" environmental have an adverse effects. Many authors investigated the effects of the immersion in demineralized [15], [16] [18]–[22] and salt [15], [19]–[22] water. Some studies also compared degradation under both artificial and natural aging [14], [17], [21]. However, comprehensive and validated data are still scarce, a large scatter and contrasting data in the results are observed, even if similar methodologies are used.
The durability effects were analysed also in the adhesively bonded joints (other aspect of this research) which are the subject of several types of research. The mechanical behaviour [23], failure modes [24]–[27] and the effect of the joint geometry on the structural response [28]–[30] were investigated. Regarding environmental effects, most of the studies focused on adhesively-bonded joints for aerospace and automotive engineering, nonetheless there are some papers that shifted their attention to the civil engineering field. For example, Zhang et al. [31], [32] demonstrated that high temperatures lower the mechanical performance of bonded joints, especially when the glass transition temperature of the adhesive is reached. This phenomenon is even more pronounced with high humidity levels.
However, validated data about the properties of adhesives used to connect pultruded materials are still scarce. Furthermore, there is a lack of understanding of the aging degradation mechanisms suffered by different types of adhesives used in GFRP joints.

Additional characteristics were considered in order to use the GFRP for the civil construction: *fire protection*, rehabilitation and sustainable solution.
Some authors [33]–[35] studied the viability of using GFRP pultruded profiles in civil field, experimental investigations were carried out to analyse their mechanical behaviour when exposed to fire (high temperature). Other search has been focused on the *rehabilitation* and *reconstruction* in order to restore the functionality of deteriored structural components as concrete mullion for Toronto school facades [36] and bridge decks [37]

- *GFRP and steel in comparison*

In this work, the adhesive structural and steel laminated used in order to increase the performance mechanical (stiffness) and reduce deformations of the GFRP structural member are investigated.

This innovative composite material is characterized by several advantages: high specific strength, lightweight, low thermal and electrical conductivity, non-corrodibility.
Moreover, even though a GFRP structure is significantly more expensive than a similar steel structure, an actual economic advantage can be obtained in the maintenance and durability, when life cycle cost is accounted for [3].
Nevertheless, compared to steel, this material presents various disadvantages. GFRPs are profiles with a high fiber content and, unlike metals, their stiffness and strength depend on the orientation of the fibers. This orthotropic nature necessarily requires the availability of data on mechanical properties that nowadays is still lacking [38]. In addition, the brittle character of the composite material determines the difficulty of realizing bolted joints. Bolting, in fact, is a not material-adapted way to connect [39], because adherents are subjected to drilling operations that cut the fibers. In this case steel-adhesive connection on GFRP represents the most efficient jointing method, leading to a more uniform load transfer [23, 31, 40] and to avoid the brittle fracture. However this kind of connection is strongly influenced by environmental conditions, which can reduce mechanical properties of the adhesives and, generally, of the adherents.

Furthermore the low elastic modulus (up to ten times lower) [41–44], and the consequent high deformability under loading conditions of the GFRP profiles impede the applications of this composite material in structures with large spans [45–47], especially when small profiles size is required, such as in curtain walls.

For this reason, it is necessary to develop suitable approaches to improve the stiffness of the GFRP pultruded material, and some authors demonstrate that coupling GFRP profiles with higher mechanical performances materials – i.e. hybridization system - is an advantageous method [41, 48, 49].
Kim and Lee [45] developed a steel-reinforced hybrid GFRP deck panel for temporary bridges. The results confirmed that the flexural stiffness of the GFRP deck panel was effectively increased by the proposed methods of hybridization. Wu et al. [41] explored two strengthening methods to improve the bearing capacities of GFRP pultruded SHS sections, by bonding alternatively CFRP plates and steel sections on the external surfaces of the GFRP profiles. Both the strengthening methods demonstrated considerable enhancement of the bearing capacities, respectively of 70 % and of 200 %.
Therefore, it was demonstrated that the use of the steel allows increasing the mechanical performance of the GFRP material. However, to the authors knowledge, validated data for designers are still scarce and there has been little research on the comparison of different types of adhesives used for the joining of GFRP and steel profiles. Most of the existing studies examine the behavior of only one adhesive used to connect GFRP decks to steel girders and were not focused on the improving of the GFRP profiles stiffness [50–53]. Furthermore, the evaluation of the influence of environmental aging was not presented, even if it is well known that bonding connections are strongly influenced by environmental conditions, which can reduce mechanical properties of the adhesives [31, 32, 50].
In the third chapter (iii) of the present work, an experimental campaign on the connection of GFRP pultruded profiles and steel laminates through three different epoxy adhesives is proposed. The objective is to investigate three different aspects. The first is the compatibility of the bonding system, through shear tests conducted on small-scale specimens (GFRP-steel single lap joints), particularly the effects of two environmental aging. The second is the response to the local stresses of the bonding system, through puncture resistance tests on full-scale specimens (GFRP-steel squared tubular short profiles) which simulate the local stress transmitted by the curtain panels bolted to the structural members; the effects of two environmental aging is also carried out. The third is the response to flexural stresses of the bonding system, through three-point bending tests on full-scale specimens (GFRP-steel squared tubular long profiles) which simulate the flexural stresses, undergoes by the whole structural members in curtain walls (i.e. the wind load).

The objective is both to reduce the GFRP profiles deformation under loading conditions, and to avoid the brittle fractures that could occur in bolted joints. In the building engineering field, in fact, these issues (deformations and brittle fractures) prevent the use of pultruded materials. In the research activity, the possibility to adhesively join a steel laminate on the pultruded profile mullion for curtain walls was verified. The containment of the deformations and the prevention of brittle fractures in the bolted joint were checked, in order to verify the pultruded curtain wall feasibility, both constructively and for its structural and energy performances.

1.3. Analysis of aluminium and GFRP profiles

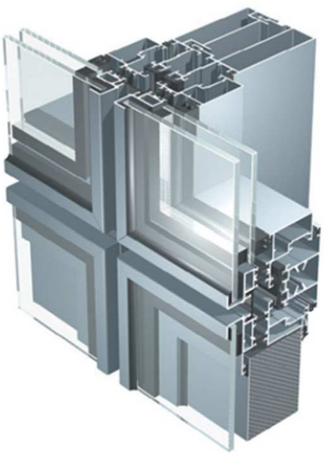
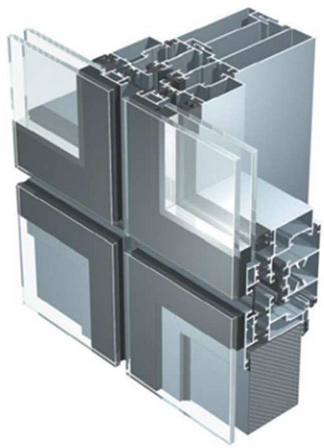
In this section, a review on the aluminium and GFRP profiles present both on the market and patented, used to build curtain walls, are shown.

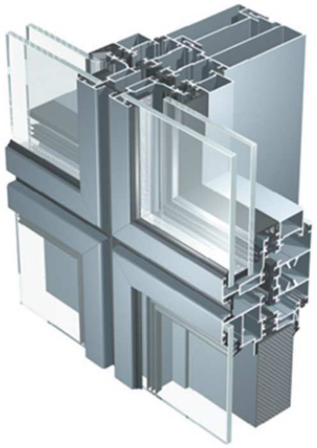
Nowadays, the curtain walls are designed mainly with aluminium alloy or steel, while rarely is used the wood material except in combination with first one material. This coupling, aluminium – wood, is used only for outer finish. With reference to GFRP material, during the search, no applications were found in this field. The composite material is present in Europe for certain civil structures as, *bridges* (Tom's Creek Bridge,1996; Clear Creek Bridge, 1996; Laurel lick Bridge, 1997; Wickwire Run Bridge, 1997; Bentley Creek Bridge, 2000; Over Deer Creek, 2001) and *gangways*, *experimental building* (Compaq Computer Corporation, in Houston and Apple Computer, in California) and *off-shore installations* (Mars Tension Leg realized by Shell Oil in the Gulf Coast and the Dow Chemical platform in Freeport, Texas). The GFRP material is used in limited way for structural timber, in Italy: an example is the pedestrian bridge made in Roma (Jubilee 2000) and the yard cover for Palace of Justice in Pescara.

The "*Structural member"* project idea was originated to define a different façade than those available on the market. The traditional mullion, in fact, usually have a considerable size and several components. These characteristics affect the thermal properties and the design of the windows. In order to overcome these problems, "*Structural member"* offers many advantageous properties as high thermal performance, easy to assemble with a low number of components.

With a view to patent a new construction element, a-research both on the market and existing patent was carried out. This last passage was useful to verify patents similar to the "*Structural member"*, in: shape, materials, and constructional arrangement.

The following a collection of the curtain wall profiles present on the market is described. The major producers are: Aluk (Verona, Italy), Metra (Brescia, Italy) and Wicona (Milan, Italy). It should be noted that the principle material is the aluminium alloy and not composite material.

Company ALUK 	***MODEL AW3B (b)*** Curtain wall characterized by aluminium profiles with thermal break; mechanic check dimension of 13mm, free structural bonding of the glass. **Material** Aluminium alloy EN AW-6060 (UNI EN 755-2) T5; EPDM Elastomeric gaskets. **Profiles dimension** Mullion depth is 90 -115 mm **Double glass dimension** Gap between cell is 14 mm; standard dimension of the double-glass, 23-30.5 mm
	***MODEL AW3M*** Curtain wall characterized by mechanic check with structural bonding of the glass. **Material** Aluminium alloy EN AW-6060 (UNI EN 755-2) T5; EPDM Elastomeric gaskets. **Profiles dimension** Mullion depth is 90 -115 mm **Double glass dimension** Gap between cells is 12 mm; thickness of the glass plate is 29 mm or 8 mm for single plate one.
	***MODEL AW3S*** Curtain wall without metal elements visually. Gap between the glass plates is 16 mm. **Material:** Aluminium alloy EN AW-6060 (UNI EN 755-2) T5; EPDM Elastomeric gaskets. **Profiles dimension** Mullion depth is 90 -115 mm **Double glass dimension** Gap between cell is 16 mm; standard dimension of the double-glass, 23-32.5 mm; the glass plate is glued to cell through structural adhesive.



MODEL AW3T

Curtain wall characterized by frame on sight. Section dimension is 60 mm and the gap between frames is 12 mm.

Material

Aluminium alloy EN AW-6060 (UNI EN 755-2) T5; EPDM Elastomeric gaskets.

Profiles dimension

Mullion depth is 90 -115 mm with the thermal break.

Double glass dimension

Gap between cell is 12 mm; standard dimension of the double-glass is 26-29 mm; absence of structural bonding.

MODEL SL60

Curtain wall used for: different inclinations, roof, tunnel and polygonal building.

Material

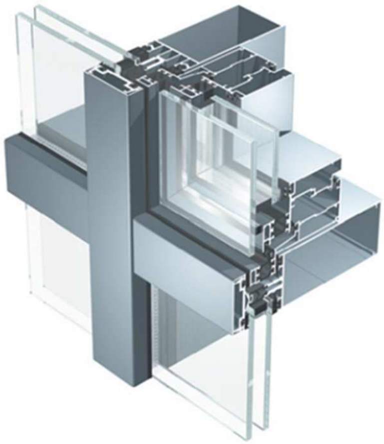
Aluminium alloy EN AW-6060 (UNI EN 755-2) T5; EPDM Elastomeric gaskets.

Profiles dimension

Mullion width is 60 mm, for external situation the mullion dimension 50 mm and 60 mm.

Double glass dimension

Dimension of the double-glass is 5-38 mm.



MODEL SL50

This curtain wall is an alternative to the SL60 system.

Material

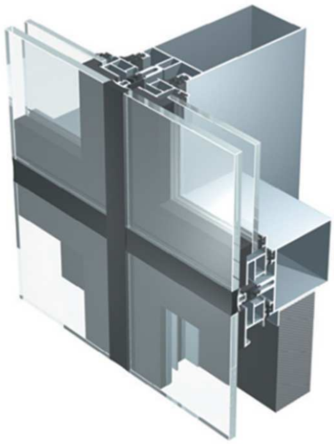
Aluminium alloy EN AW-6060 (UNI EN 755-2) T5; EPDM Elastomeric gaskets.

Profiles dimension

Mullion width is 50 mm, while the depth is between 55 – 130 mm.

Double glass dimension

Dimension of the double-glass is 5-38 mm.



MODEL SG50

The basic frame is the same of the SG50 system. This curtain wall model is characterized by limited opening.

Material

Aluminium alloy EN AW-6060 (UNI EN 755-2) T5; EPDM Elastomeric gaskets.

Profiles dimension

Gap between panels is 21 mm. The cells are assembled to sheet glass with structural adhesive.

This system is realized also without structural bonding between aluminium alloy and glass.

Double glass dimension

Dimension of the double-glass is 24-28 mm.

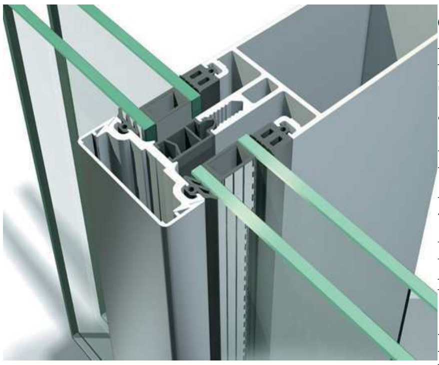
MODEL FV

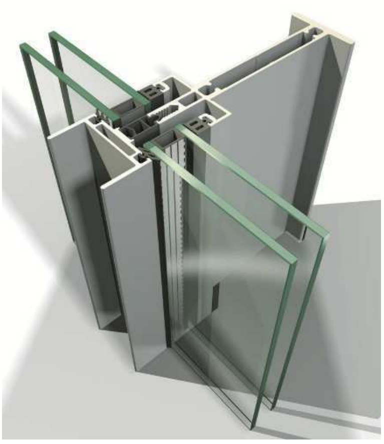
This façade replace to glass the photovoltaic panel in order to produce electricity and to avoid the penetration of infrared and UVA rays.

Material

Aluminium alloy EN AW-6060 (UNI EN 755-2) T5; photovoltaic panels.

Company METRA





MODEL Poliedra Sky-50 and 50 I

The solution preferred by designers, because of both the design and the great overall performance of sealing, insulation and strength. It is used both the new construction and restructuring.

Material

Aluminium alloy EN AW-6060 (UNI EN 755-2) T5;
EPDM gaskets; thermal-break: Tecno CMP rigid insulating spacer

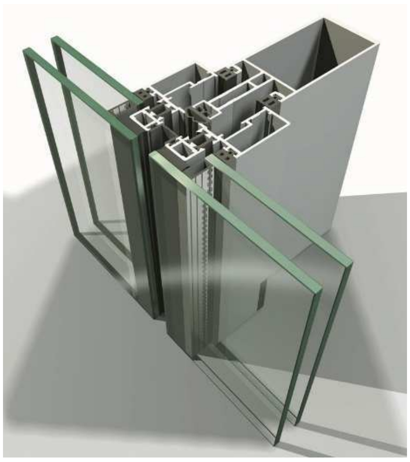
Profiles dimension

For Poliedra Sky 50: mullion deep is 42-225 mm; 50 mm deep structure, visible inside and outside
For Poliedra Sky 50 I: IPE mullion deep is 75 mm - 280 mm; 50 mm structure, visible both internally and externally visible.

Double glass dimension

Glass thickness: 8 to 45 mm.

This system also for to applicate the photovoltaic panel is designed.



MODEL Poliedra Sky-50 S

Poliedra-Sky 50 S combines the aesthetic appeal of all-glass with good insulation and sealing performance. It is a thermal break structure with tubular mullions and transoms, the lattice is only visible from the inside.

Material

Aluminium alloy EN AW-6060 (UNI EN 755-2) T5; EPDM gaskets; thermal-break: polyamide thermal bars.

Profiles dimension

The mullion deep is 42-225 mm; 50 mm deep structure, internally visible.

Double glass dimension

Glass thickness: from 24 mm to 32 mm; glazing with structural gluing or mechanical support.

MODEL Poliedra Sky-50 CV

Traditional curtain wall with mullions, tubular transoms, and thermal break; the lattice can only be seen from the inside. Poliedra-Sky 50 CV is a multipurpose all-glass curtain wall of great aesthetic effect and very easy to assemble. The internal fastening system of the glass panes allows the creation of large surfaces entirely glazed and perfectly coplanar.

Material
Aluminium alloy EN AW-6060 (UNI EN 755-2) T5; Seals: EPDM gaskets; thermal break: insulating rigid spacer made off Tecno CMP.

Profiles dimension
The mullion deep is 42-250 mm; 50 mm deep structure visible only internally

Double glass dimension
Glass thickness: from 28 mm to 38 mm; glazing with mechanical support.

MODEL Poliedra Sky-60

Poliedra-Sky 60's distinctive quality is definitely its ability to adapt its appearance to numerous architectural contexts. Traditional style curtain wall with thermal break elements. Excellent sealing and insulation properties.

Material
Aluminium alloy EN AW-6060 (UNI EN 755-2) T5; Seals: EPDM gaskets; thermal break: insulating rigid spacer made off Tecno CMP.

Profiles dimension
The mullion deep is 42-250 mm; 60 mm deep structure visible both internally and externally.

Double glass dimension
Glass thickness: from 8 mm to 45 mm.

MODEL Poliedra Sky-60 CV

Poliedra-Sky 60 CV integrates perfectly with the systems Metra Poliedra-Sky 50, 50 I, 50 S, 50 CV, 60, the casement and the shading systems. Thermal break. Excellent sealing and thermal-acoustic insulation.

Material
Aluminium alloy EN AW-6060 (UNI EN 755-2) T5; Seals: EPDM Dutral gaskets; thermal break: insulating rigid spacer made off Tecno CMP.

Profiles dimension

	The mullion deep is 42-250 mm; 60 mm deep structure, externally.visible. **Double glass dimension** Glass thickness: from 28 mm to 38 mm. external glass mechanically fixed.
	***MODEL Poliedra Sky- Fast 80*** Poliedra-Sky Fast 80 improves the aesthetic appearance of any curtain wall. You can choose the all-glass design or the version with a border along the perimeter. This façade is structured in units or with mechanical support for glazing. **Material** Aluminium alloy EN AW-6060 (UNI EN 755-2) T5; Seals: EPDM internal seals and glazing gaskets; thermal break: insulating rigid spacer in coextruded PVC. **Profiles dimension** The mullion deep from 132 mm; 80 mm deep structure, visible internally. **Double glass dimension** Glass thickness: From 30 mm to 44 mm.; external glass mechanically fixed.

Company: WICONA 	***MODEL Wictec 50*** WICTEC 50 is the basic version of the stick system curtain wall, with an extra-narrow face width of 50 mm, inside and outside. Ideal for vertical and polygon façades. **Material** Aluminium alloy EN AW-6060 (UNI EN 755-2) T66; internal and external EPDM glass panel gaskets; **Profiles dimension** The mullion depth from 50 mm to 260 mm; the system width is 50 mm. **Double glass dimension** The quality and dimensions of the glass must meet the requirements of DIN 18361, unless described to the contrary in the performance specification.

MODEL Wictec 50
Based on an innovative mechanical fixing, WICTEC 50 SG opens up a new, simpler possibility for the construction of facades made entirely from glass. Although its appearance is identical to that of a traditional SSG facade, this technology is faster, simpler and more economical to realise.

Material
Aluminium alloy EN AW-6060 (UNI EN 755-2) T66; internal and external EPDM glass panel gaskets;

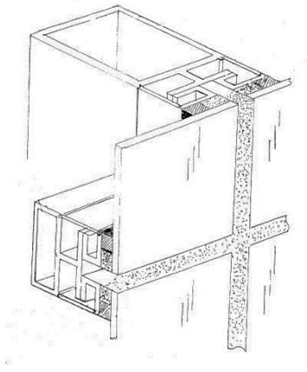
Profiles dimension
The mullion depth from 50 mm to 260 mm; the system width is 50 mm.

Double glass dimension
The quality and dimensions of the glass must meet the requirements of DIN 18361.

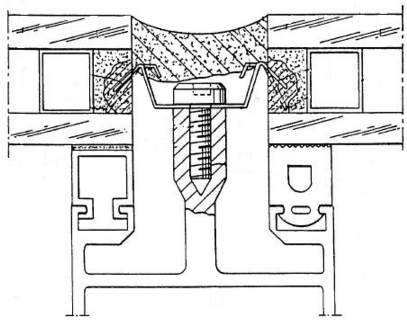
The database research made with ILO office of the Università Politecnica delle Marche, validation the *"Structural Member"* innovation in order to allow the patenting of project idea. The following the existing patents are disclosed with the aim to highlight the mainly different compared to new innovation.

- Curtain walls in aluminum alloy

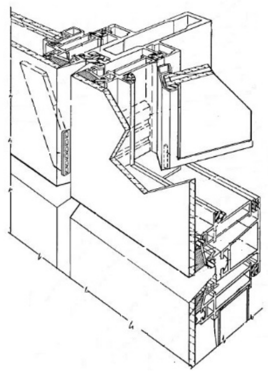
CN 2252834-U*: block prolife of consealed frame glass curtain* [annex 1].



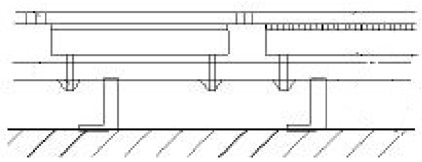
US005493831A*: method and arrangement for securing glass facade elements* [annex 2].



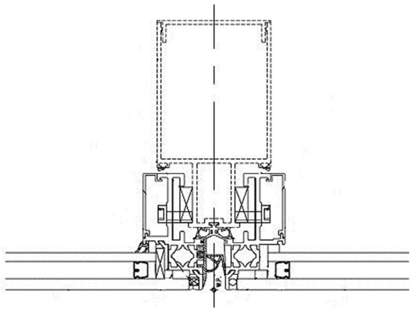
IT1200185B*: Vetrata composita per facciate continue di case e palazzi (stained glass for building curtain wall)* [annex 3].



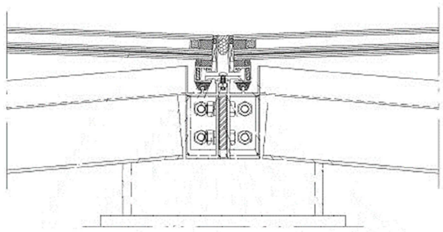
CN103206036*: Aluminum alloy thermal insulation curtain wall and manufacturing process thereof* [annex 4].



CN102953466*: half-unit curtain wall* [annex 5].

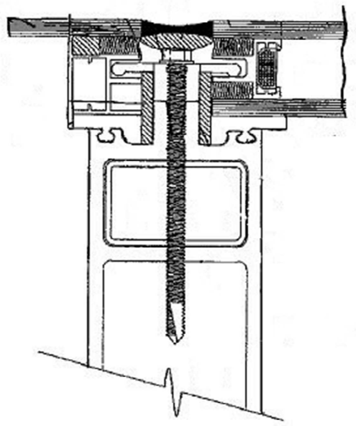


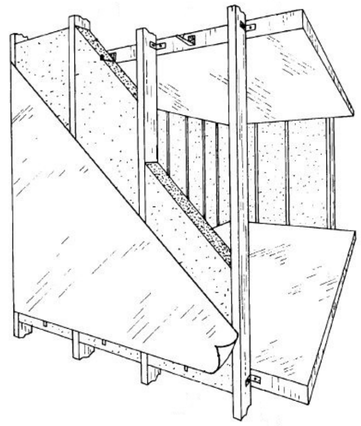
CN202359706*: non-uniplanar curtain wall connecting structure* [annex 6].



- Curtain wall in composite material

US008863454_B2: *pultruded part for use as a frame member for an exterior wall construction for a building* [annex 7].	***US0030296_A1***: *semi-curtain façade* [annex 8].





All the mullion of the curtain wall, represented here, a complex shape and high element construction shown. The mainly material used is aluminum alloy but with limited spreading of the composite material. These aspects not belonging to the guiding principle of the "*Technological Simplification*".

In the following chapters, a detailed description of the patent is provided.

1.4. Legislations

The outer covering of a building in order to maintain the performance is very important and may significantly affect on total costs of construction for approximately 15-25%. For this reason, the national (UNI) and international legislation, play a key role.

The legislation objective is to realize the design code to satisfy the seven conditions provided for in Regulation (EU) No 305/2011 for construction products (CPR- Construction Products Regulation). One important CPR requirement for the manufacturer is to prepare a document called Declaration of Performance (DoP). By drawing up a DoP the manufacturer assumes responsibility for the declared performances. In the absence of objective indications to the contrary, Member States shall presume that information which is included to be accurate and reliable.

This document shall be prepared when the product is placed on the market in the accepted language of the Member State in which the product is intended to be placed on the market. Products of the same batch which are supplied to a single user can be accompanied by a single DoP copy. Manufacturers can supply the customer with a copy of the DoP either in paper form or by electronic means. When requested by the customer, a paper copy must be supplied. The conditions under which the DoP may be available on a web site will be established by the European Commission (EC) by means of legislative act. According to the CPR a DoP has to be prepared in most cases, as Union or National provisions exist and require the declaration of essential characteristics where the product is intended to be used [51].

The current standard production for the curtain wall is hEN 13830:2015. This Harmonised Standards specifies characteristics of curtain walling and provides technical information on the varying performance requirements which apply throughout Europe and the test criteria and sequence of testing to which the product is subjected, in order to demonstrate conformity. Reference is made to other European Standards related to the performance and testing of curtain walling and, where appropriate, attention is drawn to European Standards which relate to products incorporated into curtain walling.

The main amendments to the hEN 13830:2015, Curtain walling - Product standard, concern:

- Concept of curtain wall as "kit";
- New definition of curtain wall; extension of the aim to the inclinations in the façade;
- Application of the aim to the curtain wall without glazing structural adhesive;
- New requirements for the essential characteristics;
- New informative and regulatory appendices (the use of Eurocode for the mechanical resistance verification of the curtain wall, a new test for the earthquake resistance, verifying the durability);
- Update of the ZA appendix and the chapter n.6 of the CPR 305/11 [52].

The outer covering of a building is characterized by a comprehensive regulatory framework and it is in developing due to the building material technological progress.

1.5. References

[1] P. Munafò, «Considerazioni sulle tematiche di ricerca del Settore Scientifico Disciplinare di Architettura Tecnica. Colloqui.AT.e (2015) Artec: 21-24.», Bologna, 2015, vol. Artec: 21-24.

[2] M. F. Sá, A. M. Gomes, J. R. Correia, e N. Silvestre, «Creep behavior of pultruded GFRP elements – Part 2: Analytical study», *Compos. Struct.*, vol. 93, n. 9, pagg. 2409–2418, ago. 2011.

[3] A. Godat, F. Légeron, V. Gagné, e B. Marmion, «Use of FRP pultruded members for electricity transmission towers», *Compos. Struct.*, vol. 105, n. Supplement C, pagg. 408–421, nov. 2013.

[4] D. Appelfeld, C. S. Hansen, e S. Svendsen, «Development of a slim window frame made of glass fibre reinforced polyester», *Energy Build.*, vol. 42, n. 10, pagg. 1918–1925, ott. 2010.

[5] C. Dispenza, A. A. Pisano, e P. Fuschi, «Numerical simulations of the mechanical characteristics of glass fibre reinforced C-profiles», *Compos. Sci. Technol.*, vol. 66, n. 15, pagg. 2980–2989, dic. 2006.

[6] Y. G. Chacón, S. Paciornik, e J. R. M. d'Almeida, «Microstructural evaluation and flexural mechanical behavior of pultruded glass fiber composites», *Mater. Sci. Eng. A*, vol. 528, n. 1, pagg. 172–179, nov. 2010.

[7] M. F. Sá, A. M. Gomes, J. R. Correia, e N. Silvestre, «Creep behavior of pultruded GFRP elements – Part 1: Literature review and experimental study», *Compos. Struct.*, vol. 93, n. 10, pagg. 2450–2459, set. 2011.

[8] G. J. Turvey, «Torsion tests on pultruded GRP sheet», *Compos. Sci. Technol.*, vol. 58, n. 8, pagg. 1343–1351, ago. 1998.

[9] «Tensile fatigue performance of pultruded glass fiber reinforced polymer profiles - ScienceDirect». [In linea]. Available at: http://www.sciencedirect.com/science/article/pii/S026382230400073X. [Consultato: 10-ott-2017].

[10] Y. Bai, T. Vallée, e T. Keller, «Delamination of pultruded glass fiber-reinforced polymer composites subjected to axial compression», *Compos. Struct.*, vol. 91, n. 1, pagg. 66–73, nov. 2009.

[11] J. E. Carrion, J. M. LaFave, e K. D. Hjelmstad, «Experimental behavior of monolithic composite cuff connections for fiber reinforced plastic box sections», *Compos. Struct.*, vol. 67, n. 3, pagg. 333–345, mar. 2005.

[12] L. Feo, A. S. Mosallam, e R. Penna, «Mechanical behavior of web–flange junctions of thin-walled pultruded I-profiles: An experimental and numerical evaluation», *Compos. Part B Eng.*, vol. 48, n. Supplement C, pagg. 18–39, mag. 2013.

[13] L. C. Bank, M. G. Oliva, H.-U. Bae, e B. V. Bindrich, «Hybrid concrete and pultruded-plank slabs for highway and pedestrian bridges», *Constr. Build. Mater.*, vol. 24, n. 4, pagg. 552–558, apr. 2010.

[14] G. Carra e V. Carvelli, «Ageing of pultruded glass fibre reinforced polymer composites exposed to combined environmental agents», *Compos. Struct.*, vol. 108, n. Supplement C, pagg. 1019–1026, feb. 2014.

[15] S. Cabral-Fonseca, J. R. Correia, M. P. Rodrigues, e F. A. Branco, «Artificial Accelerated Ageing of GFRP Pultruded Profiles Made of Polyester and Vinylester Resins: Characterisation of Physical–Chemical and Mechanical Damage», *Strain*, vol. 48, n. 2, pagg. 162–173, apr. 2012.

[16] J. Correia, S. Cabral-Fonseca, F. Branco, J. G Ferreira, M. I Eusébio, e M. P Rodrigues, *DURABILITY OF GLASS FIBRE REINFORCED POLYESTER (GFRP) PULTRUDED PROFILES USED IN CIVIL ENGINEERING APPLICATIONS*. 2017.

[17] J. m. Sousa, J. r. Correia, e S. Cabral-Fonseca, «Durability of Glass Fibre Reinforced Polymer Pultruded Profiles: Comparison Between QUV Accelerated Exposure and Natural Weathering in a Mediterranean Climate», *Exp. Tech.*, pag. n/a-n/a, set. 2013.

[18] K. Aniskevich, A. Aniskevich, A. Arnautov, e J. Jansons, «Mechanical properties of pultruded glass fiber-reinforced plastic after moistening», *Compos. Struct.*, vol. 94, n. 9, pagg. 2914–2919, set. 2012.

[19] Y. J. Weitsman, «Effects of Fluids on Polymeric Composites - A Review.», TENNESSEE UNIV KNOXVILLE DEPT OF MECHANICAL AND AEROSPACE ENGINEERING, TENNESSEE UNIV KNOXVILLE DEPT OF MECHANICAL AND AEROSPACE ENGINEERING, MAES-95-1.0, lug. 1995.

[20] H. Ben Daly, H. Ben Brahim, N. Hfaied, M. Harchay, e R. Boukhili, «Investigation of water absorption in pultruded composites containing fillers and low profile additives», *Polym. Compos.*, vol. 28, n. 3, pagg. 355–364, giu. 2007.

[21] «Durability of GFRP Pultruded Profiles Made of Vinylester Resin | Fiberglass | Composite Material», *Scribd*. [In linea]. Available at: https://www.scribd.com/document/291074727/Durability-of-GFRP-Pultruded-Profiles-Made-of-Vinylester-Resin. [Consultato: 10-ott-2017].

[22] K. Liao, C. R. Schultheisz, e D. L. Hunston, «Effects of environmental aging on the properties of pultruded GFRP», *Compos. Part B Eng.*, vol. 30, n. 5, pagg. 485–493, lug. 1999.

[23] T. Keller e T. Tirelli, «Fatigue behavior of adhesively connected pultruded GFRP profiles», *Compos. Struct.*, vol. 65, n. 1, pagg. 55–64, lug. 2004.

[24] Y. Zhang, A. P. Vassilopoulos, e T. Keller, «Fracture of adhesively-bonded pultruded GFRP joints under constant amplitude fatigue loading», *Int. J. Fatigue*, vol. 32, n. 7, pagg. 979–987, lug. 2010.

[25] Y. Zhang e T. Keller, «Progressive failure process of adhesively bonded joints composed of pultruded GFRP», *Compos. Sci. Technol.*, vol. 68, n. 2, pagg. 461–470, feb. 2008.

[26] H. K. Lee, S. H. Pyo, e B. R. Kim, «On joint strengths, peel stresses and failure modes in adhesively bonded double-strap and supported single-lap GFRP joints», *Compos. Struct.*, vol. 87, n. 1, pagg. 44–54, gen. 2009.

[27] M. Shahverdi, A. P. Vassilopoulos, e T. Keller, «A phenomenological analysis of Mode I fracture of adhesively-bonded pultruded GFRP joints», *Eng. Fract. Mech.*, vol. 78, n. 10, pagg. 2161–2173, lug. 2011.

[28] T. Vallée, J. R. Correia, e T. Keller, «Probabilistic strength prediction for double lap joints composed of pultruded GFRP profiles part I: Experimental and numerical investigations», *Compos. Sci. Technol.*, vol. 66, n. 13, pagg. 1903–1914, ott. 2006.

[29] T. Vallée, J. R. Correia, e T. Keller, «Optimum thickness of joints made of GFPR pultruded adherends and polyurethane adhesive», *Compos. Struct.*, vol. 92, n. 9, pagg. 2102–2108, ago. 2010.

[30] T. Vallée, *Adhesively bonded lap joints of pultruded GFRP shapes /*. 2004.

[31] Y. Zhang, A. P. Vassilopoulos, e T. Keller, «Environmental effects on fatigue behavior of adhesively-bonded pultruded structural joints», *Compos. Sci. Technol.*, vol. 69, n. 7, pagg. 1022–1028, giu. 2009.
[32] Y. Zhang, A. P. Vassilopoulos, e T. Keller, «Effects of low and high temperatures on tensile behavior of adhesively-bonded GFRP joints», *Compos. Struct.*, vol. 92, n. 7, pagg. 1631–1639, giu. 2010.
[33] J. R. Correia, Y. Bai, e T. Keller, «A review of the fire behaviour of pultruded GFRP structural profiles for civil engineering applications», *Compos. Struct.*, vol. 127, n. Supplement C, pagg. 267–287, set. 2015.
[34] J. R. Correia, M. M. Gomes, J. M. Pires, e F. A. Branco, «Mechanical behaviour of pultruded glass fibre reinforced polymer composites at elevated temperature: Experiments and model assessment», *Compos. Struct.*, vol. 98, n. Supplement C, pagg. 303–313, apr. 2013.
[35] J. R. Correia, F. A. Branco, e J. G. Ferreira, «The effect of different passive fire protection systems on the fire reaction properties of GFRP pultruded profiles for civil construction», *Compos. Part Appl. Sci. Manuf.*, vol. 41, n. 3, pagg. 441–452, mar. 2010.
[36] L. McCuaig, L. Reginato, e K. Soudki, «GFRP retrofit for façades in a Toronto school», *Constr. Build. Mater.*, vol. 22, n. 2, pagg. 61–69, feb. 2008.
[37] V. Mara, R. Haghani, e P. Harryson, «Bridge decks of fibre reinforced polymer (FRP): A sustainable solution», *Constr. Build. Mater.*, vol. 50, n. Supplement C, pagg. 190–199, gen. 2014.
[38] G. J. Turvey, «Testing of pultruded glass fibre-reinforced polymer (GFRP) composite materials and structures», *Adv. Fibre-Reinf. Polym. FRP Compos. Struct. Appl.*, pagg. 440–508, set. 2013.
[39] J. de Castro e T. Keller, «Ductile double-lap joints from brittle GFRP laminates and ductile adhesives, Part I: Experimental investigation», *Compos. Part B Eng.*, vol. 39, n. 2, pagg. 271–281, mar. 2008.
[40] Julia de Castro San Román, «Experiments on double-lap joints with Epoxy, polyurethane and ADP adhesives», vol. Appendix B-Technical Report n° CCLab2000.1b/2, mar-2005.
[41] «Improved bearing capacities of pultruded glass fibre reinforced polymer square hollow sections strengthened by thin-walled steel or CFRP - ScienceDirect». [In linea]. Available at: http://www.sciencedirect.com/science/article/pii/S0263823114003619. [Consultato: 10-ott-2017].
[42] Q. Hao, Y. Wang, e J. Ou, «Design recommendations for bond between GFRP/steel wire composite rebars and concrete», *Eng. Struct.*, vol. 30, n. 11, pagg. 3239–3246, nov. 2008.
[43] H.-Y. Kim e S.-Y. Lee, «A steel-reinforced hybrid GFRP deck panel for temporary bridges», *Constr. Build. Mater.*, vol. 34, n. Supplement C, pagg. 192–200, set. 2012.
[44] J. Qureshi e J. T. Mottram, «Behaviour of pultruded beam-to-column joints using steel web cleats», *Thin-Walled Struct.*, vol. 73, n. Supplement C, pagg. 48–56, dic. 2013.
[45] C. Wu e Y. Bai, «Web crippling behaviour of pultruded glass fibre reinforced polymer sections», *Compos. Struct.*, vol. 108, n. Supplement C, pagg. 789–800, feb. 2014.
[46] Borowicz David T. e Bank Lawrence C., «Behavior of Pultruded Fiber-Reinforced Polymer Beams Subjected to Concentrated Loads in the Plane of the Web», *J. Compos. Constr.*, vol. 15, n. 2, pagg. 229–238, apr. 2011.
[47] G. J. Turvey e Y. Zhang, «Characterisation of the rotational stiffness and strength of web-flange junctions of pultruded GRP WF-sections via web bending tests», *Compos. Part Appl. Sci. Manuf.*, vol. 37, n. 2, pagg. 152–164, feb. 2006.
[48] L. C. Hollaway, «A review of the present and future utilisation of FRP composites in the civil infrastructure with reference to their important in-service properties», *Constr. Build. Mater.*, vol. 24, n. 12, pagg. 2419–2445, dic. 2010.
[49] N. D. Hai, H. Mutsuyoshi, S. Asamoto, e T. Matsui, «Structural behavior of hybrid FRP composite I-beam», *Constr. Build. Mater.*, vol. 24, n. 6, pagg. 956–969, giu. 2010.
[50] F. Stazi, M. Giampaoli, L. Nisi, M. Rossi, e P. Munafò, «Mechanical performance reduction of GFRP specimens with polyester matrix exposed to continuous condensation», *Compos. Part B Eng.*, vol. 99, n. Supplement C, pagg. 330–339, ago. 2016.

[51] «CPR GUIDELINE FOR ALUMINIUM DOORS, WINDOWS AND CURTAIN WALLS v.2 Nov 2013». .
[52] «UNICMI - Unione Nazionale delle Industrie delle Costruzioni Metalliche dell'Involucro e dei serramenti».

Chapter 2

The research results: “Sistema per la realizzazione di facciate di edifici”, patent for curtain wall

In recent years, the research group designed and patented the *Structural Member* for curtain walls (Sistema per la realizzazione di facciate di edifici, patent application n. 102015000087569), high-performance and easy to assemble components made of GFRP pultruded profiles, structural adhesives and solar selective glass coatings. The use of these materials, characterized with higher mechanical and thermal performance than the traditional ones, allowed the design of construction elements with less pieces and, consequently, the reduction of CO_2 emissions during the entire life cycle of the products, from the production to the disposal phase. The basic principle, named “Technological Simplification” represents the new concept of environmental sustainability. In the following sections, the patented construction elements are presented.

2.1. State of art

The structural frames of traditional curtain walls are usually made of aluminium and the use of this material has a negative impact on both the design and the thermal property, due to the large size and the high thermal conductivity of the frames. Furthermore, the elevated number of components constituting the construction elements causes very high CO2 emissions during all the curtain walls life cycle.
The objective of the Structural Member patent design, named “Sistema per la realizzazione di facciate di edifici”, is the resolution of these issues.

2.2. The patent application n. 102015000087569

- *Structural member description*

The Structural Member is a linear construction element which, with reduced sections (from 55x55 mm^2 to 110x110 mm^2), allows the realization of curtain walls with high glazing areas. Panels of different sizes and materials can be used since the Structural Member presents both high load carrying capacity and stiffness, such as to keep deformations to a minimum. Furthermore, it is made of GFRP pultruded profiles, an energy saving material, which is also very durable against environmental aging. The application of the construction element is very easy.

The innovative principle consists of the use of GFRP profiles, with small sectional areas, linked to pre-tended steel wires. The Structural Member can be used to realize curtain walls with high glazing areas (max 3,5÷4 ml), thereby guaranteeing a seal against air and water and a good thermal insulation.

Furthermore, the Structural Member offers great versatility: it can be used to carry panels of different sizes and material (glass, wood, aluminum, etc.), allowing the assembly of opaque and transparent surfaces both in vertical and horizontal positions, in addition to different inclinations. It can also be used in existing buildings, in every roofs configuration.

Pultruded profiles demonstrate excellent resistivity to environmental exposures therefore the system is very durable and benefits from low maintenance costs.

This construction element allows a noticeable simplification of the production and assembly phases since it is made of a limited number of components, with simple geometries.

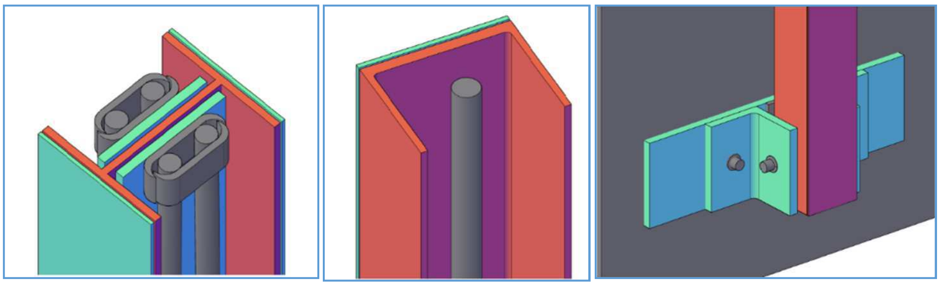


Figure 2.1. “Structural Member” 3d views: double T-section, C-section and the connection to the slab.

- *Claims*

The claims are the most important part of a patent. The goal of the claim is to point out and distinctly claim the subject matter of the invention. The patent claims will be reproduced.

1. System (100) for making building facades comprising:

- a pillar (1) intended to be connected to structural parts (W) of the building and to support panels (P) constituting the building façade; said pillar (1) comprising:

- a section (10; 210) intended to support said panels (P), said section being a pultruded profile made of synthetic resin reinforced with fiber glass and having cross-sectional dimensions lower than 100 mm x 100 mm, and

- at least one cable (2) connected to said profile and extending for the entire length of the profile, said cable (2) being obtained with a plurality of steel strands and being pretensioned,

- connection means (M) to connect said profile to the structural parts (W) of the building, and

- cable-fixing terminals (3) fixed at the ends of the cable (2) and connected to said structural parts (W) of the building or to said profile (10; 210) of the pillar.

2. The system (100) of claim 1, also comprising a plurality of cable-fixing clamps (8; 208; 308) fixed to said profile (10; 210) of the pillar to fix the cable (2) and one or more systems for pre-tensioning the cable (2).

3. The system (100) of claim 2, wherein the cable-fixing clamp (8; 208; 308) comprises opposite jaws (82; 280, 281) or a U-bolt consisting in a "U"-bent iron rod (380).

4. The system (100) of any one of the preceding claims, wherein each cable-fixing terminal (3) comprises tensioning means (35) to tension the cable (2) and said cable-fixing terminal (3) is hinged by means of a pin (32) to a bracket (7) adapted to be connected to the structural part (W) of the building or is hinged to a bolt (B) intended to be fixed to the profile (210) of the pillar.

5. The system (100) of any one of the preceding claims, also comprising a guide rail (5) integrated in said structural part (W) of the building, wherein said connection means (M) and/or said cable-fixing terminals (3) are connected to said guide rail (5) to adjust the position of said pillar (1).

6. The system (100) of any one of claims 2 to 5, wherein said profile (10; 210) of the pillar has a base (11) or central core (211) whereto said cable-fixing clamps (8; 208; 308) are fixed.

7. The system (100) of any one of the preceding claims, wherein said profile (10) of the pillar has a "U"-shaped cross-section and said profile (10) of the pillar comprises a base (11) and two wings (12) that protrude from the base defining a seat (13) wherein said cable (2) is disposed; wherein the wings (12) are faced towards the structural part (W) of the building and the base (11) is faced outwards in order to fix said panels (P) on the base (11) of the pillar profile.

8. The system (100) of claim 7, wherein said connection means (M) comprise brackets (4) made of profiles with an "L"-shaped cross-section; each bracket (4) comprising a first portion (40) intended to be connected to the structural part (W) of the building and a second portion (41) provided with a slot (42) wherein a bolt (43) slides, being fixed to a wing (12) of the pillar profile in order to adjust the distance of the pillar profile from the structural part (W) of the building.

9. The system (100) of any one of the preceding claims, wherein said profile (110) of the pillar has an "H"-shaped cross-section and said profile (210) of the pillar comprises a central core (211), a back wing (212) connected to the central core and a front wing (212) connected to the central core, in such manner to define two seats (213) wherein said cables (2) are disposed, wherein the back wing (212) is intended to be connected to the structural part (W) of the building and the front wing (212') is faced outwards to support said panels (P) of the façade.

10. The system (100) of claim 9, wherein said connection means (M) comprise angular brackets (4) directly connected to said back wing (212) and to said central core (211) of the pillar profile or connected to an intermediate bracket (9) connected to said back wing (212) of the pillar profile.

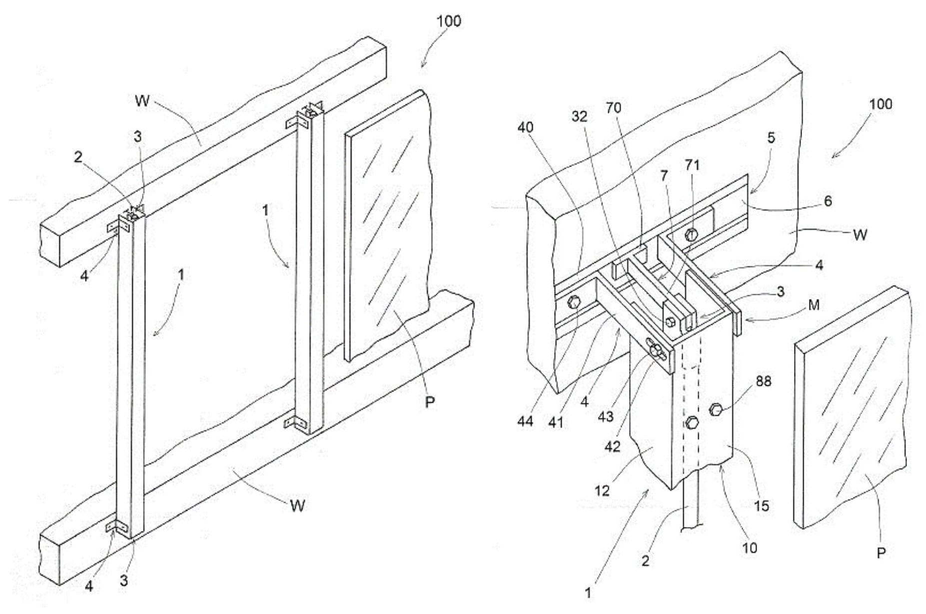


Figure 2.2. The mullion (1) is fixed to the loft (W) in order to support the façade panels (P); the mullion consists of a composite material profile (10) connected to strand (2).

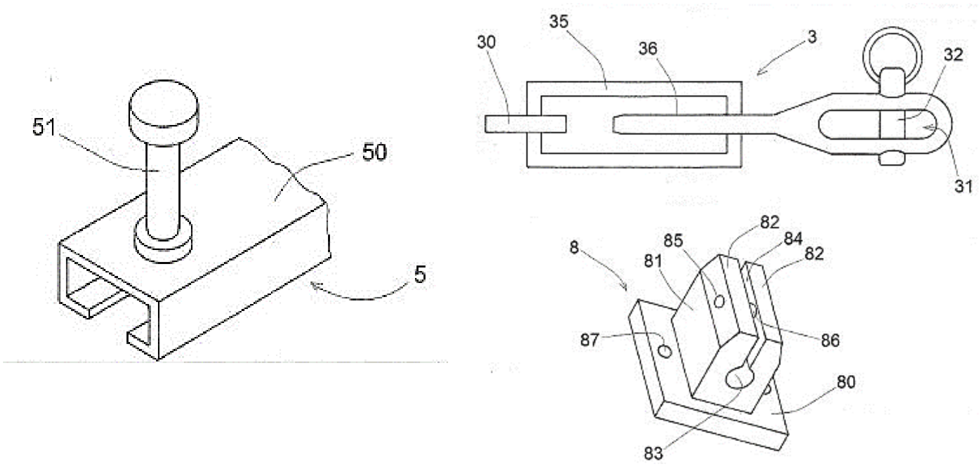


Figure 2.3. The channel (5) is embedded in the loft; fork terminal (3) connected to strand (30); the clamp (8) permits in line the strand.

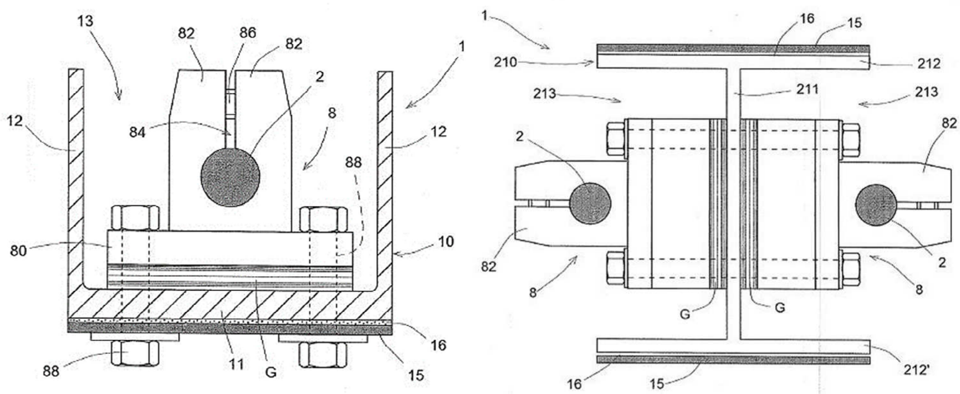


Figure 2.4. Cross-section of the mullion with the C profile (hypothesis 1); Cross-section of the mullion with the double T profile (hypothesis 2).

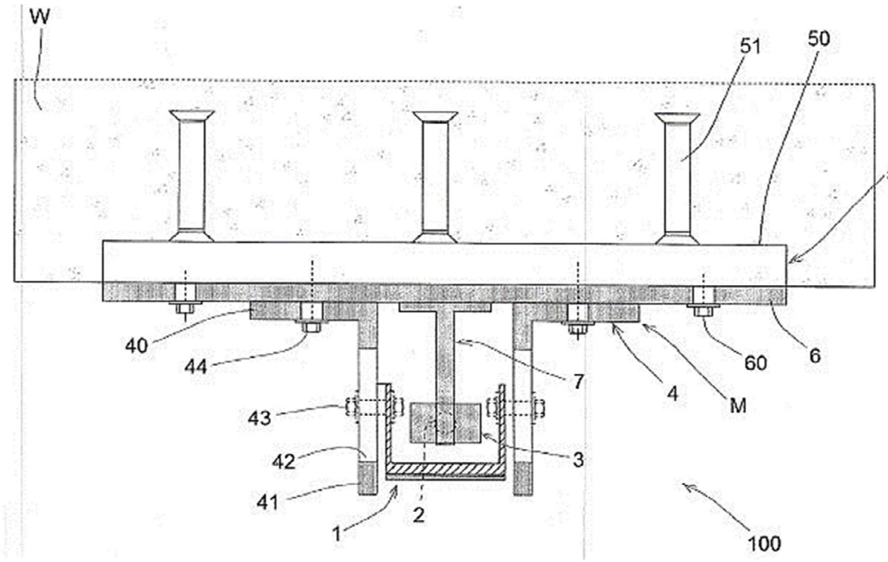


Figure 2.5. View from above, Cross-section of the façade system (hypothesis 1) embedded in the loft (W) through the Halfen channel (5) and brackets (M).

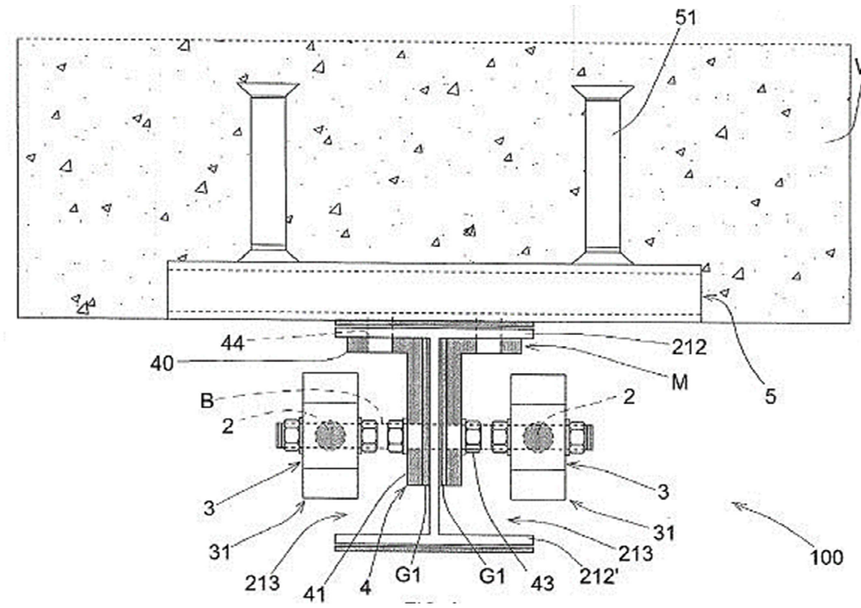


Figure 2.6. View from above, Cross-section of the façade system (hypothesis 2) embedded in the loft (W) through the Halfen channel (5) and brackets (M).

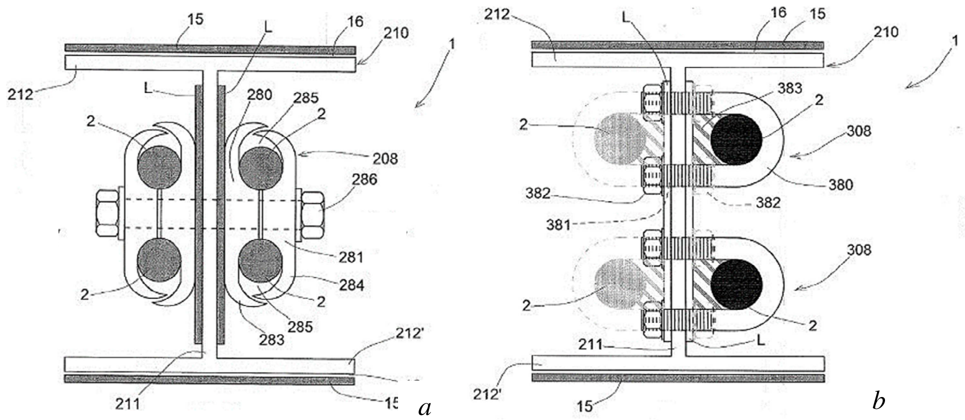


Figure 2.7. Cross-section of the double T profile (hypothesis 2) with four strands and different clamps *a* e *b*.

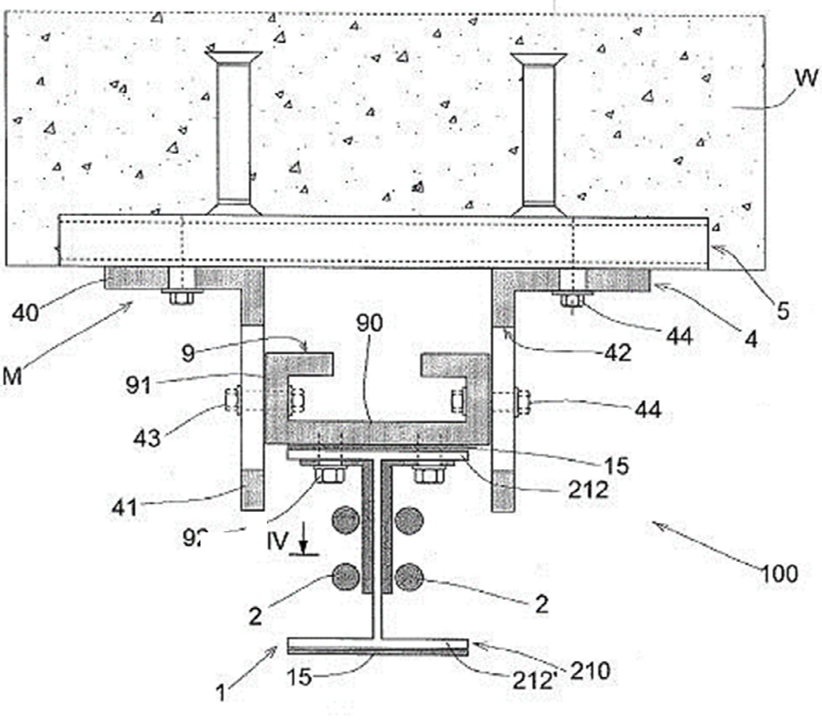


Figure 2.8. View from above, cross-section of the façade system (hypothesis 2) with four strands, embedded in the loft (W) through the Halfen channel (5) and brackets (M).

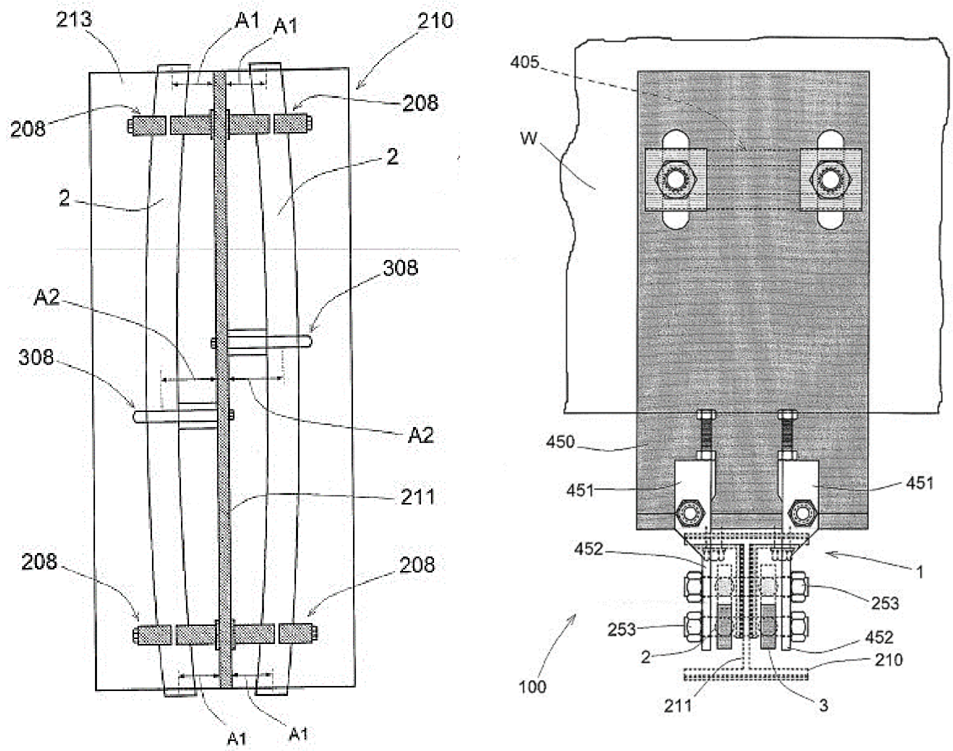


Figure 2.9. Cross-section, front view of the façade system; particular of the system with four strands anchorage to the loft (W) through the Halfen brackets.

2.3. Product information

The Structural Member includes:

- GFRP profiles with different sections (C and double T) with areas less than 90x90 mm2;

- steel laminates bonded to GFRP profiles with the objective of tightening the composite profiles and to facilitate the fixing of the panels;

- one or more pre-tended steel wires linked to the GFRP profile through several terminals, with the objective of containing deformations. The steel wires allow to reduce the member's length of free inflection on every occasion. The ends of the steel wires are connected to the building's structure through forks.

The Structural Member is linked to the building's structure (slabs) through connection systems readily available on the market (corner guides Halfen, etc.).

2.4. List of figures

Figure 2.1. Structural Member 3d views double T-section, C-section and the connection to the slab.

Figure 2.2. The mullion (1) is fixed to the loft (W) in order to support the façade panels (P); the mullion consists of a composite material profile (10) connects to strand (2).

Figure 2.3. The channel (5) is embedded in the loft; fork terminal (3) connected to strand (30); the clamp (8) permits in line the strand.

Figure 2.4. Cross-section of the mullion with the C profile (hypothesis 1); Cross-section of the mullion with the double T profile (hypothesis 2).

Figure 2.5. View from above, cross-section of the façade system (hypothesis 1) embedded in the loft (W) through the Halfen channel (5) and brackets (M).

Figure 2.6. View from above, cross-section of the façade system (hypothesis 2) embedded in the loft (W) through the Halfen channel (5) and brackets (M).

Figure 2.7. Cross-section of the double T profile (hypothesis 2) with four strands and different clamps *a* e *b*.

Figure 2.8. View from above, cross-section of the façade system (hypothesis 2) with four strands, embedded in the loft (W) through the Halfen channel (5) and brackets (M).

Figure 2.9. Cross-section, front view of the façade system; particular of the system with four strands anchorage to the loft (W) through the Halfen brackets.

Chapter 3

On GFRP-steel hybrid bonding systems: mechanical performances before and after the ageing treatments.

In this work, the reliability of the *Structural Member* basic principle, i.e. the hybrid system of GFRP pultruded profiles bonded with steel laminates, is verified, with the objective of containing GFRPs deformations. The contents of this chapter will be published in a scientific international journal.

3.1. Abstract

In this paper, the contribution in terms of stiffness increase by coupling steel laminates to GFRP pultruded profiles, through three epoxy adhesives, is investigated. The objective is to verify the applicability of this hybrid system in structural members for curtain walls. Different specimens types were employed in order to investigate on: the compatibility of the bonding system (shear tests on GFRP-steel single lap joints); the response to the local stresses of the bonding system (puncture tests on GFRP-steel squared tubular short profiles); the response to flexural stresses of the bonding system (three-point bending tests on GFRP-steel squared tubular long profiles). The effects of two environmental ageing, continuous condensation and UV radiations, were also analysed. The results demonstrated the compatibility of the bonding system and the stiffness increase of GFRP profiles when the steel reinforcements were applied. Analytical studies were comparable with those observed in the experimental tests, confirming the advantageous method of hybridization. With regard to artificial ageing, the continuous condensation demonstrated the worst effects on the specimens, while better results were registered after the UV radiations. The combinations of the two ageing conditions showed unexpectedly better results, with the enhancement of the mechanical performance of the joints.

Nomenclature

AF	Adhesive failure	***L***	Steel plate positioned on the lower side of the GFRP profile
A_{GFRP}	Section area of the GFRP profile	***LFTF***	Light-Fiber-Tear Failure
A_{STEEL}	Section area of the steel plate	***MF***	Mixed failure
A_t	Application temperature	***NO***	No detachment
B_e	External dimension of the section area's base	***P.D.***	Partial detachment
B_i	Internal dimension of the section area's base	***S***	Displacement
CF	Cohesive failure	S_t	Service temperature
DIC		***T.D.***	Total detachment
DSC	Differential scanning calorimeter	T_0	Un-aged conditions
EPX1	First epoxy adhesive	T_{cc}	Artificial ageing in climatic chamber
EPX2	Second epoxy adhesive	T_{eig}	Extrapolated onset temperature
EPX3	Third epoxy adhesive	T_{efg}	Extrapolated end temperature
E_t	Young modulus in tension	T_g	Glass transition temperature
E_{GFRP}	Young modulus of GFRP profiles in tension	T_{uv}	Artificial ageing under UV rays
E_{STEEL}	Young modulus of steel plates in tension	***U***	Steel plate positioned on the upper side of the GFRP profile
F	Load carrying capacity	***U-I***	Steel plates positioned in the upper-inner side of GFRP profile
H_e	External dimension of the section area's height	***UV***	Ultraviolet radiations
H_i	Internal dimension of the section area's height	W_t	Working time at 22 °C
I_{GFRP}	Moment of inertia of the GFRP profiles section area	***X***	The distance of the neutral axis from the barycentre
I_{STEEL}	Moment of inertia of the steel plate section area	ε_t	Tensile strain
k_{GFRP}	Stiffness of the GFRP sample	σ_t	Tensile strength
k_{STEEL}	Stiffness of the steel plate	σ_{ys}	Tensile yield strength
l	Span length	τ	Average shear strength
$K1_{GFRP\text{-}STEEL}$	Stiffness of the GFRP-steel specimen: materials work together		
$k2_{GFRP\text{-}STEEL}$	Stiffness of the GFRP-steel specimen: materials do not collaborate		

3.2. Introduction

Despite the several advantages, it is well known in the literature that GFRP profiles present low elastic modulus with respect to steel (up to ten times lower) [1-4], preventing its use in the civil construction sector [5-7] especially when small profiles size is required, such as in curtain walls.
For this reason, it is necessary to develop suitable approaches to improve the stiffness of the GFRP pultruded material, and some authors demonstrate that coupling GFRP profiles with higher mechanical performances materials, especially steel, is an advantageous method [1,3]. However, to the authors knowledge, validated data for designers are still scarce and there has been little research on the comparison of different types of adhesives used for the joining of GFRP and steel profiles. Furthermore, the evaluation of the influence of environmental ageing was not presented, even if it is well known that bonding connections are adversely influenced by environmental conditions [8-10].

In the present work, an experimental campaign on the connection of GFRP pultruded profiles and steel laminates through three different epoxy adhesives is proposed. The objective is to investigate on three different aspects. (1) The first is the compatibility of the bonding system, through shear tests conducted on small-scale specimens (GFRP-steel single lap joints), also deepening on the effects of two environmental ageing. (2) The second is the response to the local stresses of the bonding system, through puncture resistance tests on full-scale specimens (GFRP-steel squared tubular short profiles) which simulate the local stress transmitted by the curtain panels bolted to the structural members; the effects of two environmental ageing is also carried out. (3) The third is the response to flexural stresses of the bonding system, through three-point bending tests on full-scale specimens (GFRP-steel squared tubular long profiles) which simulate the flexural stresses, undergoes by the whole structural members in curtain walls (i.e. the wind load).

3.3. Methods

3.3.1. Phases

The research includes experimental and analytical studies, divided into the following phases:

- *Experimental tests* were carried out to evaluate both the GFRP-steel compatibility and the steel contribution to enhancing the mechanical performances of the GFRP profiles. The experimental programme comprised: (i) material characterization tests, (ii) shear tests on adhesively bonded GFPR-steel single lap joints, (iii) puncture tests on GFPR-steel squared tubular short specimens and (iv) three-point bending tests on GFPR-steel squared tubular long specimens. The GFRP tubular specimens used in the two latter experimental tests (iii, iv) were adhesively joined to steel plates in three configurations, with the steel plates positioned in the upper, lower and “upper-inner” sides of the GFRP profiles (Fig.3.1), which are alternative positions of steel laminates with respect to the loading direction. Furthermore, the effect of two environmental ageing, namely continuous condensation and UV exposures, were analysed in steps (ii, iii) of the experimental programme.

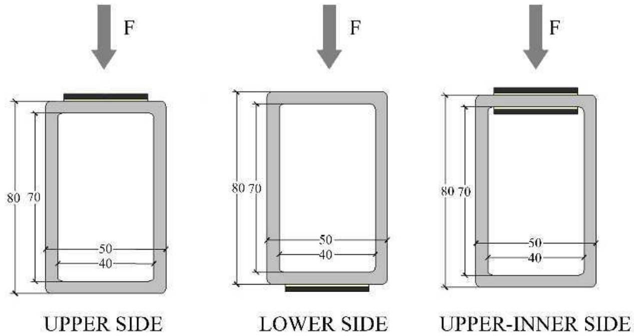


Figure 3.1. GFRP-steel squared tubular specimens in three different configurations, with the steel plates positioned in the upper, lower and “upper-inner” sides of the GFRP profiles.

(i) The materials (GFRP profiles and three epoxy adhesives) characterization tests provided the main mechanical properties of the different components involved in the GFPR-steel composite systems, namely their elasticity modulus, tensile strength, and elongation. The steel mechanical properties (reported in Table 3.1) were obtained from the manufacturer’s data sheet.

Table 3.1. GFRP profiles and steel mechanical properties according to manufacturer’s data sheets.

GFRP PROFILES [a]				*STEEL PROFILES* [b]			
E_t *(GPa)*	σ_t *(Mpa)*	ε_t *(%)*		E_t *(GPa)*	σ_{ys} *(Mpa)*	σ_t *(Mpa)*	ε_t *(%)*
25.0	250-450	1.0-1.8		198.0	326.7	385.5	29.1

[a] According to ASTM D638 / UNI 5819
[b] According to EN 10025-2: 2004

(ii) The shear tests allowed to evaluate the compatibility between the GFRP and steel and to compare the mechanical behaviour of the single lap joints bonded with three epoxy adhesives, namely their load carrying capacity, displacement, and stiffness.
(iii) The puncture tests permitted to simulate the local stress transmitted by the curtain panels bolted to the GFRP structural members, comparing the load carrying capacity, the displacement and the stiffness of GFRP-steel squared tubular short specimens (with a length of 400 mm) bonded with three epoxy adhesives, in three configurations (Fig.3.1). The steel plates are used with aim of reinforcing the GFRP bolted area, weakened by the drilling that cuts the composite’s fibres.
(iv) The three-point bending tests were performed to simulate the stress of the whole structural member that occurred in curtain walls (when it is subjected to the wind load), comparing the load carrying capacities, the displacements and the stiffness of GFPR-steel squared tubular long specimens (with a length of 1000 mm) bonded with the best adhesive resulted in the previous tests, in three different configurations (Fig.3.1). The steel plates are used with aim of enhancing the flexural stiffness of GFRP profiles.

- *Analytical studies* were carried out to validate the contribution of the steel, adhesively joined to GFRP squared tubular specimens, to the stiffness increase of the GFRP profiles (without reinforcements) in the elastic range. These comprised the calculation of:
  - the elastic modulus of the GFRP squared tubular samples without steel plates;
  - the stiffness of the GFRP squared tubular samples without steel plates;
  - the stiffness of the GFRP-steel squared tubular specimens in two different hypothesis: in the first situation the GFRP and the steel perfectly work together; in the second one, the two material do not collaborate. These calculations were performed for the three different configurations (Fig. 3.1).

The results were finally compared with those obtained through experimental tests (iv).

3.3.2. Experimental tests

3.3.2.1. Material characterization tests

Adherents

The first material is the pultruded E-glass fibre reinforced polyester composite, supplied by Fibrolux, Germany. This material consists of alternating layers of unidirectional fibre roving and chopped strand mat embedded in an isophthalic polyester matrix. A polyester surface veil is used to protect the matrix against environmental actions. The material properties according to manufacturer’s data sheet are reported in Table 3.1.

As a result of the pultrusion process, the fibre roving is not uniformly distributed. In order to determine the mechanical properties, GFRP laminates were tested in tension, according to [11,12]. The width of laminates was 25 mm, the thickness 5 mm and the length 100 mm. The free length was 70 mm and the gauge length of the extensometer was set to 50 mm. The tests were performed with a Zwick/Roell Z050 testing machine, using an extensometer to measure the strain and applying a displacement rate of 5 mm/min. Because of the small size of the used specimens, some of them may contain more fibre roving than others, and this produces a scatter in the mechanical properties. For this reason, three specimens were used for each considered ageing conditions that are: no ageing (T_0), exposure to severe humidity and high temperatures (T_{cc}), and exposure to UV radiation (T_{uv}) [8]. The results are summarised in Table 3.2.
The second material is the S235JR steel grade supplied by Termoforgia, Italy. The material properties according to manufacturer data sheet are reported in Table 5.1.

Table 3.2. Mechanical properties in tension of GFRP and steel materials.

Artificial exposure	*GFRP PROFILES*		
	E_t *(GPa)*	σ_t *(Mpa)*	ε_t *(%)*
T_0	29.8 ±2.6	168.8 ±31.1	0.7 ±0.2
T_{cc}	27.1 ±2.6	251.8 ±61.9	0.9 ±0.2
T_{uv}	27.8 ±6.5	199.4 ±91.6	0.8 ±0.3

Adhesives

Three epoxy adhesives were considered in the experimental program, designated EPX1, EPX2, and EPX3. Table 3.3 presents the relative technical and mechanical characteristics, reported from manufacturers. Some technical data were not available.
In order to determine adhesives mechanical properties, five specimens of each type of adhesive were tested in tension, according to [11, 13]. The dimensions of the dumbbell specimens are shown in Fig. 3.2.

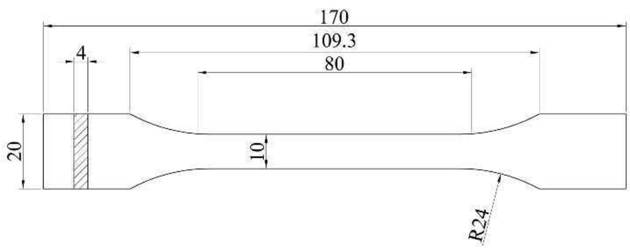


Figure 3.2. Dumbbell specimens dimensions.

Table 3.3. Technical and mechanical characteristics of the epoxy adhesives reported by manufacturers.

Adhesive	*EPX1*	*EPX2*	*EPX2*
Chemical base	two-part epoxy adhesive	two-part epoxy adhesive	two-part epoxy adhesive
Consistency	controlled flow	pasty	fluid
W_t *(min)*	>300	120	5-20
A_t *(°C)*	15 to 25	15 to 25	20
S_t *(°C)*	-40+120	-40+80	-40+100
T_g *(°C)*	/	71	/
Surface treatment	sand	sand and degrease	sand and degrease
τ* *(MPa)*	33.5	15	/
σ_t *(Mpa)*	/	17	17
E_t *(MPa)*	/	1700	/
ε_t *(%)*	3	5	/
Use	structural	semi-structural	semi-structural

* On aluminium/steel adherents

All specimens were cured at room temperature for about one month. The results (Table 3.4) were consistent with the data reported by manufacturers, confirming the highest performance of the first epoxy adhesive and the worst load bearing capacity of EPX3, which showed the highest deformability among the tested adhesives.
In order to determine adhesives glass transition temperature (T_g), three samples of each type of adhesive were tested with a differential scanning calorimeter (*DSC*), according to the standard [14]. DSC plots were obtained by heating samples from 25 °C to 120 °C at a rate of 20 °C/min under an inert gas flow of 100 ml/min. The samples weights were in the range of 10 to 15 mg with a precision of 0.01 mg. The T_g was determined (according to procedure 10.2.9 of [14]) as the midpoint temperature between the extrapolated onset temperature (T_{eig}) and the extrapolated end temperature (T_{efg}). The results (Table 3.4) showed that among structural adhesives, EPX2 had the highest T_g (on average 67 °C) and similar temperatures were obtained for EPX1.

Table 3.4. Mechanical properties in tension and glass transition temperatures of the adhesives.

Series	E_t *(MPa)*	σ_t *(Mpa)*	ε_t *(%)*	T_g *(°C)*
EPX1	2966.39 ± 44.12	27.34 ± 0.77	2.39 ± 0.65	61.07 ± 3.34
EPX2	1774.03 ± 30.28	17.11 ± 0.70	3.81 ± 0.23	66.87 ± 0.45
EPX3	648.60 ± 29.56	11.13 ± 1.02	7.26 ± 0.56	46.90 ± 0.63

3.3.2.2. Mechanical tests

Shear tests

The s*ingle lap joints* were manufactured from GFRP and steel laminates bonded with three epoxy adhesives. The geometry of the specimens was manufactured according to [D 4896 – 01]. The width of laminates was 25.4 mm and the length 100 mm; the overlap length was 25.4 mm. The thickness of the GFRP and steel adherents were respectively 5 mm and 3 mm. The test program consisted of a series of twelve specimens per adhesive type, as illustrated in Table 5.5, subdivided according to the ageing condition: four without ageing (T_0), four

after exposure to a hot-wet environment (T_{cc}), and four after exposure to UV radiations (T_{uv}). Furthermore, since the tested joints bonded with the EPX1 and EPX2 adhesives resulted in having the best performances, other six specimens per these adhesive types were subjected to two further combined ageing. Three joints were exposed first to the hot-wet environment, and later under UV radiations (T_{cc}+T_{uv}); three joints were subjected first to UV radiations and later to the hot-wet environment (T_{uv}+T_{cc}).
A different bonding thickness among three epoxy adhesives was employed, respectively 0.3 mm, 2 mm and 1mm for EPX1, EPX2 and EPX3 adhesives, as recommended by manufacturers.

Table 3.5. Test programme

Samples	***Adhesive***	***Configuration***	T_0	T_{cc}	T_{uv}	$T_{cc}+T_{uv}$	$T_{uv}+T_{cc}$
Single lap joints	EPX1	/	4	4	4	3	3
	EPX2	/	4	4	4	3	3
	EPX3	/	4	4	4	-	-
GFRP-steel squared tubular short specimens	EPX1	U[a]	3	3	-		
		L[b]	3	3	-	-	-
		U-I[c]	3	3	3		
	EPX2	U	3	3	-		
		L	3	3	-	-	-
		U-I	3	3	3		
	EPX3	U	3	3	-		
		L	3	3	-	-	-
		U-I	3	3	3		
	without steel	/	3	-	-	-	-
GFRP-steel squared tubular long specimens	EPX1	U	3				
		L	3	-	-	-	-
		U-I	3				
	without steel	/	3	-	-	-	-

[a] the steel plate positioned on the upper side of the GFRP profile
[b] the steel plate positioned on the lower side of the GFRP profile
[c] the steel plates positioned in the upper-inner side of the GFRP profile

All the tests were implemented on a Zwick/Roell Z050 testing machine of 50 kN capacity under displacements control. Fig. 5.3a shows the setup where specimens were subjected to the shear test. The load was applied at the slow rate of 1.25 mm/min. The elongation was measured by extensometer and the gauge length was set to 55 mm. All specimens were loaded up to the joint failure.

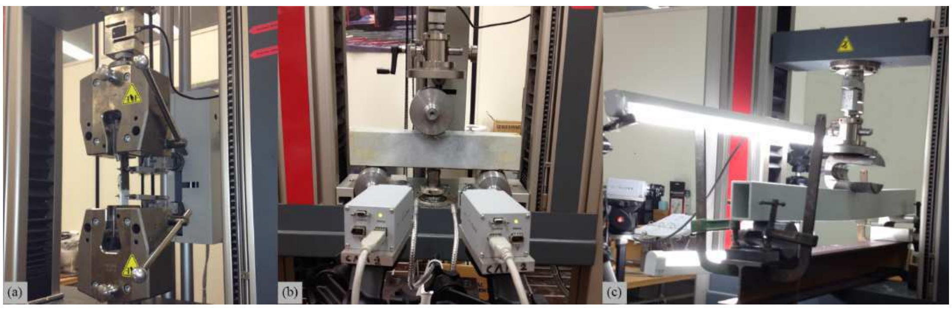


Figure 3.3. Experimental setup: tensile test on GFRP-steel single lap joints (a), puncture resistance test on GFRP-steel squared tubular short specimens (b), bending test on GFRP-steel squared tubular long specimens (c).

Puncture tests

The *GFRP-steel squared tubular short specimens* were manufactured from GFRP squared tubular profiles and steel laminates bonded with three epoxy adhesives. The production method of the specimens was according to a previous study, which studied different joining configuration of steel profiles and CFRP laminates [15]. In the present study the GFRP

tubular profiles were adhesively joined to steel plates in three different configurations: with the steel plates positioned in the upper (Fig.3.1a), lower (Fig.3.1b) and "upper-inner" (Fig.3.1c) sides of the GFRP profiles. The section area of the GFRP profiles was 50 X 80 mm^2, the thickness was 5 mm, and the length of the profiles was 400 mm. The geometry of the steel plates was 35 X 400 mm^2, and the thickness was 2 mm.
The test program consisted of a series of twenty-one specimens per adhesive type, as illustrated in Table 3.5, subdivided according to the ageing condition: nine without ageing (T_0), nine after exposure to a hot-wet environment (T_{cc}), and three after exposure to UV radiations (T_{uv}). The influence of the UV exposure was analysed only on the specimens in the "upper-inner" configuration, which presented the highest amount of adhesive. For the three adhesives, the same bonding thickness used in the single lap joints was employed.
To the sake of comparison, three GFRP squared tubular specimens without the steel reinforcement (with the same geometry) were tested.
All the tests were implemented on a Zwick/Roell Z050 testing machine of 50 kN capacity under displacements control. Fig. 3.3b shows the three-point bending setup where specimens were subjected to the puncture test. The load was applied at the slow rate of 3 mm/min The displacement in the lower side of the profiles was recorded every 1.68 s using two video camera data logger (Fig. 3.3b), (DIC method), until the specimens failure.

Three-point bending tests

The *GFRP-steel squared tubular long specimens* were manufactured from GFRP squared tubular profiles and steel laminates bonded with the best adhesive (EPX1) resulted in the previous tests. The same production method of the specimens studied in the puncture resistance test was followed. The section area of the GFRP profiles was 50 X 80 mm^2, the thickness was 5 mm, and the length of the profiles was 1000 mm. The geometry of the steel plates was 35 X 1000 mm^2, and the thickness was 2 mm.
The test program (Table 3.5) consisted of a series of nine specimens subdivided according to the geometry configuration: three with the steel plates positioned on the upper side (Fig. 3.1a), three on the lower side (Fig. 3.1b) and three on the "upper-inner" side (Fig. 3.1c) of the GFRP profiles. The 0.3 mm bonding thickness was employed for all the specimens.
To the sake of comparison, three GFRP squared tubular specimens without the steel reinforcement (with the same geometry) were tested.
All the tests were implemented on a Zwick/Roell Z050 testing machine of 50 kN capacity under displacements control. Fig. 3.3c shows the three-point bending setup where specimens, in all the different configurations, were subjected to the bending test. The load was applied at the slow rate of 3 mm/min. The displacement in the lower side of the profiles was recorded every 1.68 s using two video camera data logger (Fig. 3.3c), (DIC method), until the specimens failure.

3.3.2.3. Artificial ageing

Two types of ageing were taken into account, one to reproduce the external environment exposure (T_{cc}) and another to reproduce the UV irradiation effect (T_{uv}).
The simultaneous exposure to heat and high humidity levels is one of the most harmful condition of adhesives and plastics [9, 10]. This external environment exposure (T_{cc}) was simulated using a climatic chamber "Angelantoni" CST-130 S model (Fig. 3.4a). A total number of thirty-nine samples (twelve single lap joints and twenty-seven squared tubular short specimens) were aged at the constant temperature of 40 °C and at the relative humidity of 100 %, according to ISO 6270-2 [16], for six months without interruption.
The exposition to UV radiations can dissociate the molecule bonds in most polymers, leading to the degradation of polymeric materials [17]. This ageing type (T_{uv}) was simulated using eight fluorescent UV lamps (Philips Actinic BL TL-D). A total number of eleven samples (five single lap joints and six squared tubular short specimens) were aged according to [18] with some adaptations. In fact, as highlighted in a previous work [8], the effects of high temperatures (40 °C) are much more relevant than those of UV rays. So these two extreme environmental conditions should be separately analysed to deepen the UV influence alone. The specimens were subjected to high UV radiations but under laboratory conditions (temperature of 21 °C, relative humidity of 33 %). The recorded temperature on specimens

surface was about 26 °C. The samples were placed inside a wooden structure equipped with three lamps at the top, three at the bottom and two at the sides (Fig. 3.4b), in order to guarantee a uniform distribution of irradiation on the bonding area. The lamps emitted on a wavelength in the range of 340-400 nm [19], with a peak at 370 nm, producing a UV irradiance between 41 and 45 W/m² on the specimens surfaces. Cycle II of 24 hours [18] was repeated 42 times (overall 1000 hours) without interruption.

Furthermore, the coupling of the two previous artificial exposures was investigated, in order to analyse the effects of the combined ageing conditions in single lap joints bonded with the two adhesives resulted with the best performance (EPX1 and EPX2), also in different sequences (T_{cc}+T_{uv}, T_{uv}+T_{cc}). The test programme per each adhesive is the following (see Table 3.5): three samples were firstly subjected to high humidity and temperatures levels (for six months), and later under UV radiations (for 1000 hours); other three samples underwent UV radiations (for 1000 hours) and then they were exposed to high humidity and temperatures levels (for six months).

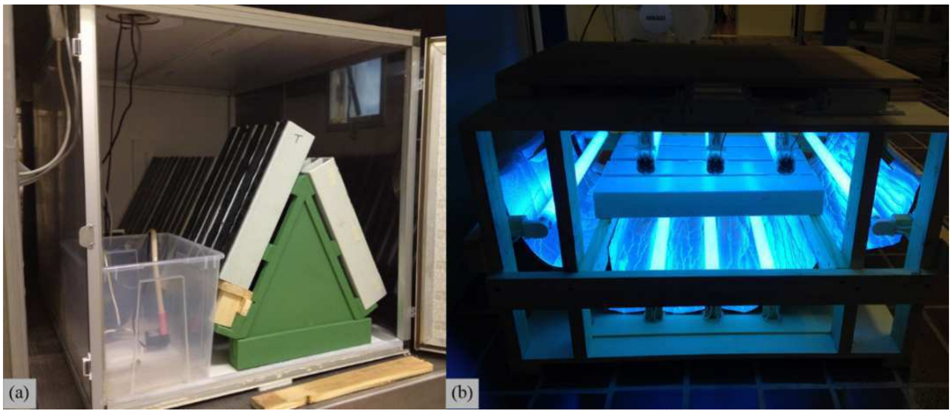


Figure 3.4. Specimens subjected to the ageing conditions: the hot-wet environment in the climatic chamber (a) and the UV radiation in the wooden structure equipped with lamps (b).

3.3.3. Analytical studies

Analytical calculations of the samples stiffness aim to check the results obtained through the previous experimental tests and to validate the contribution of the steel, adhesively joined to GFRP squared tubular specimens, to the increase of the stiffness of the GFRP profiles in the elastic range. The following parameters were calculated:

1. The elastic modulus of the GFRP squared tubular long profiles.

The elastic modulus $\mathbf{E_{GFRP}}$ [MPa] of the GFRP profiles was obtained through the following formula:

$$E_{GFRP} = l^3 F / (48\, I_{GFRP}\, S) \quad (1)$$

where: l [mm] is the span length, F [N] is the load carrying capacity and s [mm] is the displacement of the GFRP profiles: these latter two parameters are the maximum values registered after experimental tests in the elastic ranges. $\mathbf{I_{GFRP}}$ [mm^4] is the moment of inertia of the GFRP profiles section areas that, in this case, is symmetrical with respect to both x and y-axis, and it is calculated through the following formula:

$$I_{GFRP} = B_e H_e^3 / 12 - B_i H_i^3 / 12 \quad (2)$$

where: B_e and B_i [mm] are respectively the external and internal dimension of the section area's base, H_e and H_i [mm] are respectively the external and internal dimension of the section area's height.

2. The stiffness of the GFRP squared tubular long profiles.

The stiffness $\mathbf{k_{GFRP}}$ [N/mm] of the GFRP samples without the steel reinforcement was calculated through the following formula:

$$k_{GFRP} = 48\, E_{GFRP}\, I_{GFRP} / l^3 \quad (3)$$

3. The stiffness of the GFRP-steel squared tubular long profiles.

The stiffness $\mathbf{k_{GFRP\text{-}STEEL}}$ [N/mm] of the GFRP-steel bonding system was calculated in two different hypothesis: in the first case, the GFRP and the steel perfectly work together ($\mathbf{k1_{GFRP\text{-}STEEL}}$); in the second one, the two material do not collaborate ($\mathbf{k2_{GFRP\text{-}STEEL}}$). These calculations were performed for the three different configurations of the specimens (Fig. 3.1): the formulas used in the upper and in the lower configurations differ from those employed in the upper-inner configuration, due to the relative different distance of the neutral axis from the barycentre of the sections (see Fig. 3.5).

Upper and lower configurations: GFRP and steel work together

$$k1^{UL}_{GFRP\text{-}STEEL} = k^{UL}_{GFRP} + k^{UL}_{STEEL} = 48\, E_{GFRP}\, I^{UL}_{GFRP} / l^3 + 48\, E_{STEEL}\, I^{UL}_{STEEL} / l^3 \quad (4)$$

where: E_{STEEL} [MPa] is the elastic modulus of the steel (see Table 1); $\mathbf{I^{UL}_{GFRP}}$ [mm^4] and $\mathbf{I^{UL}_{STEEL}}$ [mm^4] are respectively the moments of inertia of the GFRP and steel profiles section areas; the latter two parameters were calculated through the following formulas:

$$I^{UL}_{GFRP} = I_{GFRP} + A_{GFRP} X^2 \quad (5)$$

$$I^{UL}_{STEEL} = I_{STEEL} + A_{STEEL} [(H_e/2 - X) + (S_{STEEL}/2)]^2 = (B_i\, S^3_{STEEL})/12 + A_{STEEL} [(H_e/2 - X) + (S_{STEEL}/2)]^2 \quad (6)$$

where: A_{GFRP} [mm^2] and A_{STEEL} [mm^2] are respectively the section areas of the GFRP and steel profiles; S_{STEEL} [mm] is the thickness of the steel profile; $\mathbf{X^{UL}}$ [mm] is the distance of the neutral axis from the barycentre calculated through the following formula (see Fig. 3a and 3b):

$$X^{UL} = (E_{STEEL}\, B_i\, S_{STEEL}\, H_e/2 + E_{STEEL}\, B_i\, S^2_{STEEL}/2) / (2E_{GFRP}\, H_e\, S_{GFRP} + 2E_{GFRP}\, B_i\, S_{GFRP} + E_{STEEL}\, B_i\, S_{STEEL}) \quad (7)$$

where: S_{GFRP} [mm] is the thickness of the GFRP profile.

Upper and lower configurations: GFRP and steel do not collaborate

$$k2^{UL}_{GFRP\text{-}STEEL} = k_{GFRP} + k_{STEEL} = 48\, E_{GFRP}\, I_{GFRP} / l^3 + 48\, E_{STEEL}\, I_{STEEL} / l^3 \quad (8)$$

Upper-inner configuration: GFRP and steel work together

$$k1^{UI}_{GFRP\text{-}STEEL} = k^{UI}_{GFRP} + k^{UI}_{STEEL} = 48\, E_{GFRP}\, I^{UI}_{GFRP} / l^3 + 48\, E_{STEEL}\, I^{UI}_{STEEL} / l^3 \quad (9)$$

where: $\mathbf{I^{UI}_{GFRP}}$ [mm^4] and $\mathbf{I^{UI}_{STEEL}}$ [mm^4] are respectively the moments of inertia of the GFRP and steel profiles section areas; the latter two parameters were calculated through the following formulas:

$$I^{UI}_{GFRP} = I_{GFRP} + A_{GFRP} X^2 \quad (10)$$

$$I^{UI}_{STEEL} = I^{UI1}_{STEEL} + I^{UI2}_{STEEL} =$$

$$I_{STEEL} + A_{STEEL} [(H_e/2 - X) + (S_{STEEL}/2)]^2 + I_{STEEL} + A_{STEEL} (H_e/2 - X - S_{GFRP} - S_{STEEL}/2)^2 \quad (11)$$

where: $\mathbf{X^{UI}}$ [mm] is the distance of the neutral axis from the barycentre calculated through the following formula (see Fig. 5c):

$X^{UI}= (E_{STEEL}\, B_i\, S_{STEEL}\, H_e - E_{STEEL}\, B_i\, S_{GFRP}\, S_{STEEL}) / (2E_{GFRP}\, H_e\, S_{GFRP} + 2E_{GFRP}\, B_i\, S_{GFRP} + 2E_{STEEL}\, B_i\, S_{STEEL})$ (12)

Upper-inner configuration: GFRP and steel do not collaborate

$k2^{UI}_{GFRP\text{-}STEEL} = k_{GFRP} + 2\, k_{STEEL} = 48\, E_{GFRP}\, I_{GFRP} / l^3 + 2\, (48\, E_{STEEL}\, I_{STEEL} / L^3)$ (13)

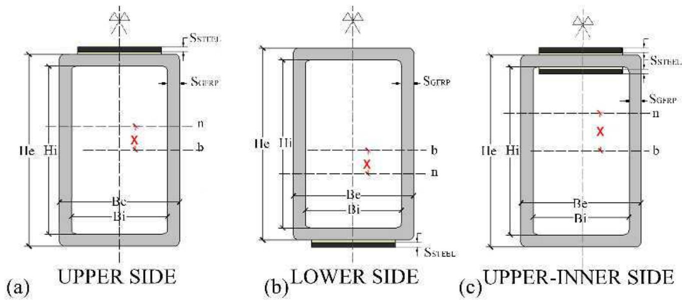


Figure 3.5. GFRP-steel squared tubular specimens in three different configurations: different positions of the neutral axis (n) with respect to the barycentre (b).

3.4. Experimental results

In this section, the mechanical responses and the failure modes of all the GFRP-steel specimens (single lap joints, squared tubular short and long profiles) are presented and analysed. The results are subdivided according to mechanical tests typology.

3.4.1. Shear tests

3.4.1.1. Mechanical performance

Table 3.6 shows the average results of un-aged (as produced) and aged GFRP-steel single lap joints, subjected to shear tests: the load carrying capacities (N), the displacements (mm) and the stiffness (kN/mm) are presented. The load-displacement trends of the specimens bonded with the three epoxy adhesives are showed in figure 3.6.

Table 3.6. Mechanical properties of GFRP-steel single lap joints bonded with three different adhesives: results before (T_0) and after (T_{cc}, T_{uv}, T_{cc}+T_{uv}, T_{uv}+T_{cc}) the ageing treatments.

Adhesive	*Ageing condition*	*EPX1*	*EPX2*	*EPX3*
LOAD	T_0 (N)	5052.70 ± 1505.86	2818.54 ± 774.91	2480.49 ± 253.30
	T_{cc} (%)	- 15.20	- 25.70	- 51.49
	T_{uv} (%)	+ 15.54	+ 21.37	+ 24.63
	T_{cc} + T_{uv} (%)	+ 29.12	- 15.95	-
	T_{uv} + T_{cc} (%)	+ 21.65	+ 36.60	-
DISPL.	T_0 (N)	0.20 ± 0.06	0.12 ± 0.03	0.10 ± 0.01
	T_{cc} (%)	+ 92.96	+ 68.94	+ 561.97
	T_{uv} (%)	+ 6.58	+ 88.82	+ 78.71
	T_{cc} + T_{uv} (%)	+ 18.70	- 15.39	-
	T_{uv} + T_{cc} (%)	+ 12.79	+ 20.62	-
STIFFNESS	T_0 (N)	30694.25 ± 4291.36	30909.75 ± 2557.24	32549.75 ± 2736.74
	T_{cc} (%)	- 93.53	- 84.96	- 92.45
	T_{uv} (%)	- 20.03	- 32.13	- 37.63
	T_{cc} + T_{uv} (%)	+ 19.80	- 14.41	-
	T_{uv} + T_{cc} (%)	+ 11.26	+ 6.71	-

With regard to *un-aged samples* (T_0), the *load* carrying capacity of the specimens bonded with the first epoxy adhesive (EPX1) resulted in the highest value, in particular twice than

the EPX3 joints. However, the latter adhesive registered the best *stiffness* result, with a value of about 32500 N/mm. Very similar data were observed in the other two adhesives.
With regard to *aged* samples, the continuous condensation treatment (T_{cc}) demonstrated higher negative effects on the mechanical responses of the joints than the UV exposure (T_{uv}). In the previous ageing condition, in fact, all the joints, registered *load* decreasing values, up to 50 % for EPX3 adhesive, while in the latter one (T_{uv}), increments of the data were showed (especially for EPX3).
The *displacements* recorded by the specimens showed very high increments in both the ageing treatments, especially after the hot-wet (T_{cc}) exposure. The only exception was the first epoxy adhesive after the UV treatment that demonstrated a slight increment of 6.58 %.
The *stiffness* of the joints, after the continuous condensation treatment, resulted considerably worsened, with decrements of about 90 % for all the adhesives. Better results (about -30 %) were observed for the specimens that underwent the UV radiations and EPX1 adhesive showed the best behaviour.

With regard to the *combination* of the *environmental conditions*, both the ageing treatments (T_{cc}+T_{uv} and T_{uv}+T_{cc}) showed better effects on the mechanical responses of the joints than those registered in the previous ageing conditions (T_{cc} and T_{uv}). The best results were obtained after the T_{uv}+T_{cc} exposure: the load carrying capacity registered increments up to 36 % for the second epoxy adhesive (EPX2) and increased stiffness were observed for all the joints. In the other environmental condition (T_{cc}+T_{uv}), the best results were registered by EPX1, both in the load carrying capacity (+29 %) and the stiffness (+20 %) values, while negative effects were showed by EPX2 (respectively of -16% and -14 %).

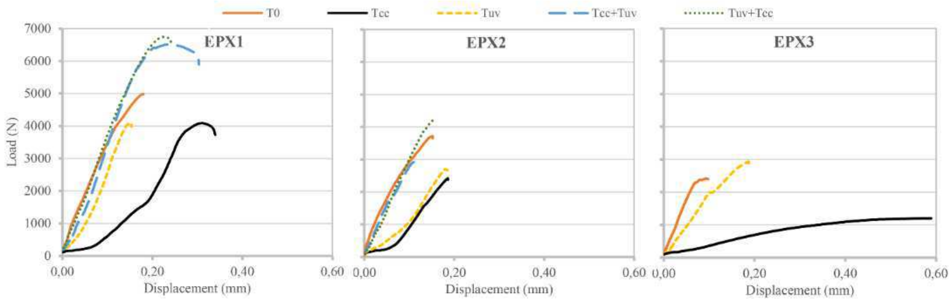


Figure 3.6. Representative load-displacement trends of GFRP-steel single lap joints before (T_0) and after the ageing treatments (T_{cc}, T_{uv}, T_{cc}+T_{uv}, T_{uv}+T_{cc}): comparison of three different epoxy adhesives.

By comparing the tested adhesives, EPX1 demonstrated the best mechanical performance both in un-aged and aged conditions, registering the highest load carrying capacity. With regard to the stiffness, after the hot wet condition, it showed lower decreasing values than those registered under the UV radiations. Both the ageing combinations improved the mechanical properties of the adhesive, especially when the specimens were firstly subjected to high humidity and temperatures levels and later under UV radiations (T_{cc}+T_{uv}).

3.4.1.2. Failure modes

Fig. 3.7 shows four types of failure modes occurred during specimens mechanical tests and classified according to [19]. The first is an “Adhesive Failure” (*AF* - Fig. 3.7a) and occurred at the interface between the adherend and the adhesive, this is usually not accepted in adhesive technology [20]. The second is a “Cohesive Failure” (*CF* - Fig. 3.7b), occurring within the adhesive layer: this reveals a good compatibility between adhesive and adherents. In the third figure (Fig. 3.7c) a “Light-Fiber-Tear Failure” (*LFTF*) is presented and occurred within the GFRP adherent, with few glass fibres transferred from the adherent to the adhesive. In Fig. 3.7d there is an example of “Mixed Failure” (*MF*), combining two of the failure modes described above.

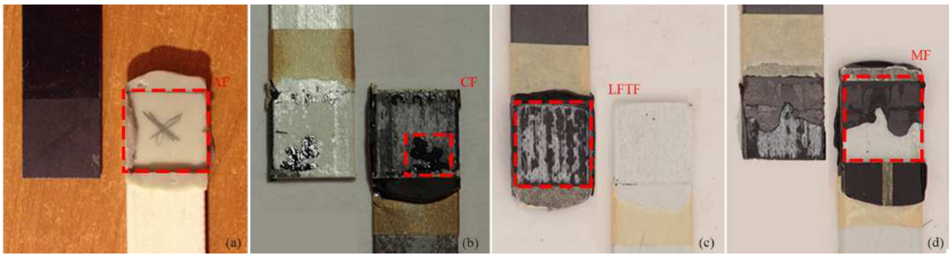


Figure 3.7. Failure modes of GFRP-steel single lap joints: adhesive AF (a), cohesive CF (b), light-fiber-tear LFTF (c) mixed MF (d) failures.

The percentage of fracture mode was evaluated by a graphical estimation. Table 3.7 shows the results of un-aged and aged specimens.
In the *un-aged* condition (T_0), the joints bonded with EPX1 showed the best performance since the LFTF failure modes mostly occurred. In this case, in fact, the optimum adhesion between the adherents led to the delamination of the GFRP profiles. The worst behaviour was registered by EPX3 that showed all adhesive failures.
After the *ageing* treatments (T_{cc} and T_{uv}), very similar effects were registered by all the adhesives. The first epoxy showed slight worsening of the performance especially after the UV exposure, with almost adhesive – light fibre tear failures. EPX2 joints presented a decrease of the data with all adhesive fractures and, EPX3 confirmed the un-aged results.
After the *combination* of the *ageing* treatments (T_{cc}+T_{uv} and T_{uv}+T_{cc}), all the specimens showed a slight enhancement of the performance than those registered in the previous ageing conditions (T_{cc} and T_{uv}). Similar results were registered in the two artificial exposures: the first epoxy adhesive presented almost all mixed failure modes, with a high percentage of the LFTF type. The second epoxy showed little percentages of cohesive failures even if the main fracture type remained the adhesive one.

Table 3.7. Failure modes of GFRP-steel single lap joints: results before (T_0) and after the ageing (T_{cc}, T_{uv}, T_{cc}+T_{uv}, T_{uv}+T_{cc}) treatments: adhesive (AF), cohesive (CF), mixed (MF), light-fiber-tear (LFTF) failures.

	T_0	***T_{cc}***	***T_{uv}***	***T_{cc} + T_{uv}***	***T_{uv} + T_{cc}***
EPX1	3 LFTF 1 MF (20% LFTF, 80% AF)	2 LFTF 1 MF (90% LFTF, 10% AF) 1 MF (85% LFTF, 15% AF)	1 LFTF 2 MF (40% LFTF, 60% AF) 1 MF (20% LFTF, 80% AF)	1 LFTF 1 MF (50% LFTF, 50% AF) 1 MF (95% LFTF, 5% CF)	1 LFTF 2 MF (80% LFTF, 20% AF)
EPX2	1 LFTF 3 AF	4 AF	4 AF	1 AF 1 MF (90% AF, 10% CF) 1 M (95% AF, 5% CF)	2 AF 1 MF (95% AF; 5% CF)
EPX3	4 AF	4 AF	4 AF	/	/

Table 3.8. Mechanical properties of GFRP squared short specimens, with and without the steel reinforcement: results before (T_0) and after (T_{cc}, T_{uv}) the ageing treatments.

Adhesive	***Configuration***	***Load***				***Displacement***				***Stiffness***			
		T_0 (N)	dev.st.	T_{cc} (%)	T_{uv} (%)	T_0 (mm)	dev.st.	T_{cc} (%)	T_{uv} (%)	T_0 (N/mm)	dev.st.	T_{cc} (%)	T_{uv} (%)
EPX1	U	15859,21	2434,83	-17,38	-	0,98	0,98	+28,32	-	18599,89	1906,98	-30,41	-
	L	12338,46	1603,75	-3,26	-	0,79	0,79	+74,48	-	18249,46	2611,05	-36,05	-
	U-I	11238,64	2363,16	+5,39	+18,81	0,61	0,61	+60,36	+57,72	22552,05	4389,90	-43,63	-40,04
EPX2	U	11900,37	782,53	-25,95	-	0,78	0,78	+11,34	-	16282,86	1630,84	-40,33	-
	L	13874,00	1173,74	-16,71	-	1,01	1,01	+37,28	-	15041,12	816,01	-9,35	-
	U-I	12351,41	810,21	-31,74	-22,13	0,62	0,62	-13,54	-7,27	21554,12	991,69	-30,17	-19,73
EPX3	U	7959,96	1794,53	-29,02	-	0,48	0,48	-3,81	-	19861,34	2744,33	-9,31	-
	L	13974,55	417,86	-24,56	-	1,76	1,76	+17,15	-	15512,10	264,05	-49,71	-
	U-I	7643,22	313,21	-20,42	+1,78	0,50	0,50	-8,38	-1,97	20345,13	6162,22	-28,23	-17,56
Without steel		14556,56	347,10	-	-	1,06	0,06	-	-	12647,50	92,63		

3.4.2. Puncture tests

3.4.2.1. Mechanical performance

Table 5.8 shows the average results of un-aged (as produced) and aged GFRP-steel squared tubular short specimens, subjected to puncture tests: the load carrying capacities (N), the displacements (mm) and the stiffness (kN/mm) are presented. The considered values are the maximum data recorded in the elastic range. Per each adhesive type, all the specimen's configurations (upper, lower and upper-inner) are compared to GFRP profiles tested without the steel reinforcements.
With regard to *un-aged samples* (T_0), the *load* carrying capacity of the hybrid specimens resulted always lower than those of the un-reinforced GFRP profiles: this is because, during the load application, the steel plates penetrated inside the samples, indenting the composite's surfaces and weakening the performance of the bonding systems. The only exceptions were the specimens in the upper configuration bonded with EPX1 adhesive, registering the best behaviour. With regard to EPX2 and EPX3, the specimens in the lower configuration showed the highest results, with very similar values.
The *displacements* recorded by the GFRP-steel samples presented almost all lower values than the un-reinforced ones, especially the specimens bonded with EPX3 adhesive in the upper and upper-inner configurations.
The *stiffness*, as expected, of the steel reinforced specimens were always the highest among all the samples, for every configuration and tested adhesives. The best results were showed by specimens in the upper-inner configurations, and the highest value was again registered by EPX1 adhesive.
The same conclusions could be drawn analysing the load-displacement trends, in the elastic range (Fig. 3.8), of representative specimens. On the other hand, in the plastic range, the un-reinforced GFRP profile showed better performance than the hybrid ones, declaring mostly higher load carrying capacity and stiffness values. This is because of the steel plates, indenting the GFRP surfaces, worsened the mechanical response of the composites profiles, in the long term.

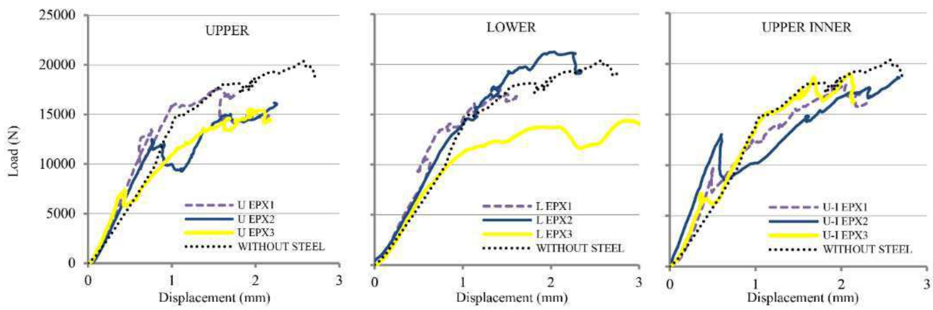


Figure 3.8. Representative load-displacement trends of GFRP-steel squared tubular short specimens, bonded with three epoxy adhesives, in un-aged condition (T_0): comparison of the three different configurations with the un-reinforced profile.

With regard to *aged* samples (T_{cc} and T_{uv}), the two artificial treatments had similar effects on the mechanical responses of the hybrid specimens, which resulted generally worsened. A lowered *load* carrying capacity was showed, with decrements up to 30 %, with some exceptions: the UV treatments, in fact, increased the performance of the samples bonded with EPX1 adhesive of about 19 % and a little increment was also registered by EPX3 adhesive.
The *displacements* resulted increased in almost all the GFRP-steel specimens, and the highest results were recorded by the samples bonded with EPX1 adhesive (of about 60 %), both after T_{cc} and T_{uv} treatments. Therefore, very high *stiffness* decrease was registered by the hybrid specimens, for all the configurations and tested adhesives.
On the other hand, as showed in figures 3.9 and 3.10, aged specimens maintained higher stiffness in the elastic range than un-reinforced GFRP samples, especially after UV radiations. The only exceptions were presented by the hybrid profiles in the lower configuration, which showed the lowest trend also in initial conditions (T_0).

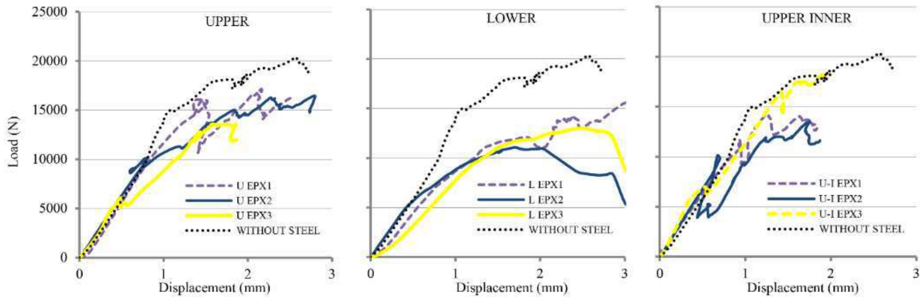


Figure 3.9. Representative load-displacement trends of GFRP-steel squared tubular short specimens, bonded with three epoxy adhesives, after the continuous condensation treatment (T_{cc}): comparison of the three different configurations with the un-reinforced profile.

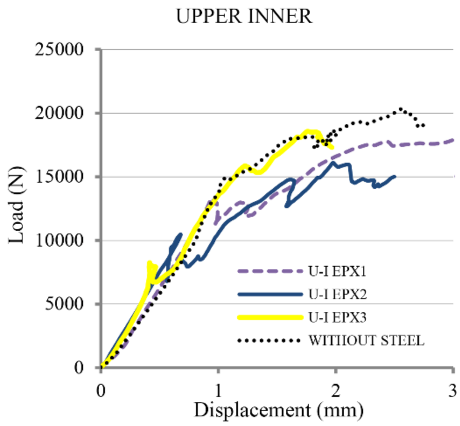


Figure 3.10. Representative load-displacement trends of GFRP-steel squared tubular short specimens in the upper-inner configuration, after the UV exposure (T_{uv}): comparison of three epoxy adhesives with the un-reinforced profile.

These results confirmed the advantageous method of hybridization, even when the bonding system is exposed to adverse environmental conditions. By comparing the tested adhesives, EPX1 demonstrated the best mechanical characteristics in un-aged condition and, even if it presented the highest decrements after ageing, it maintained the better performance in terms of load carrying capacity and stiffness values, with respect to the other tested adhesives.

3.4.2.2. Failure modes

Fig. 3.11a presents the typical cracks occurred in GFRP profiles, both in un-reinforced and hybrid specimens after puncture tests: in the compression zone, the loading member caused structural deformations along the z-axis and web-flange separations with a 45˚ interlaminar shear crack at each corner of the pultruded GFRP section occurred [1]. As showed in Fig. 3.11b, the GFRP-steel specimens in the upper and upper-inner configurations presented greater structural deformations, since the steel laminate penetrated inside the GFRP profile during the load application.

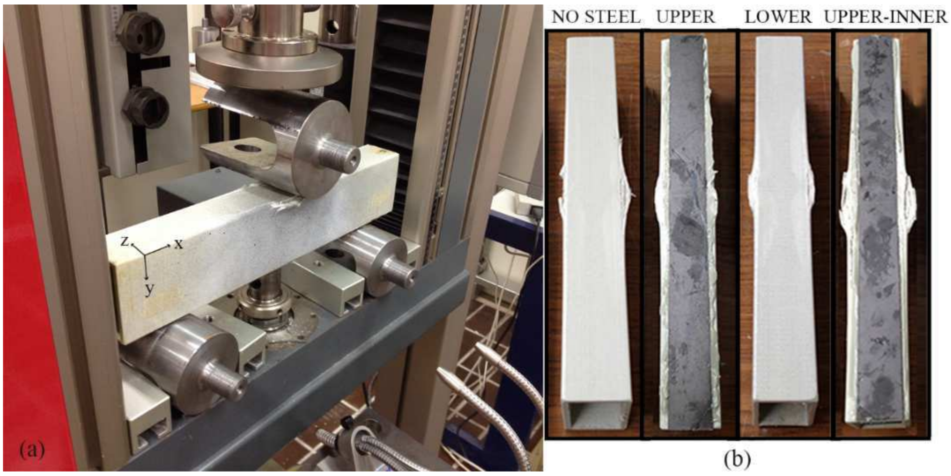


Figure 3.11. Failure modes of GFRP-steel squared tubular short specimens: typical cracks (a) and comparison of un-reinforcement samples with reinforced ones in the three different configurations (b).

With regard to GFRP-steel bonding conjunctions, the failure modes occurred always in the "adhesive" type (according to the classification of ASTM D5573-99 [19]). The hybrid specimens, for the tested adhesive in three different configurations, registered different behaviours. Table 3.9 shows the results before and after the ageing treatments.

Table 3.9. Failure modes of GFRP squared short specimens with the steel reinforcement: results before (T_0) and after (T_{cc}, T_{uv}) the ageing treatments: partial detachment (P.D.), total detachment (T.D), no detachment (NO) of the steel laminates.

	T_0			***T_{cc}***			***T_{uv}***
	U	**L**	**U-I***	**U**	**L**	**U-I***	**U-I***
EPX1	NO	NO	75% P.D.	NO	NO	P. D.	50% P.D.
EPX2	NO	NO	P.D.	NO	NO	50% P.D. 50% T.D.	50% P.D.
EPX3	35% P.D.	P.D.	T.D.	NO	P.D.	NO	T.D.

*The detachment occurred only for the steel laminate positioned in the inner side of the squared tubular profiles.

In the *un-aged* condition (T_0), EPX1 and EPX2 presented very similar behaviours: in the upper and lower configurations, any detachment occurred between GFRP and steel profiles, while in the upper-inner configuration the first epoxy adhesive showed a better performance of about 25%. The worst results were registered by EPX3 with the separation of the steel laminate in all the cases.

After the *continuous condensation* (T_{cc}) treatment, very similar results than the un-aged condition were showed by EPX1 and EPX2, with a slight worsening of the failure modes in the upper-inner configuration. An unexpected behaviour was observed for EPX3 that improved its performance when the steel laminates were positioned in the upper and upper-inner sides of the GFRP profiles.

After the *UV* (T_{uv}) exposure, better results than the un-aged condition were registered by EPX1 and EPX2, while EPX3 showed the same behaviour.

3.4.3. Three-point bending tests

3.4.3.1. Mechanical performance

Table 3.10 shows the average results of GFRP-steel squared tubular long specimens subjected to three-point bending test: the load carrying capacities (N), the displacements (mm) and the stiffness (kN/mm) are presented. The considered values are the maximum data recorded in the elastic range. All the specimen's configurations (upper, lower and upper-inner), bonded with the best adhesive resulted in the previous experiments, are compared to GFRP profiles tested without the steel reinforcements.
The *load* carrying capacity of the hybrid specimens was higher than the un-reinforced GFRP profiles for the upper and lower configurations, respectively of about 7 % and 10 %. For the samples with the steel laminates positioned in the upper-inner side of the GFRP profile, the result was very similar.
The *displacements* recorded by the GFRP-steel samples presented all lower values than the un-reinforced ones, especially the specimens in the upper-inner configuration.
The *stiffness* of the steel reinforced specimens was always the highest, for every configuration.
The specimens in the lower configuration registered the best increment, of about 80 %. In fact, the lower side of the GFRP profile was subjected to the tensile stresses and the steel reinforcement allowed higher containment of the deformations than in the other positions.
To summarise, also in the three-point bending tests, the steel reinforcement allowed to increase the mechanical performance of the GFRP squared tubular profiles, in particular in the lower configuration.

Table 3.10. Mechanical properties of GFRP squared long specimens, with and without the steel reinforcement.

Adhesive	***Configuration***	***Load*** (N)			***Displacement*** (mm)			***Stiffness*** (N/mm)		
		medium	dev.st.	Δ*(%)	medium	dev.st.	Δ*(%)	medium	dev.st.	Δ*(%)
EPX1	U	15493.99	1147.18	-0.22	6.60	0.59	-28.92	3466.85	42.64	+47.80
	L	15909.07	846.70	+7.14	6.92	0.67	-16.82	4834.80	685.26	+30.52
	U-I	14429.68	531.00	+10.01	5.64	0.82	-12.75	3925.90	14.00	+82.02
Without steel		14462.12	766.92	-	7.94	1.29	-	2656.15	21.28	-

* the percentage variation is respect to the un-reinforced specimens (without steel).

3.4.3.2. Failure modes

After three-point bending tests, similar failure modes occurred in GFRP profiles, both in un-reinforced and hybrid specimens. Analogue failures than the squared tubular short profiles (section 5.4.2.2) were observed, with the only difference of the cracks propagation length. In this case, in fact, the high stiffness due to the geometry of the profiles (length of 1000 mm) allowed obtaining lower structural deformations than the shorter ones (400 mm). Furthermore, with respect to the previous puncture tests, any detachment of the steel plates was observed for all the configurations.

3.5. Analytical results

The stiffness results for the GFRP-steel squared tubular long specimens, obtained through analytical calculations, were comparable with those observed in the experimental tests and confirmed the enhancement of the GFRP mechanical response thanks to the steel contribution.
With regard to the *un-reinforced* GFRP profile, the stiffness calculation was consistent with the experimental result, respectively 2664.50 N/mm and 2656.15 N/mm.
About the *reinforced* specimens, the stiffness obtained in the case of the GFRP-steel perfect collaboration demonstrated the highest value in the upper-inner configuration (4877.65 N/mm). In all the configurations lower results were calculated when the two materials do not work together, and they were comparable with those registered by the un-reinforced specimens in the experimental test.
The stiffness data recorded during experimental tests are included among the values calculated in analytical studies, as showed in Figure 5.12. The only exception was observed

in the lower configuration, where the experimental value is slightly higher than the analytical one when the steel and GFRP work together.

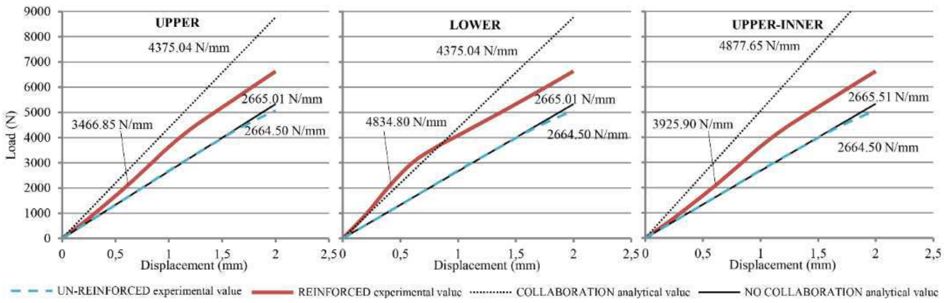


Figure 3.12. Comparison of experimental and analytical stiffness results of GFRP squared long specimens.

3.6. Discussion

The present study aims to evaluate both the GFRP-steel compatibility and the steel contribution to enhancing the mechanical performances of the GFRP profiles, also considering the effects of different environmental ageing conditions.

Regarding the mechanical performance in *un-aged* condition, the *bonding compatibility* between GFRP profiles and steel laminates was confirmed by the results obtained through *shear tests* on the single lap joints. The values were consistent with the data reported by manufacturers, confirming the highest performance of the first epoxy adhesive (EPX1). The *hybridization method*, consisting of GRFP squared tubular profiles adhesively joined to steel plates, resulted advantageously since it enhanced the *stiffness of* GFRP specimens subjected both to local and to flexural stresses.

The *puncture tests* revealed that the stiffness of the reinforced samples, with the steel laminates positioned in the three different configurations (upper, lower, upper-inner sides of the GFRP profiles), were higher than the un-reinforced ones, especially where a double reinforcement was applied. This result is consistent with other authors findings, which demonstrated the higher performance of hybrid specimens with respect to those without reinforcements [2, 3]. On the other hand, the load carrying capacity of the hybrid samples resulted lower than those of the un-reinforced GFRP profiles: during the load application, the steel plates penetrated inside the samples, indenting the composite's surfaces and weakening the performance of the bonding systems. The only exception was showed by the first epoxy adhesives in the upper configuration, which resulted in the best performance of the tested adhesive.

The *three-point bending tests* demonstrated the best performance of the hybrid specimens in terms of both loads carrying capacity and stiffness, especially when the steel laminate was positioned in the lower configuration. In fact, the lower side of the GFRP profile was subjected to the tensile stresses and the steel reinforcement allowed higher containment of the deformations than in the other positions.

The *analytical stiffness results* of the GFRP-steel squared tubular long specimens were comparable with those observed in the experimental tests and confirmed the steel contribution to the enhancement of the GFRP mechanical response.

Regarding the effects of the two *ageing conditions*, the continuous condensation and UV exposures, similar results were observed in all the tested specimens: single lap joints and short tubular squared profiles. The *load* carrying capacity registered a decrease after the hot-wet exposure, while the UV exposure led to the opposite results. This is because, as stated in another study [8], during the UV ageing the specimens were inevitably heated by radiations, reaching surface temperature values of about 26 °C. This even small temperature increase could have determined a slight increase of the load carrying capacity, thanks to the cross-linking of the polymer network [17]. The *stiffness*, after both the environmental conditions, showed decreasing trends, especially after the continuous condensation treatment. In fact, some authors stated that adhesively bonded joints exposed to different temperatures and humidity levels registered high stiffness degradation, even without reaching the adhesive's

glass transition temperature [9]. With regard to specimens exposed to the UV radiations, all the tested adhesives demonstrated a scarce UV resistance. This is because of the wavelength of UV radiation, in the range of 90–400 nm, usually cause polymers bond dissociation and the consequent decrease in adhesives elastic modulus [17, 22].
However, hybrid squared tubular specimens subjected to ageing treatments maintained higher stiffness in the elastic range than un-reinforced GFRP samples, especially after UV radiations, up to 36 % for the second epoxy adhesive. These results confirmed the advantageous method of hybridization, even when the bonding system is exposed to adverse environmental conditions.

Regarding the *combination* of the two *ageing conditions*, the effects on the single lap joints were better than the previous artificial treatments separately analysed. The best results were observed for the samples firstly subjected to UV radiations and later under high humidity and temperatures levels: both the *load* carrying capacity and the *stiffness* of the two adhesives registered increasing values respect to the un-aged ones. This could be explained by the effects of the UV radiations: as showed in the single ageing treatment, the UV exposure led to an increase of the load carrying capacity of the joints thanks to the cross-linking of the adhesives polymers. This previous effect resulted beneficially also after the exposition to the hot-wet exposure, which was the highest damaging conditions for the joints.
Regarding the second combination (when the sample were exposed to high humidity and temperatures levels and later underwent UV radiations), the first epoxy adhesive showed higher results with respect to the initial conditions, while the second one registered decreasing data, although it maintained good performance thanks to the enhancement of its mechanical properties after the UV exposure. The aim of a future work is to deepen into the chemical compositions of the two epoxy adhesives, to analyse the effects of the combined artificial ageing.

3.7. Conclusions

In the present study, an experimental campaign on the bonding connection of GFRP pultruded profiles and steel laminates through three different epoxy adhesives is proposed. The contribution in terms of stiffness increase and deformations control by coupling steel laminates to GFRP pultruded profiles was analysed with the objective to verify the applicability of this hybrid system in structural members for curtain walls. Mechanical tests (shear, puncture and flexural) were performed on different specimens types and the effects of two environmental conditions, continuous condensation and UV radiations, were investigated.
The main outcomes are:

- Shear tests allowed demonstrating the compatibility of the GFRP-steel bonding system and the best mechanical performance of the first epoxy adhesive (EPX1) was observed, both in un-aged and aged conditions.
Between the two ageing treatments, the continuous condensation demonstrated higher negative effects on the joints, registering stiffness decreasing values up to 93 %. Instead, after the UV radiations, the load carrying capacity of the joints were increased thanks to a further polymerization of adhesives for slightly high (26 °C) temperatures.
The specimens were also subjected to the combinations of the continuous condensation and the UV radiations, in two different sequences: in the previous, the samples were firstly subjected to high humidity and temperatures levels and later under UV radiations (T_{cc}+T_{uv}); in the latter, the samples underwent UV radiations and then they were exposed to high humidity and temperatures levels (T_{uv}+T_{cc}). Both the ageing treatments showed better effects on the mechanical responses of the joints than those registered in the ageing conditions separately analysed, and the best results were obtained after the T_{uv}+T_{cc} exposure in terms of load carrying capacity and stiffness increases.

- Puncture tests permitted to simulate the local stress transmitted by the curtain panels bolted to the GFRP structural members, demonstrating that the stiffness of the GFRP reinforced profiles, with the steel laminates positioned in the three different configurations (upper, lower, upper-inner sides of the GFRP profiles), was higher than the un-reinforced ones. In the plastic range, instead, the un-reinforced GFRP profile showed better performance than

the hybrid ones. This is because of the steel plates, indenting the GFRP surfaces, worsened the mechanical response of the composites profiles, in the long term.
EPX1 showed the best mechanical characteristics in un-aged condition, overall maintaining better performance than the other adhesives after the two artificial exposures.
The two ageing treatments demonstrated negative effects on the specimens, especially the continuous condensation one. However, hybrid squared tubular profiles subjected to ageing treatments maintained higher stiffness in the elastic range than un-reinforced GFRP.

- Flexural tests were performed to simulate the stress of the whole structural member that occurred in curtain walls (when it is subjected to the wind load), demonstrating that the best performance of the hybrid specimens in terms of both loads carrying capacity and stiffness, especially when the steel laminate was positioned in the lower configuration. In fact, the lower side of the GFRP profile was subjected to the tensile stresses and the steel reinforcement allowed higher containment of the deformations than in the other positions.
The analytical stiffness results of the GFRP-steel squared tubular long specimens were comparable with those observed in the experimental tests and confirmed the steel contribution to the enhancement of the GFRP mechanical response.

These results confirmed the reliability of the *Structural Member* for curtain walls basic principle, i.e. the hybrid system of GFRP pultruded profiles bonded with steel laminates. This result allows enhancing the GFRPs flexural performance and the containment of deformations, even maintaining small transversal areas.

3.8. Reference

[1] Wu C, Bai Y, Zhao X-L. Improved bearing capacities of pultruded glass fibre reinforced polymer square hollow sections strengthened by thin-walled steel or CFRP. *Thin-Walled Structures* 89 (2015) 67–75.
[2] Haoa Q, Wangb Y, Oua J. Design recommendations for bond between GFRP/steel wire composite rebars and concrete. *Engineering Structures* 30 (2008) 3239-3246
[3] Kim H-Y, Lee S-Y. A steel-reinforced hybrid GFRP deck panel for temporary bridges. *Construction and Building Materials* 34 (2012) 192–200
[4] J. Qureshi, J. T. Mottramb. Behaviour of pultruded beam-to-column joints using steel web cleats. *Thin-Walled Structures* 73 (2013) 48–56.
[5] Wu C, Bai Y. Web crippling behavior of pultruded glass fibre reinforced polymer sections. *Composite Structures* 108 (2014) 789–800
[6] Borowicz DT, Bank LC. Behavior of pultruded fiber-reinforced polymer beams subjected to concentrated loads in the plane of the web. *Journal of Composites for Constructions* 15(2) (2010) 229–38.
[7] Turvey GJ, ZhangY. Characterisation of the rotational stiffness and strength of web–flange junctions of pultruded GRP WF-sections via web bending tests. *Composites Part A* 37(2) (2006)152–64.
[8] Stazi F, Giampaoli M., Rossi M, Munafo P. Environmental ageing on GFRP pultruded joints: Comparison between different adhesives. *Composite Structures* 133 (2015) 404–414
[9] Zhang Y, Vassilopoulos A. P, Keller T. Environmental effects on fatigue behavior of adhesively-bonded pultruded structural joints. *Composite Science and Technology* 2009; 69; 1022-1028.
[10] Zhang Y, Vassilopoulos A. P, Keller T. Effect of low and high temperatures on tensile behavior of adhesively-bonded GFRP joints. *Composite Structures* 2010; 92; 1631-1639.
[11] EN ISO 527-1:2012. Plastics -Determination of tensile properties – Part 1: General principles.
[12] ISO 527-4:2012. Plastics -Determination of tensile properties – Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites.
[13] EN ISO 527-2:2012. Plastics -Determination of tensile properties – Part 2: Test conditions for moulding and extrusion plastics.
[14] ASTM D 3418-03. Standard test method for Transition Temperatures of Polymers By Differential Scanning Calorimetry.
[15] Elchalakani M. CFRP strengthening and rehabilitation of degraded steel welded RHS beams under combined bending and bearing. *Thin-Walled Structures* 77 (2014) 86–108

[16] ISO 6270-2:2005. Paints and varnishes — Determination of resistance to humidity — Part 2: Procedure for exposing test specimens in condensation-water atmospheres
[17] Nguyen T, Bai Y, Zhao X, Al-Mahaidi R. Effects of ultraviolet radiation and associated elevated temperature on mechanical performance of steel/CFRP double strap joints. *Composite Structures* 2012; 94; 3563–3573.
[18] ASTM D904-99. Standard Practice for Exposure of Adhesive Specimens to Artificial Light.
[19] ASTM D5573-99 Standard practice for classifying failure modes in fiber-reinforced-plastic (FRP) joints.
[20] De Castro J. Experiments on double-lap joints with Epoxy, polyurethane and ADP adhesives. *Composite Construction Laboratory, Appendix B* – Technical Report n. CCLab2000.1 b/2.
[21] Grassie N, Scott G. *Polymer degradation and stabilization*. Cambridge: Cambridge University Press; 1988.

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Chapter 4

Technological and performance verification through SimaPro and Midas Gen software

4.1. Introduction

Nowadays, a modern façade mainly refers to energy efficiency by obtaining the best thermal insulation coefficient, **with solutions and details harmonized with other types of finishes once the architectural and technical requirements of a building have been met.**
In addition to water-tightness, wind loads resistance, heat, moisture, sound and burglary proof, the façades have to perform ergonomic functions, such as using natural light and solar heat, as well as natural ventilation.
Contemporary façades are distinguished by a design with profiles that have gradually smaller visible widths and a perfect integration of the complementary systems of windows, doors, shading systems, balconies, bannisters, awnings and even photovoltaic panels in the façade system. You can choose from a variety of colours and finishes, both for interior and exterior parts of the profile: matte, glossy, metallic or various other textures.
The curtain walls are modern façades with excellent thermal and sound insulation qualities, but especially with endless possibilities of design and style. It is not only a solution for offices or bank buildings, but also for interior closing spaces or skylights construction (self-supporting or applied on steel, concrete, or wood structures). Curtain wall systems are made up of:

• Own structural system consisting of mullions (vertical elements) and spacers/traverses (horizontal elements);

• Panels mounted on their own structural system, which may be ÷ transparent glass panels (fixed or mobile) or opaque panels;

• Clamping, fastening, sealing and finishing devices (special parts, gaskets and putties);

• Thermal insulating windows.

One of the greatest tendencies of the contemporary architecture is to directly connect the interior spaces with the exterior onces as much as possible [1].

The mains objectives of this chapter is to study how the change of mullion materials would affect the health and the environmental impacts associated to a typical curtain wall (CW) system over its life cycle. The mullion materials studied include extruded aluminium and GFRP (composite material). To achieve the objective, a numerical simulation thought the Life Cycle Assessment (LCA) method have been applied. Results indicate that CW system with extruded aluminium mullions causes the most damage to the environment and human health over their life cycle respect to the GFRP one [2].
The mechanical analysis, on a wide glazed mirror, was carried out as well, in order to evaluate the behaviour of the mullion, when subjected to wind loads. The mechanical behaviour of the *Structural Member* in different materials such as steel, aluminium, GFRP and GFRP coupled to steel was analysed. The different results were compared thanks to the Structural Member model created through Midas Gen, finite element software. It is shown that the GFRP-steel coupling allows reducing the mullion deformations and the verification of the regulations UNI EN 13830:2015 “Norme di prodotto delle facciate continue”.

4.2. Life cycle assessment methodology

The study of the *Structural Member* demonstrates the feasibility of the use of composite material coupled with steel for such systems. In order to analyse all aspects of the building component, an environmental impact assessment in additional to the consumptions produced by a GFRP building element with low emissive glass compared to a similar aluminium product is carried out using the LCA methodology.

The lifecycle analysis of a façade is performed by comparing a façade with GFRP-steel and low emissive glass with a traditional aluminium one even if with low emissive glass.

In according to the ISO 14040:2006, the Life Cycle Assessment (LCA) is a compilation and evaluation of inputs, outputs and potential environmental impacts of a product system throughout its life cycle. The LCA methodology is based on an objective process of assessing energy and environmental loads related to a process, activity or management by identifying the energy and materials used and the waste released into the environment. The results obtained provide an assessment of the energy and environmental aspects but do not include economic and social factors.

Below a brief description of the methodology, legislations and factors involved in computing, impact and damage categories are reported.

The method of the life cycle analysis of a product consists of:
- measuring emissions of air, water, soil and natural substances (minerals, fossil fuels, water, wood, soil occupation, sun and wind energy) attributed to the life cycle (production, consumption and transport) of the study object;

- characterizing such emissions according to the impacted categories (eg global warming, acidification, eutrophication, ecosystem ecotoxicity, material consumption, fossil fuel consumption or non-renewable energy consumption). Each impacted category is measured with its own unit of measurement;

- attributing categories of damage (human health, ecosystem quality, resources use and the ability of the ecosystem to produce its fruits).

The Life Cycle Assessment (LCA) analysis was performed with the aid of the software SimaPro according to the ISO 14040:2006 [3] based on the following steps:
1. *Goal and scope definition*: the goal was to compare the environmental impact of the adoption of different glazing systems. The functional unit was 1 m^2 (15 kg) of glass. As regard the system boundaries, in this study the examined unit processes examined in this study were the use phase (heating, cooling and artificial lighting consumptions);

2. *Life Cycle Inventory Analysis (LCI)*: the data for the construction were obtained mainly from Eco-Invent database. Yearly thermal, electric and artificial lighting consumptions were quantified from the dynamic analysis with Energy Plus software, assuming to be constant over 30-yr glass lifespan. The energy needs (Kwh) were calculated for a room with south-west exposure and referred to the functional unit through the multiplication by a factor obtained as the ratio of the functional unit surface (1 m^2) to the total surface of external vertical wall adjacent to the selected room;

3. *Life Cycle Impact Assessment (LCIA)*: the Global Warming Potential (IPCC 2001 GWP) was used and the results expressed in kg CO^2eq;

4. *Interpretation of the LCA results*: the final phase of the LCA study is the interpretation which deals with implications of the results achieved in the impact assessment phase, recommendations and research limitations.

4.2.1. Comparison between aluminium and GFRP-steel façade

In order to understand the LCA methodology application and the results deriving therefrom, the characteristics of the two façades (GFRP and aluminium) identifying the first phase of the process, namely the *definition of the target and scope*, are here described.
The GFRP and aluminium façades analyzed are respectively made up of a composite and aluminium mullion. For both configurations, a low emissive glass composed of a clear glass exterior plate and an inner sheet with low emissivity with a 6/18/6 mm argon space is used.
The wall studied is of Marche Polytechnic University type office. This latter is characterized by an area of 35 m^2, for a height of 7m, with three blind walls and the fourth one (to the west) where the continuous façade is located. The façade dimensions are 7m x 5m.

The stratigraphy of the different walls, from the outside:

1) the inner walls, facing north and south, consist of:
- Plasterboard 2.5 cm
- Air gap 10 cm
- Plasterboard 2.5 cm.

2) the east facing wall consists of:
- Plasterboard 5 cm.

3) the outer wall facing the west (where the façade is located) is composed of:
- Concrete 4 cm;
- Pot bricks 25 cm;
- Air gap 5 cm;
- Bricks 8 cm;
- EPS 20 cm;
- Plaster 1 cm.

4) the roof and the floor are composed of:
- Flooring 1.5 cm;
- Predalles floor 40 cm;
- Plasterboard 5 cm.

The percentage of glass on the GFRP facade is equal to 70% (Fig.4.1.a) of the entire facade, greater than the aluminium, which is equal to 65% (Fig.4.1.b).

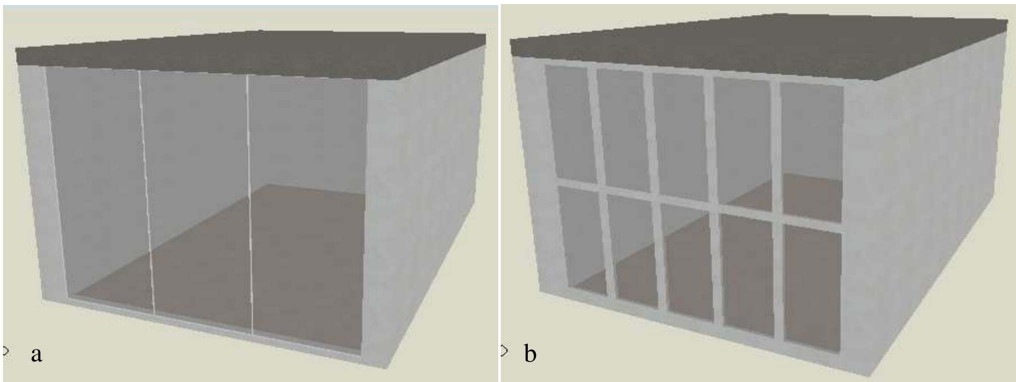

Figure 4.1. a) Façade model in GFRP; b) façade model in aluminium.

The functional unit considered is 1 m^2 of the entire continuous façade. This value is in relation to its service life of 30 years, assuming that both façades have the same lifetime. Regarding the system boundaries, the process units examined in this study involve three lifecycle phases: construction, consumption (heating/cooling) evaluated by the Design Builder software [4] and transport (from the production site to the yard).

In the next stage, the *inventory analysis*, we considered the phases of assembly and life cycle. In the assembly phase, the individual elements of the façade are chosen.
Regarding the curtain wall in GFRP (fig.4.2.) the elements were selected from the Ecoinvent Unit Processes database present in the program, for an amount of 1 m^2 (quantity chosen as study sample). The elements considered are:
- GFRP mullion coupled with a steel plate (experimental type model, chapter 3). Corresponding pultruded weight 2.17 kg and steel 0.785 kg;
- two glass sheets, one coated with a layer of silver and the other one not, forming the low emissive double glass. Corresponding weight 14.85 kg;
- argon gas inside the double glass. Corresponding weight 0.032 kg;
- silicone. Corresponding weight 0.39 kg.

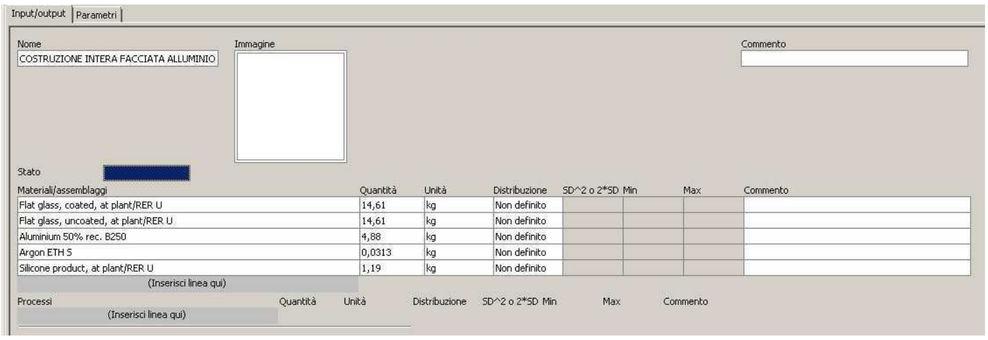

Figure 4.2. The products settings were chosen to evaluate the GFRP façade.

For the aluminium façade (fig.4.3.) the elements were selected from the Ecoinvent Unit Processes database present in the program, for an amount of 1 m^2 (quantity chosen as study sample). The elements considered are:
- the aluminium mullion chosen as a 50% recyclable material. Corresponding weight 4.88 kg;
- two glass sheets, one coated with a layer of silver and the other one not, forming the low emissive double glass. Corresponding weight 14.61 kg;
- argon gas inside the double glass. Corresponding weight 0.0313 kg;
- silicone. Corresponding weight 1.19 kg.

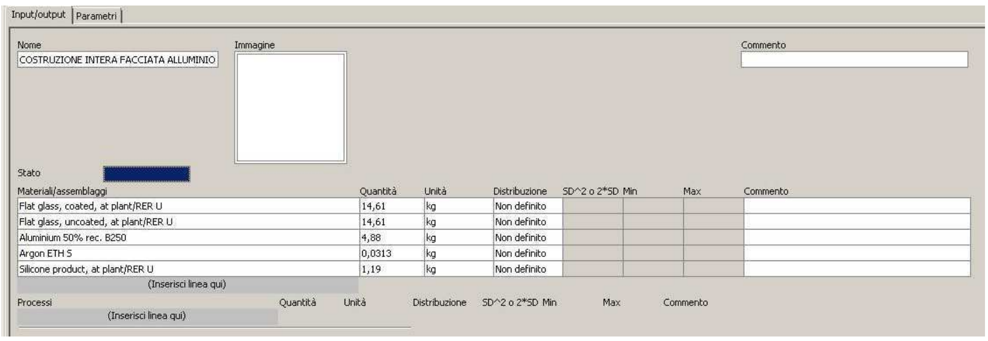

Figure 4.3. The products settings were chosen to evaluate the aluminium façade

In all the elements selected we already took into consideration the raw materials consumption, their transport at the production site and the whole process until the finished product.

In the life cycle we introduce the processes that come into play after the production date, as the transport of the product on site, the installation, and any maintenance during the life cycle. Trucks inside this stage from the Ecoinvent Unit Processes database are selected.
The GFRP transport (Fig.4.4.) assumed involves the use of a truck with a capacity of 16t, from the mullion production site (Udine) to Ancona for a 489km route. For the glass

transport, the journey starts at the glass production place in Pisa to Jesi (the glass store for the double glass assembly). The transport ends in a yard in Ancona, where the installation finally takes place.

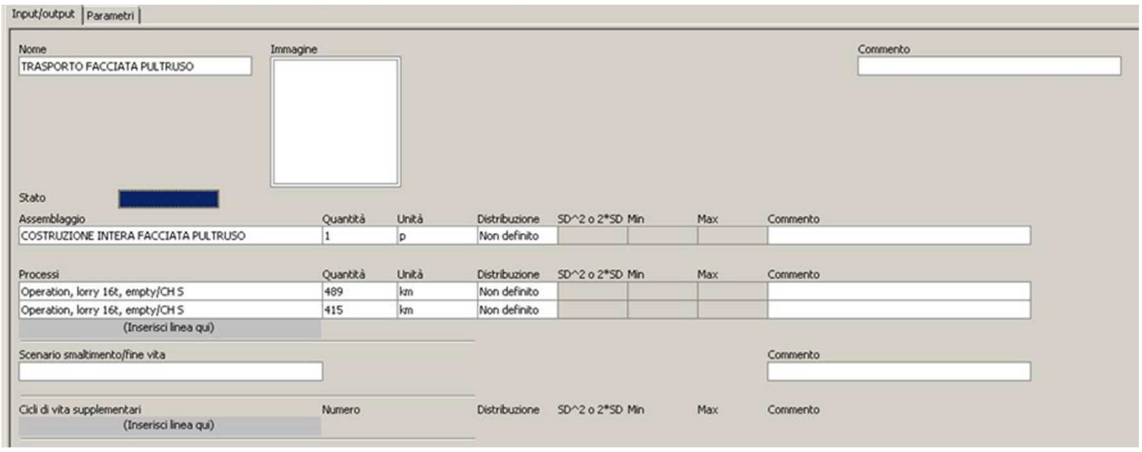

Figure 4.4. Process settings considered for the life cycle of the GFRP façade.

The energy consumption considered are (fig.4.5.):

- the kWh consumed during the heating-up period, determined by the previous energy simulation [4], $71{,}254\ \frac{kwh}{m^2 year}$, referring to the room's surface area of $35m^2$, multiplied by the functional unit of $1m^2$ (relating to the 35 m^2 of the façade) and by the glass lifetime equal to 30 years, in according to the companies

$$2138\text{ kwh} = 71{,}254\ \frac{kwh}{m^2 year} * 35m^2 * \frac{1\ m^2}{35\ m^2} * 30\ years$$

- the kWh consumed for cooling, determined by a previous study [4], was $76{,}313\ \frac{kwh}{m^2 year}$, referring to the room's surface area of $35m^2$, referring to the room's surface area of $35m^2$, multiplied by the functional unit of $1m^2$ (relating to the 35 m^2 of the façade) and by the glass lifetime equal to 30 years, in according to the companies

$$2289\text{ kwh} = 76{,}313\ \frac{kwh}{m^2 year} * 35m^2 * \frac{1\ m^2}{35\ m^2} * 30\ years$$

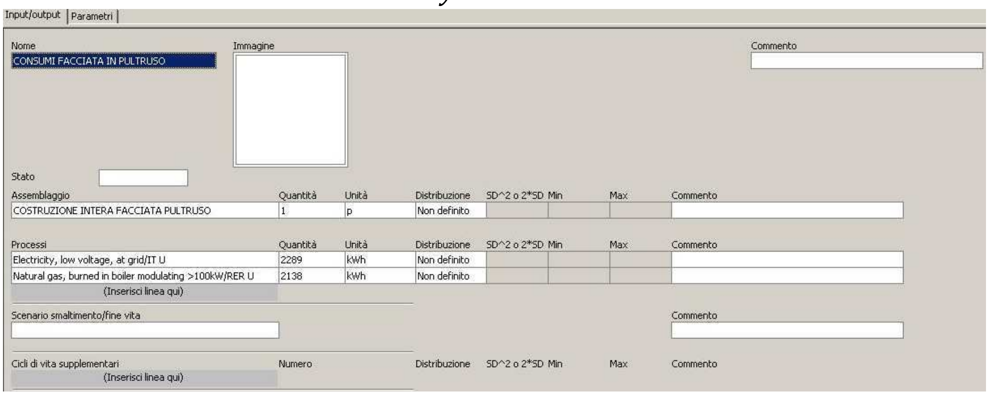

Figure 4.5. Setting the façade consumption in GFRP material.

The aluminium transport (Fig.4.6.) assumed, involves the use of a truck with a capacity of 16t, from the mullion production site in Udine to Ancona for a 489km route. For the glass transport, the journey starts at the glass production place in Pisa, to Jesi (the glass store for the double glass assembly). The transport ends in a yard in Ancona, where the installation finally takes place.

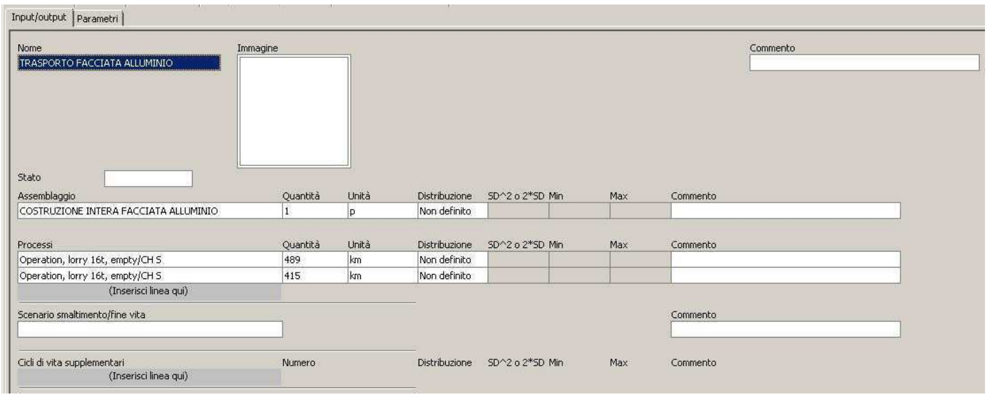

Figure 4.6. Process settings considered for the life cycle of the aluminium façade.

The energy consumption considered (fig.4.7.):

- the kWh consumed during the heating-up period, determined by the previous energy simulation [4], $89{,}56\ \frac{kwh}{m^2 year}$, referring to the room's surface area of 35m^2, multiplied by the functional unit of 1m^2 (relating to the 35 m^2 of the façade) and by the glass lifetime equal to 30 years, in according to the companies

$$2687\ \text{kwh} = 89{,}56\ \frac{kwh}{m^2 year} * 35m^2 * \frac{1\ m^2}{35\ m^2} * 30\ years$$

- the kWh consumed for cooling, determined by a previous study [4], was $63{,}519\ \frac{kwh}{m^2 year}$, referring to the room's surface area of 35m^2, referring to the room's surface area of 35m^2, multiplied by the functional unit of 1m^2 (relating to the 35 m^2 of the façade) and by the glass lifetime equal to 30 years, in according to the companies

$$1906\ \text{kwh} = 63{,}519\ \frac{kwh}{m^2 year} * 35m^2 * \frac{1\ m^2}{35\ m^2} * 30\ years$$

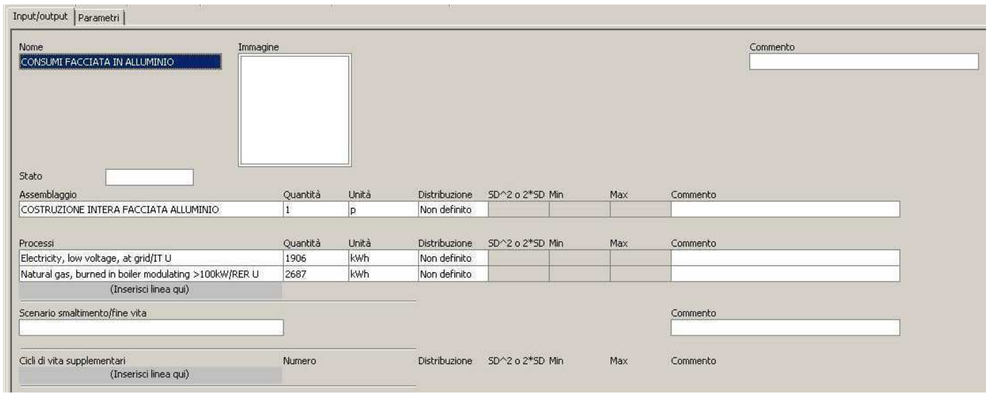

Figure 4.7. Setting the façade consumption in aluminium material.

The environmental impact assessment study is based on some methods of calculating the damage, including:

- Eco-indicator 99, is a method that analyses three different types of damages: human health, ecosystem quality and resources. The relevant information about the Eco-indicator 99 is that the standard unit given in all the categories is the point (Pt) or millipoint (mPt). Since the aim of this method is the comparison of products or components, the value itself is not the most relevant but rather a comparison of values;
- Cumulative Energy Demand (CED), is used as an indicator of energy requirements. CED covers the energy requirements through the life cycle, including direct and

indirect energy uses, the most relevant processes and sub-processes that go into the manufacture of the material;

- Environmental Priority Strategies (EPS 2000), EPS includes an impact assessment (characterisation and weighting) method for emissions and use of natural resources, which can be applied in any Life Cycle Assessment (LCA). The results of the EPS impact assessment method are damage costs for emissions and use of natural resources expressed as ELU (Environmental Load Units). One ELU represents an externality corresponding to one Euro environmental damage cost;
- Global Warming Potential (IPCC 2001 GWP), is a quantified measure of the globally averaged relative radiative forcing impacts of a particular greenhouse gas. It is defined as the cumulative radiative forcing – both direct and indirect effects – integrated over a period of time from the emission of a unit mass of gas relative to some reference gas (IPCC 1996). Carbon dioxide (CO2) was chosen by the IPCC as this reference gas and its GWP is set equal to one (1). GWP values allow you to compare the impacts of the emissions and the reductions of different gases. The GWP depends on the following factors: the absorption of infrared radiation by a given species, the spectral location of its absorbing wavelengths and the atmospheric lifetime of the species.

4.2.2. Results and discussions

The lifecycle assessment of the two types of curtain walls, for 30 years, shows that the impacts are different depending on the method used and the analyzed category (Tab.4.1.). All results were expressed according to the characterization phase (indicator category) and only the overall results of each method are reported in relation to the weighted analysis in point (Pt). For each category, multipliers have been reported to obtain their Pt.

The study carries out by the *Eco-indicator 99* method shows that the aluminium façade has a higher environmental impact than that in the GFRP. The most important environmental impact is man-made fossil fuel (Fossil Fuels), which is the result of high carbon dioxide emissions contributing to global warming, followed by a high percentage of respiratory inorganics (carcinogenic substances) which represents the risk for human health.

The *Cumulative Energy Demand* (CED) method shows that the GFRP façade has a lower total energy cost than the aluminium one. Even with this method, the greatest contribution is given by the non-renewable energy of fossils.

The study carried out through the *Environmental Priority Strategies 2000* (EPS 2000) method shows that for the human health category there is a disadvantage in the case of the aluminium facade. For the ecosystem production capacity category (the two study cases highlight the same positive effect (negation indicates the benefit to the environment). For the abiotic stock resource category, the greatest impact is with the use of GFRP. In the end, the last category of biodiversity (the variety of living things that populate the earth), the aluminium facade is more burdensome.

Analyzing total loss, the EPS 2000 method shows that the lowest impact is due to the façade in the GFRP.

In the *Global warming potential* (GWP) method, the façade in GFRP has lower carbon dioxide emissions [5].

Method / construction technique	Unit (characterization)	Conversion to Pt	Facciata in Alluminio	Facciata in Pultruso
Eco-indicator 99 (H) - hierarchist perspective				
HUMAN HEALTH	DALY	* 65.1 $DALY^{-1}$ * 300 Pt	5,06E+01	4,93E+01
Carcinogens	DALY		1,26E+00	1,09E+00
Respiratory organics	DALY		5,43E-02	5,17E-02
Respiratory inorganics	DALY		3,70E+01	3,61E+01
Climate change	DALY		1,21E+01	1,19E+01
Radiation	DALY		1,60E-01	1,35E-01
Ozone layer	DALY		9,03E-03	6,46E-03
ECOSYSTEM QUALITY	PDF m^2yr	*1.95 E - 4 P.m2 yr^{-1} * 400 Pt	1,56E+01	1,60E+01
Ecotoxicity	PDF m^2yr (=0.1 * PAFm^2yr)		7,20E+00	7,63E+00
Acidification/ Eutrophication	PDF m^2yr		6,25E+00	6,48E+00
Land use	PDF m^2yr		2,18E+00	1,93E+00
RESOURCES	MJ Surplus	* 1.19 E -4 MJ $S.^{-1}$ * 300 Pt	1,13E+02	1,11E+02
Minerals	MJ Surplus		2,93E+00	1,93E+00
Fossil fuels	MJ Surplus		1,10E+02	1,09E+02
TOTALE	Pt		1,79E+02	1,76E+02
Cumulative Energy Demand - CED				
NOT RENEWABLE SOURCES	MJ-Eq	*1	4,54E+04	4,47E+04
Fossil	MJ-Eq		4,18E+04	4,13E+04
Nuclear	MJ-Eq		3,61E+03	3,37E+03
RENEWABLE SOURCES	MJ-Eq	*1	3,19E+03	2,93E+03
Biomass	MJ-Eq		8,20E+01	9,05E+01
Wind, solar, geothe	MJ-Eq		7,43E+01	8,84E+01
Water	MJ-Eq		3,04E+03	2,75E+03
TOTALE	Pt		4,86E+04	4,76E+04
Environmental Priority Strategy - EPS 2000				
HUMAN HEALTH	Person Yr		5,43E+02	4,66E+02
Life Expectancy	Person Yr	*85,000 ELU/P. Yr * 1 Pt	3,75E+02	3,16E+02
Severe Morbidity	Person Yr	*100,000 ELU/P. Yr * 1 Pt	1,18E+02	9,95E+01
Morbidity	Person Yr	*10,000 ELU/P. Yr * 1 Pt	2,09E+01	2,04E+01
Severe Nuisance	Person Yr	*10,000 ELU/P. Yr * 1 Pt	2,13E+01	2,20E+01
Nuisance	Person Yr	*100 ELU/P. Yr * 1 Pt	7,99E+00	8,10E+00
ECOSYSTEM PRODUCTION CAPACITY	kg		-4,27E+00	-4,27E+00
Crop Growth Capacity	kg	*0,15 ELU/Kg * 1 Pt	1,47E+00	1,51E+00
Wood Growth Capacity	kg	*0,04 ELU/Kg * 1 Pt	-5,63E+00	-5,65E+00
Fish and Meat production	kg	*1 ELU/Kg * 1 Pt	-3,46E-01	-3,65E-01
Soil Acidification	H + eq	*0,01 ELU/Kg * 1 Pt	2,33E-01	2,39E-01
Prod. Cap. Irrigation Water	kg	*0,003 ELU/Kg * 1 Pt	0,00E+00	0,00E+00
Prod. Cap. Drinking water	kg	*0,03 ELU/Kg * 1 Pt	0,00E+00	0,00E+00
ABIOTIC STOCK RESOURCES	ELU		1,04E+03	1,08E+03
Depletion of reserves	ELU	* 1 ELU/ELU * 1 Pt	1,04E+03	1,08E+03
BIODIVERSITY	NEX		4,25E+00	4,19E+00
Species Extinction	NEX	* 1.1 E 11 ELU/NEX * 1 Pt	4,25E+00	4,19E+00
TOTALE	Pt		1,58E+03	1,54E+03
Global Warming Potential - IPCC 2001 GWP				
IPCC GWP 20a	kg CO_2-Eq		3,14E+03	3,08E+03

Table 4.1. Results obtained from the four methods of assessing the damage of the LCA.

The graph with the separate parameters of the various processes is shown in order to better understand the impact of the process considered in the life cycle between construction, heating consumption, cooling and transport consumption. For this reason, the three methods listed above are used: Eco-indicator 99, CED and EPS 2000 (fig. 4.8.).

In all three methods, the negative impact of the aluminium façade is highlighted as it causes more damage to the environment. By analyzing every single cycle of life cycle it is possible to say that:

- the construction of the aluminium façade is more burdensome;

- cooling consumption (summer consumption) has a significant impact on both façades, in particular in the facade of the GFRP;

- in heating consumption (winter consumption) the greatest impact is given by the aluminium façade;

- even with regard to transportation, the most heavy-duty façade is aluminium;

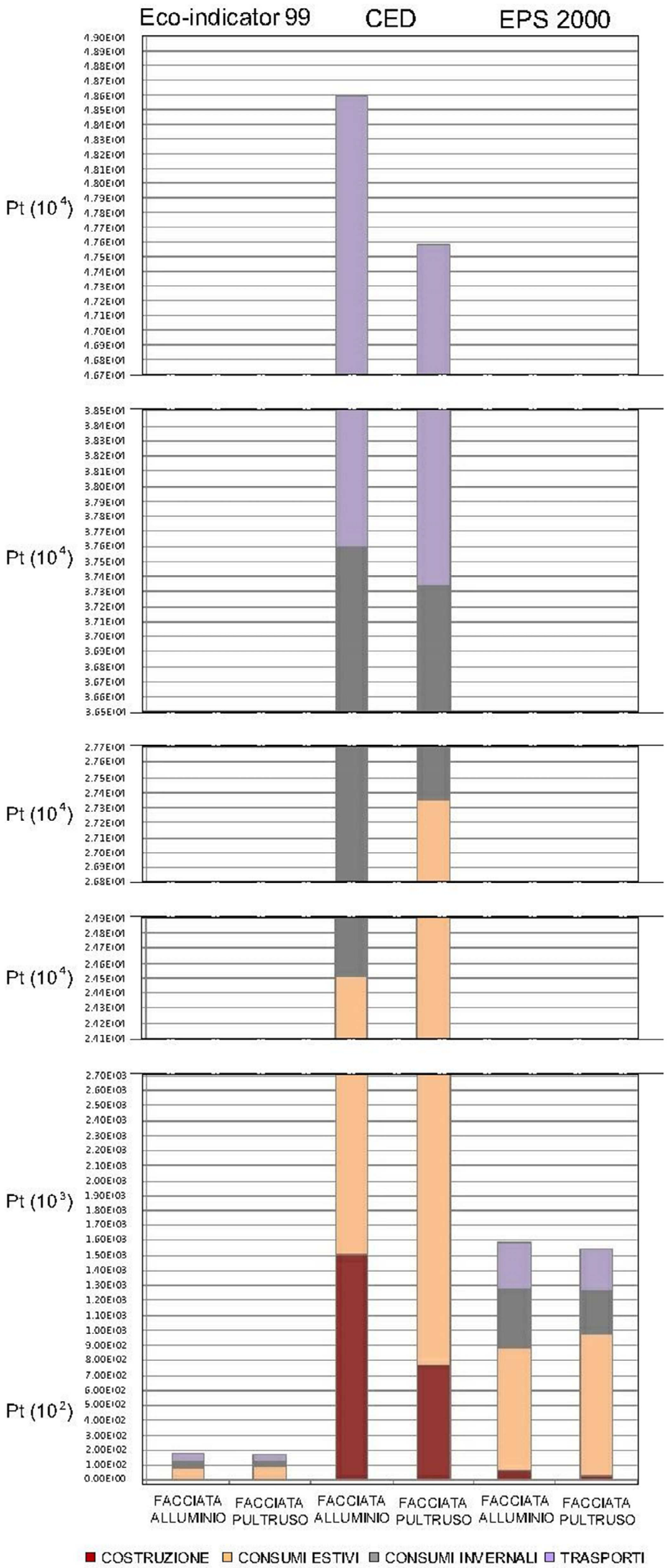

Figure 4.8. LCA comparison between the two curtain walls in the three methods used Eco-indicator 99, CED, and EPS 2000.

The study is further elaborated using only the Eco-indicator 99 method (fig.4.9.), which shows that in both GFRP and aluminium cases, the façade assembly (mullion, glass, silicon and argon) does not give a significant footprint in the damage to the ecosystem. In both cases ,the most important process is that of energy consumption, particularly cooling, where the GFRP façade has a greater impact on aluminium one. Conversely, in heating consumption where the aluminium façade affects. This difference is due to the consumption of the corresponding to the type of glass used, low emission glasses are thermal insulation glasses. This latter improve the energy efficiency of buildings and reduce significantly the heating costs in favour of comfort during the winter months and of the expenses during the summer months. For this reason, the GFRP façade that has larger glass than the aluminium one is better for the winter consumption and worse for the summer consumption. Regarding the transport, the incidence in aluminium façade is high compared to GFRP one. This is despite the glass and mullion where by the same distance are taken.

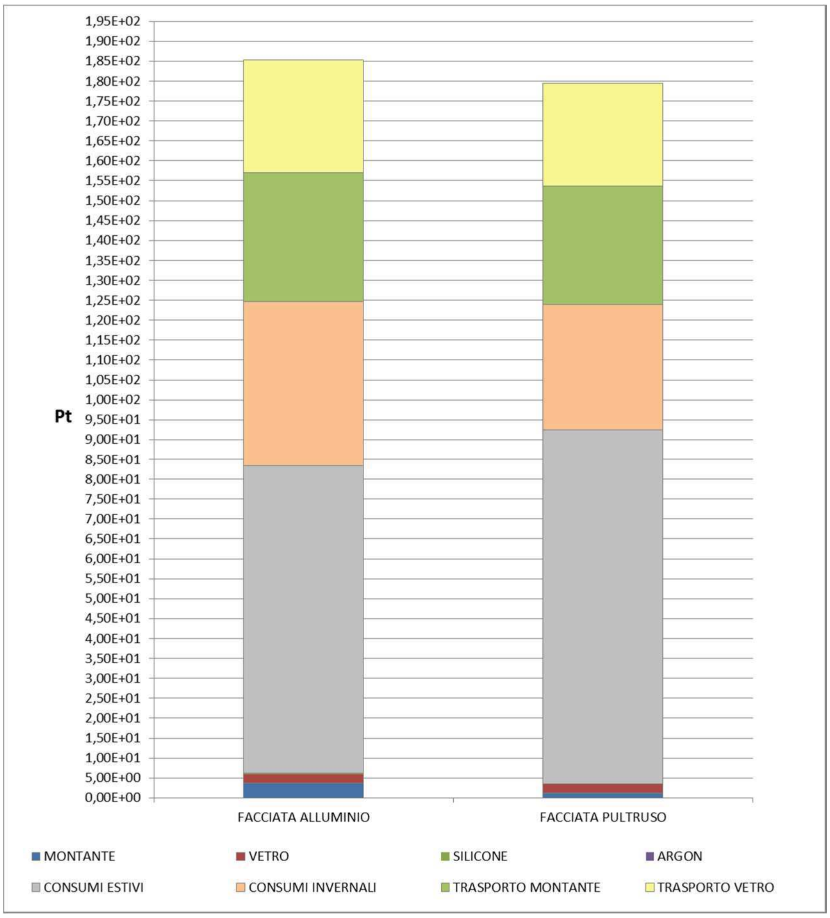

Figure 4.9. Comparison between the two facades with the Eco-indicator 99 method with separate construction, consumption and transport values.

Analysing only the construction phase, separately by the other life cycle processes, the aluminium façade (fig.4.10, 4.11.) shows a high incidence. This is due to the mullion component that creates more harm to the ecosystem. For the GFRP façade, the glass is the element that causes much damage. Regarding Argon gas, his behaviour is identic for both facades, while the silicone shows greater incidence in aluminium curtain wall.

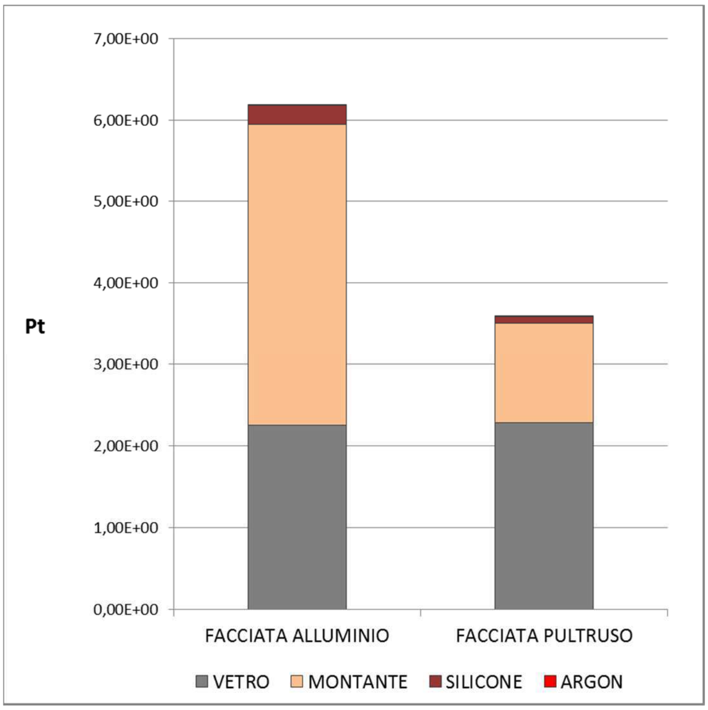

Figure 4.10. Construction comparison between the two facades with the Eco-indicator 99 method.

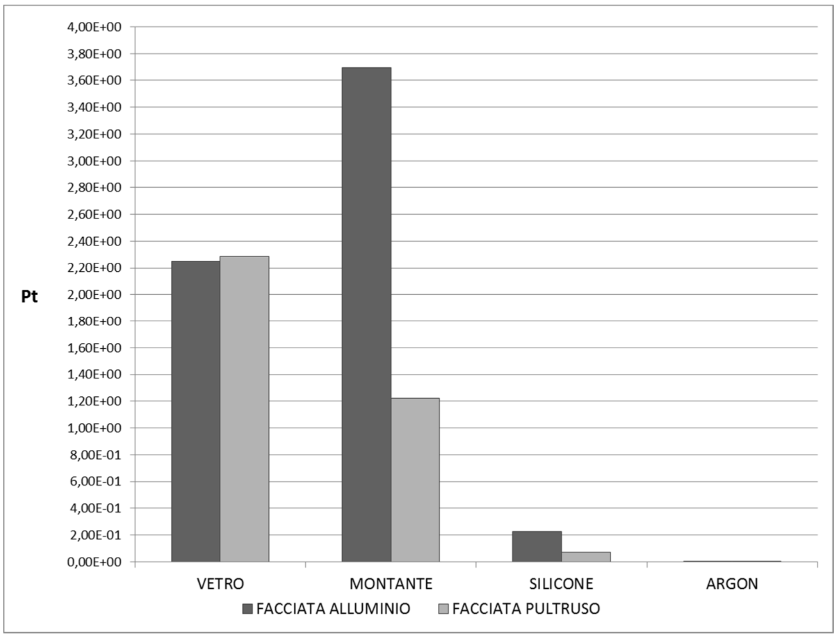

Figure 4.11. Construction comparison between the two facades with the Eco-indicator 99 method.

Through Eco.indicator 99 method the damage categories most powerful in construction, consumption and transport of the two materials, aluminium and GFRP (fig.4.12, 4.13) are analysed.

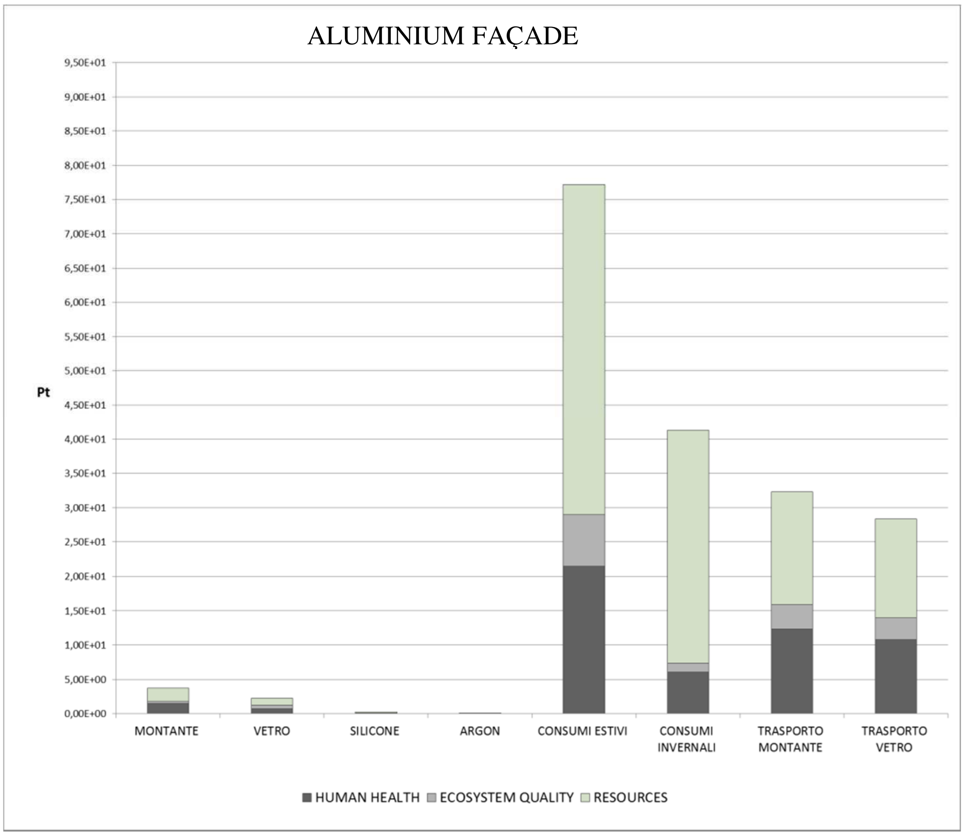

Figure 4.12. LCA Eco-indicator 99duddivision method for aluminum façade damage category.

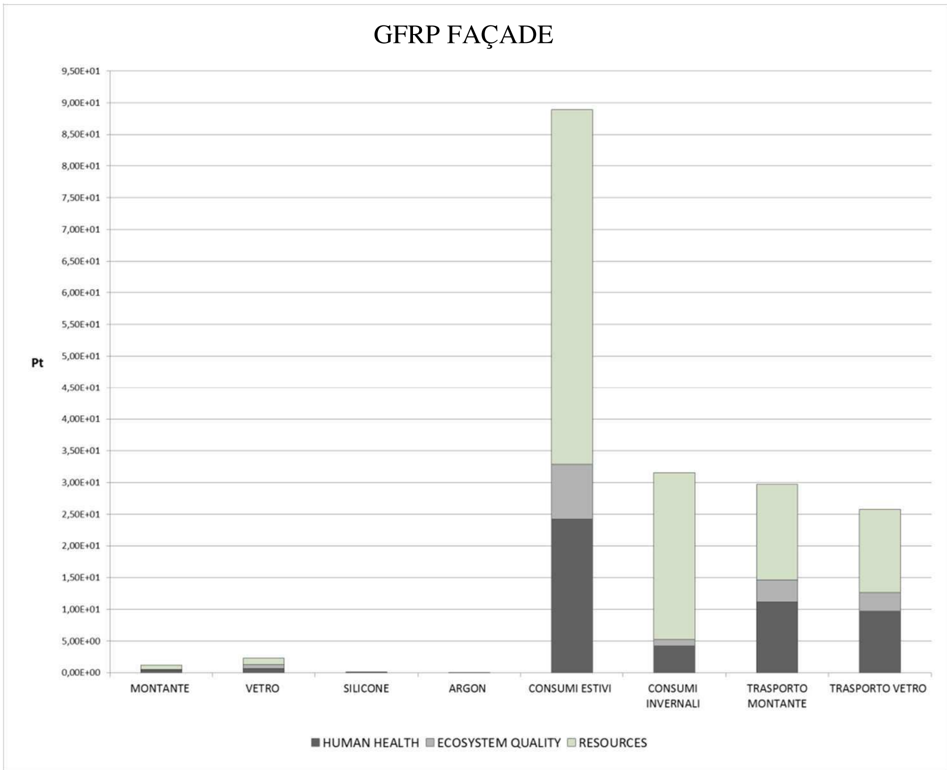

Figure 4.13. LCA Eco-indicator 99duddivision method for GFRP façade damage category.

The two graphs show that:
- in both cases, in the construction phase the damage categories do not affect much;

- during summer consumption, the damage categories are significant, in particular, for both facades. The most influential damage categories are Resources (environmental emissions of Fossil Fuel) and Human Health (harm to human health);
- during the winter consumption, the most influential damage category is Resources, especially for the aluminium façade;
- in the transports in a similar way both Resources and Human Health are affected in a similar way.

All methods used in LCA analysis show the environmental damage caused by the GFRP façade respect to the aluminium one, during a lifetime of 30 years. For the production phase, transport, assembly and product disposal (GFRP and aluminium), the environmental impact is similar for both façades. The main differences are the CO_2 emissions linked to the energy consumption during the management phase: during the winter consumption, the aluminium façade registered an environmental impact greater than the GFRP one caused by high thermal conductivity of the aluminium; during the summer consumption, the façade with hybrid mullion register a high impact due to greater glazed surfaces than the aluminium one (+5%). The problem with solar selective film can be overcomed in order to prevent the interior overheating of the building.

4.3. Modelling and comparison between a traditional material and GFRP-steel façade through Midas Gen software

In this study, the modelling phase was developed in collaboration with Promo Spa, Corridonia (Italy). The company was founded in 1977 and operates in the consulting field, design, construction and installation of architectural enclosures, glass and metal constructions.

Midas Gen [6] software has allowed modelling, through shell elements, a continuous panel façade of 3500 × 3500 mm^2 dimensions. For the design model, the data from the experiment described above in Chapter 3 for the definition of the properties of the materials (GFRP-steel, adhesives) and the requirements of CNR-DT 210/212 (Design Instructions, Design and Construction Controls with Glass Structural Elements) for modelling adhesives (Chapter 6.2. 4 and 6.2.5) were used. The study of the façade mechanical behaviour and the relative mullion deformation tests were carried out following the indications of EN 13830: 2015 " Norme di prodotto delle facciate continue " (which defines the maximum deformability limits of façade elements subject to 'wind action'). For this façade, the deformability limit must be less than 5mm+L/300, where "L" indicates the maximum façade dimension (3500 mm).

The façade being studied (Fig.4.14) is characterized by a GFRP mullion (rectangular section) reinforced with a steel plate placed on the underside (defined as low configuration). The mirror with the most traditional commercial materials, such as aluminium and steel, was compared in order to study its deformation behaviour.

Briefly, the dimensional features of the model considered and the actions involved:

- mirror size: 3500x3500 mm^2;
- mullion dimension: 120 mm x 60 mm, squared tubular profile;
- glass thickness: 20 mm laminated glass;
- constraints considered are: hinges placed at the four corners of the mirror and two supports at the bottom of the glass (said hands) placed to support it;
- materials considered are: steel, aluminium, GFRP and GFRP reinforced with steel plate;
- experimental data considered are: equivalent elastic modulus of the GFRP and the equivalent elastic modulus of the GFRP coupled with steel plate (*E eq GFRP* and *E eq GFRP+steel*);
- agent actions are: own weight and wind kinetic action of 100 Kg/m^2.

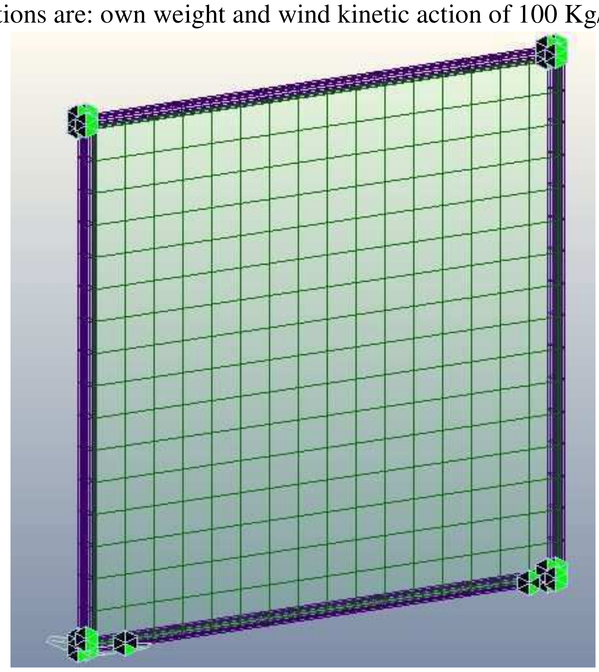

Figure 4.14. Calculation model adopted in extruded view.

The first modelling phase provided the reproduction of the single specimen in GFRP with shell elements subjected to the bending test in order to set experimental data to be included in the program (fig. 4.15.). In this phase, the technical data provided by Topglass Spa were taken into considered. The experimental data registered the profile deformation of 8.41mm, compatible with the model result equal to 8.27 mm. This first step allowed to implement the model. The same operation was performed by inserting the equivalent elastic modulus values calculated by the analytical process in order to simplify the modelling of composite material from orthotropic to isotropic like steel and aluminium material. Below are the mechanical properties inserted in the model considering the equivalent elastic modulus of the composite material.

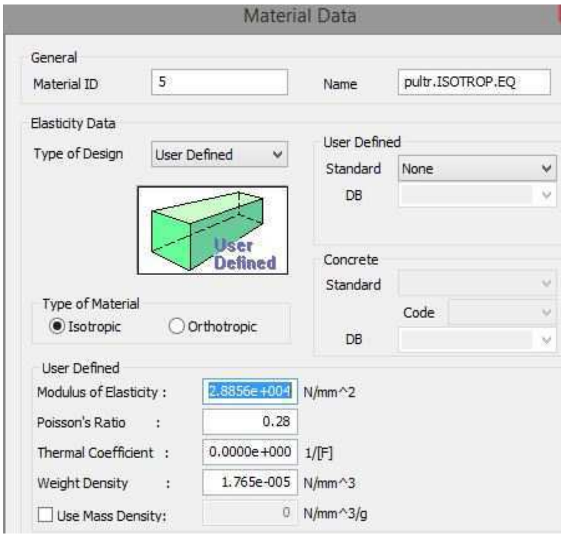

Figure 4.15. Parameters of isotropic GFRP material.

The same consideration is given for the GFRP profile coupled to a steel plate with the structural adhesives, in order to define an equivalent elastic modulus that allows mathematically modelling a coupled system as a single isotropic material. Below (Fig.4.16.) is the equivalent mechanical properties of the coupled system used in this analysis:

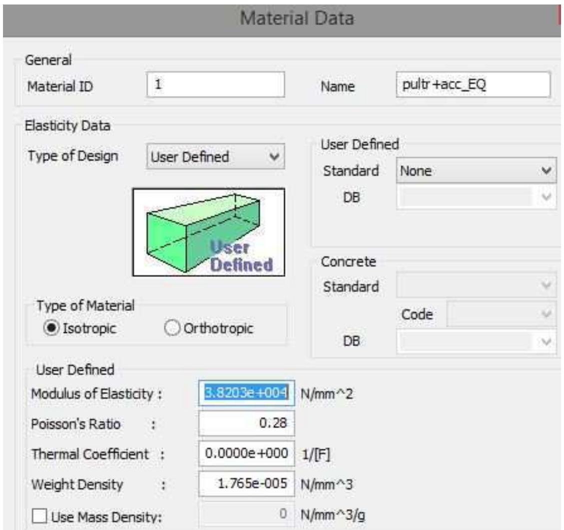

Figure 4.16. Parameters of the hybrid material, GFRP-steel.

The modelling envisaged the study of the glazed mirror characterized by GFRP-steel mullion compared to traditional materials. In addition, the comparison of the glazed mirrors characterized or not by the presence of silicone was performed.

Three types of curtain wall were modelled, as follows:

a) a first typology characterized by the presence or absence of silicone in order to study structural collaboration with glass. The model with the silicone was realized through the "beam and release" constraint with the aim to reproduce the concept of façade supported, while the model without silicone was reproduced the "rigid link" bond designed to simulate a series of bolts in order to ensure the facade position;

b) the second type of shell modelling is characterized by a greater mesh of elements in order to obtain likely results;

c) the third type is characterized by a different modelling of the silicone made by the solid brick element;

d) the fourth type of modelling is characterized by a C shaped mullion (open-section).

Material	*Modelling Shell*						*Limit deformation (mm)*
	a. Silicon	a. no Silicon	b. Silicon	b. no Silicon	c. Silicon	c. no Silicon	
Steel	√	√	√	√	√	√	16.47
Aluminium	√	√	√	√	√	√	
GFRP	-	-	-	-	-	-	
GFRP+steel	-	-	-	-	-	-	
E.eq. GFRP	√	√	-	√	-	√	
E.eq. GFRP+steel	√	√	√	√	√	√	

Table 4.2. Schematic representation of models developed and analyzed - √: checked; -: no checked.

4.3.1. Results and discussions

The model carried out with the Midas Gen software has allowed to analyze and verify the mechanical behaviour of the glazed mirror (3500 × 3500 mm2, laminated glass with a thickness of 20mm) applied on a GFRP mullion reinforced with steel plate (upper configuration high). The four types of models are shown below, respecting the order given in the previous paragraph.

Type a) the model is characterized by the presence or absence of silicone in order to understand the collaboration of the latter with the glass. The results obtained between the two models show a variation, in deformation terms, below 10% (tab.4.3.). In conclusion, the silicone only allows keeping the glazing in place, without providing any structural contribution.

Type b) the model is characterized by greater mesh elements (shell+). The boundary conditions are the same compared to the type “a” model in order to obtain more likely results. Respect to the previous model, significant differences there was no (tab. 4.4.). Here too, there are variation below the 10% between the models, with or without silicone. For this reason, it seems that the silicone only allows keeping the glazing in place, without providing any structural contribution.

Type c) the model is characterized by a different silicone modelling performed with the solid brick element. The boundary conditions are the same respect to the previous models in order to evaluate the differences in terms of deformations. The results (tab.4.5.) show significant variations due to a different silicon modelling, despite the input data have not undergone any change.

Type d) the model is characterized by a different profile section: the C shaped. The glazed mirror is supported by an omega mullion. The analysis carried out, not check requirements of the current legislation because of the mullion high deformations (bending). Below are the results (tab.4.6.).

MATERIAL	MODELLING SHELL								
	def. (mm)		***limit def.***	***Δ respect to limit def. (%)***		***Max tension (Mpa)***		***Δ % def. between two models***	***Δ % tension between two models***
	silicone	***no silicone***	***mm***	***silicone***	***no silicone***	***silicone***	***no silicone***		
Steel (S275)	1.74	1.72	16.47	-89.43	-89.55	167.6	164.1	-1.15	-2.09
Aluminium	5.51	5.45		-66.54	-66.90	160.4	160.6	-1.09	0.12
GFRP (datasheet TOPGLASS)	44.15	43.6		168.12	164.78	149.7	149.8	-1.25	0.07
E eq GFRP	**12.41**	**12.27**		-24.64	-25.49	154.3	154.5	-1.13	0.13
GFRP-steel	20.11	19.83		22.13	20.43	GFRP 41,1 steel 471,7	GFRP 40,8 steel 467,0	1.41	1.47
E eq GFRP-steel	**9.42**	**9.31**		-42.79	-43.46	158.2	158.4	-1.17	0.13

Table 4.3. Model type a) characterized by the presence or absence of silicone.

MATERIAL	MODELLING +SHELL								
	def. (mm)		***limit def.***	***Δ respect to limit def. (%)***		***Max tension (Mpa)***		***Δ % def. between two models***	***Δ % tension between two models***
	silicone	***no silicone***	***mm***	***silicone***	***no silicone***	***silicone***	***no silicone***		
Steel (S275)	2.21	2.17	16.47	-86.58	-86.82	171	171.1	-1.81	0.06
Aluminium	7	6.88		-57.49	-58.22	163.4	163.6	-1.71	0.12
GFRP (datasheet TOPGLASS)	56.45	55.85		242.81	239.17	153.1	153.6	-1.06	0.33
E eq GFRP	**15.81**	**15.53**		-3.99	-5.69	157.7	157.8	-1.77	0.06
GFRP-steel	21.65	20.83		31.48	26.50	GFRP 65,9 steel 299	GFRP 64,7 steel 287,5	3.94	1.47
E eq GFRP-steel	**12**	**11.79**		-27.13	-28.40	161.6	161.7	-1.75	0.06

Table 4.4. Model type b) characterized by a greater mesh.

MATERIAL	def. (mm) silicone brick	limit def. (mm)	∆ respect to limit def. (%)	Max tension (Mpa)	∆ respect to silicone (%)
	MODELLING +SHELL				
Steel (S275)	1.93	16.47	-88.28	60.40	-12.67
Aluminium	6.12		-62.84	44.40	-12.57
GFRP (datasheet TOPGLASS)	44.98		173.10	32.80	-20.32
E eq GFRP	**13.64**		-17.18	38.20	-13.73
GFRP-steel	27.38		66.24	GFRP 17,8 steel 150,1	26.47
E eq GFRP-steel	**10.43**		-36.67	40.20	-13.08

Table 4.5. Model type c) characterized by a different silicone modelling performed using the solid brick element.

MATERIAL	def. (mm) silicone brick	limit def. (mm)	∆ respect to limit def. (%)	Max tension (Mpa)	∆ respect to silicone (%)
	MODELLING +SHELL				
Steel (S275)	13.86	16.47	-15.85	58.40	24.19
Aluminium	22.26		35.15	59.20	-16.97
GFRP (datasheet TOPGLASS)	96.86		488.10	47.50	-5.28
E eq GFRP	**36.3**		120.40	57.00	-18.65
GFRP-steel	41.68		153.07	GFRP 27,9 steel 130,1	-22.30
E eq GFRP-steel	**30.31**		84.03	57.80	-19.56

Table 4.6. Model type d) characterized by a different profile section of the C form.

4.4. Conclusion

The simulation with the SimaPro software shows the environmental damage caused by the GFRP façade respect to the similar aluminium one, during a lifetime of 30 years. For the production phase, transport, assembly and product disposal (GFRP and aluminium), the environmental impact is similar for both façades. The main differences are the CO_2 emissions linked to energy consumption during the management phase: during the winter consumption, the aluminium façade registered an environmental impact greater than the GFRP one caused by high thermal conductivity of the aluminium; during the summer consumption, the façade with hybrid mullion registered a high impact due to the greater glazed surfaces than the aluminium one (+5%). The problem with the solar selective film can be overcomed in order to prevent the interior overheating of the building.

The simulation with the Midas Gen software studies the mechanical behaviour of the glazing mirror (3500 × 3500 mm^2, laminated glass of 20mm thickness) applied on a hybrid mullion characterized by the GFRP material coupled with the steel plate (upper configuration). The results of the mullion deformation due to the wind action show an inflexion decrease about of 33% respect to the maximum inflexion imposed by the current legislation: 5mm+L/300, where "L" indicates the maximum facade dimension (3500 mm).

4.5. References

[1] S.C. BORDAS INDUSTRIAL GROUP OF ALUMINIUM S.A.
[2] Rahman Azari-Na, Yong-Woo Kimb. Comparative assessment of life cycle impacts of curtain wall mullions. *Building and Environment* 48 (2012) 135e145)
[3] ISO 14040, Environmental Management. Life Cycle Assessment. Principles and Framework, 2006.
[4] Chiara Pesaresi, Tesi di laurea specialistica: Verifica sperimentale delle prestazioni meccaniche degli incollaggi pultruso-acciaio per componenti edili, tesi di laurea, Facoltà di Ingegneria Corso Edile-Architettura, anno accademico 2013-2014.
[5] Maria Sole Nunzi, Tesi di laurea specialistica: Verifica sperimentale delle prestazioni meccaniche degli incollaggi pultruso-acciaio (invecchiati e non). Facoltà di Ingegneria Corso Edile-Architettura, anno accademico.2014/2015.
[6] Midas Gen Analysis Manual

4.6. List of tables and figures

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Chapter 5

Market investigation

The aim of this research is to demonstrate the applicability of innovative materials for the realization of curtain walls in order to transfer of innovative construction elements to the market: the *Structural Member* for curtain walls.
The results demonstrated the feasibility of this process, which is founded on the "Technological Simplification". The principle is the use of innovative materials [1-4] (such as GFRP pultruded profiles and structural adhesives) which, thanks to their high mechanical and thermal properties, allow the design and the production of construction elements with less components than the traditional ones. Furthermore, the production process is feasible for manufacturers without changing their production line. The results are ease of production and installation and, simultaneously, the reduction of the environmental impact.
In this section, the market investigation curtain walls is reported, as well as analysis of the production costs.

5.1. Curtain walls market

In this chapter also window market will be mentioned because the curtain walls are part of the shutters sector.

With the objective of *Structural Member* commercialisation, a market analysis was carried out, both on national and international (Europe and the USA) levels. The market data showed positive trends for curtain walls. According to a global research [5], the market will increase exponentially in 2018 and the request will mainly concern high thermal performance products. If only considering the window market, the trade covers over 17 billion euros [6].

5.1.1. The European market

According to the report of Interconnection Consulting [2], the European window market will increase exponentially in 2018.
The wood-metal window market will gain shares from 7,7 % in 2009 to 10,6 % in 2017. A consistent decrease in both the wood window market (-14 %) and the aluminum one (-8,3 %) was predicted. An increase for the PVC-aluminum window market was also forecasted.
The market shares are: wood: 18,7 %, aluminium: 27 %, wood-metal: 10 %, PVC-aluminium: 3,7 %.

5.1.2. The USA market

According to the report of Freedonia Inc. [5], the USA window market will increase with a different requirement: high-energy efficient products, such as triple glasses and thermal-insulated surfaces will increase in demand.
The aluminum window market still remains the market leader until 2018, despite the strong competition from plastic windows, which have lower prices than aluminum ones. The wood window market will increase up to 10,1 billion dollars in 2018.

5.1.3. The Italian market

According to the report of UNICMI [7], despite the actual construction market crisis, the window and curtain walls market are registering positive trends, reaching respectively the values of 1.404 and 474 million euros (Figures 5.1 e 5.2).

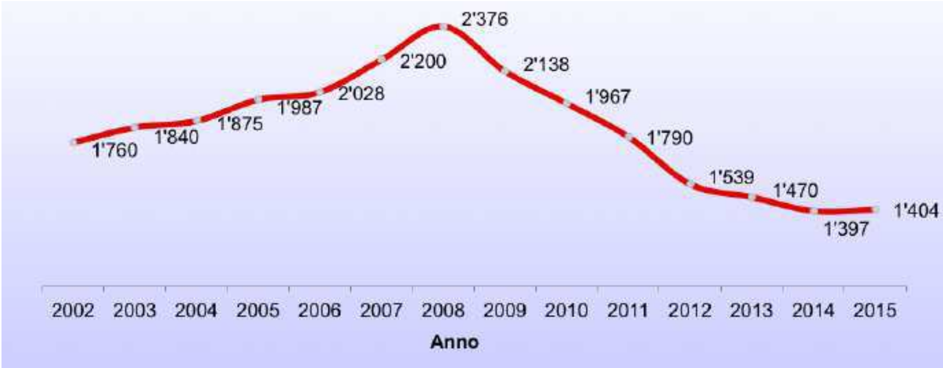

Figure 5.1. Windows market trend (values in millions of euros, UNICMI report 2016 [7]).

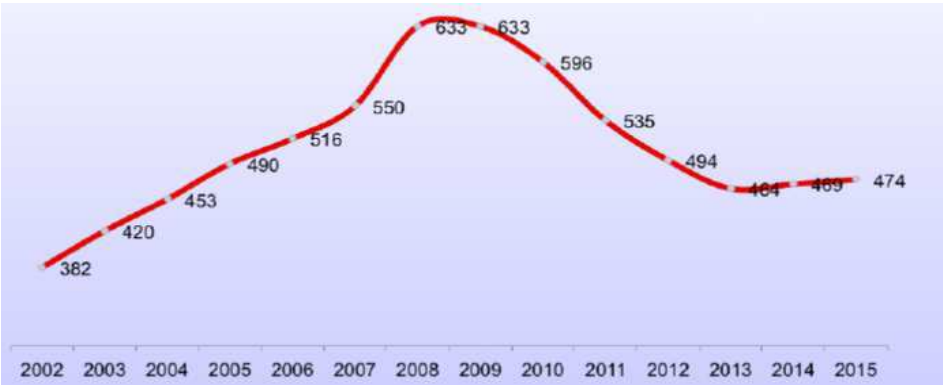

Figure 5.2. Curtain walls market trend (values in millions of euros, UNICMI report 2016 [7]).

Furthermore, the *Structural Member* for curtain walls are applicable both in new constructions and in restorations, the latter constituting 71,9 % of the total investments in the construction sector.

5.1.3.1. The market sector

The Italian market sector is highly fragmented, due to the prevalence of small size companies. Only 1857, of the total amount of 12000, are capital companies. In this sector, two different groups are distinguished:
- the windows manufacturers, which are small-medium sized companies; the materials used are wood, aluminum, and PVC. The business model is nearly based on an ample and diversified offer, therefore the companies are able to cover several markets sectors (figure 5.3);
- the curtain walls manufacturers, which are medium-large sized companies; they are specialized on the curtain walls construction and they operate also in the international market. The main markets are England, France, South-West Asia, Medium Orient and USA (figure 5.4).

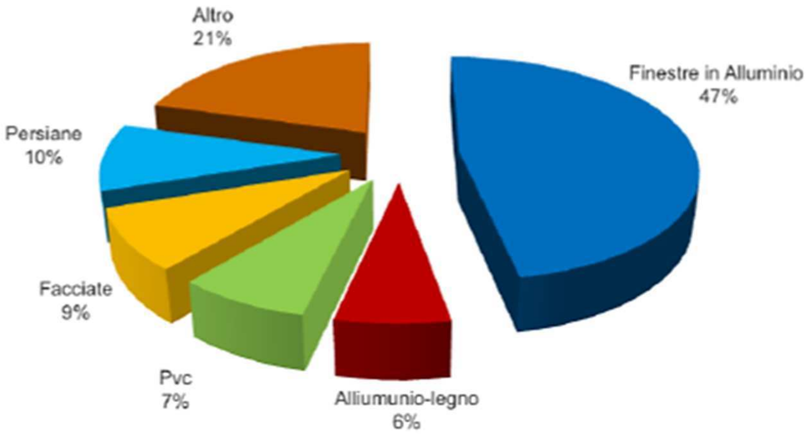

Figure 5.3. The distribution of the windows market (UNICMI report 2016 [7]).

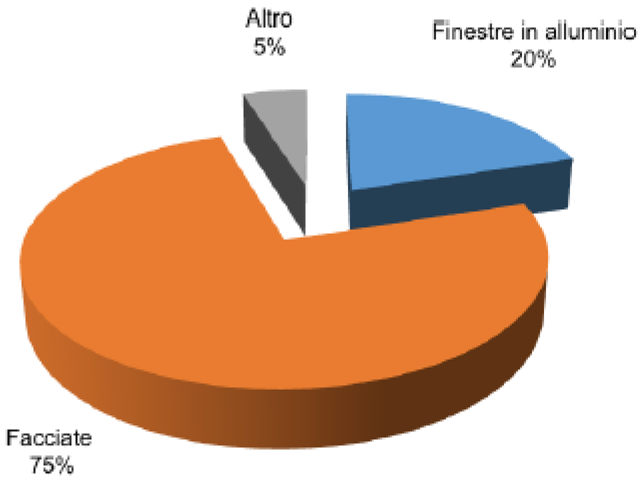

Figure 5.4. The distribution of the curtain walls market (UNICMI report 2016 [7]).

Thanks to the high thermal and mechanical properties of the GFRP profiles, the *Structural Member* for curtain walls have a special design. The glass surfaces of the curtain walls realized with the *Structural Member* are wider than in the other construction elements available on the market, also with smaller frames sections. Both the products can be used in new constructions and in restorations.

The UNICMI report showed that the customer's choice is in accordance with the maximum ratio of "value for money", and high thermal performance products are mostly preferred. The *Structural Member* for curtain walls is in accordance with this trend since their prices are competitive with those of the other components with similar performances available on the market (see section 5.1.3.4).

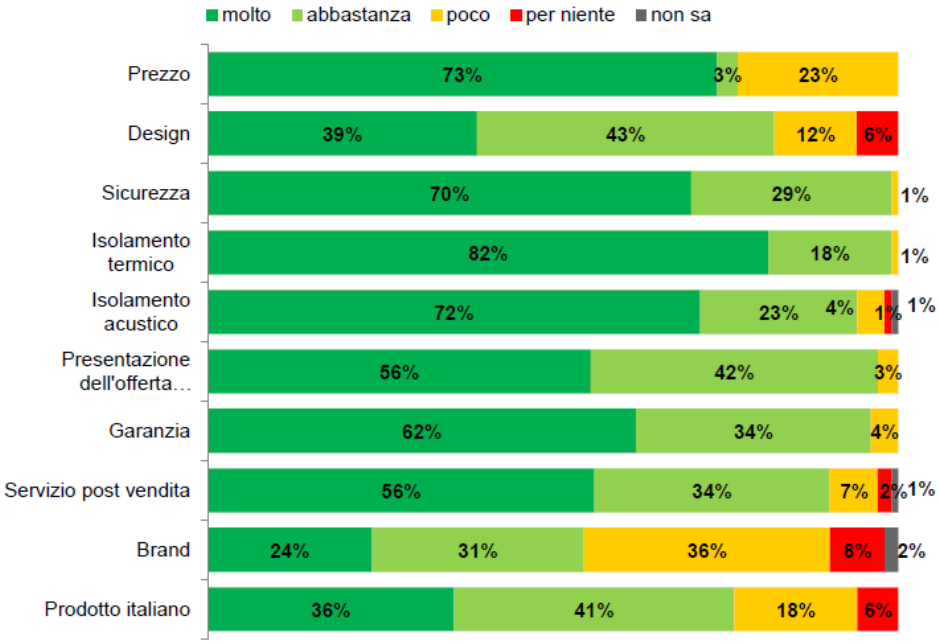

Figure 5.5. Windows customer's choice parameters (UNICMI report 2016 [7]).

5.1.3.2. The possible competitors

Very few Italian manufacturers produce windows with GFRP pultruded frames. These companies (Tip Top Fenster, Agostini e Levante serramenti) are aluminum and plastic window manufacturers that decided to widen the range of products with innovative materials (such as GFRP pultruded profiles) following the traditional technical/constructional concept (the large window frame sizes). The number of international manufacturers is higher than the national one, especially in the European (Germany, Denmark, Finland) and North American countries, which operate in the world market.
With regard to curtain walls, the Italian market is not covered and the main manufacturers (Metra, Aluk, Zanetti, Wicona) produce aluminum frames. The same conclusion can be drawn from the analysis of the international market.

5.1.3.3. The possible customers

The possible customers of the *Structural Member* for curtain walls are:
- the manufacturers of window and curtain walls. Even though they are possible competitors, they could sell the two patents in order to increase and innovate their products;
- the manufacturers of GFRP pultruded profiles and double glass. They could be interested in creating an inner section dedicated to the production of windows and curtain walls;
- engineers and architects, which could be interested in employing the two construction elements in building design.

5.1.3.4. Production costs and sales prices

The production costs of the *Structural Member* for curtain walls were evaluated by adding together the individual costs of their components.
With regard to the *Structural Member* for curtain walls, the following components were taken into account: the GFRP profiles (C and double T sections), the steel wires (one/four), the adhesive, the steel laminates and the steel connection systems.
As shown in Table 5.1, the production costs of the *Structural Member* are competitive with respect to an aluminum frame for curtain walls only for the C-section, while the GFRP frame with double T-section is more expensive. On the other hand, the number of GFRP frames is

lower than the aluminum ones (of about 10 %) thanks to the high mechanical properties of the fibre-reinforced composite material. Furthermore, the GFRP profiles section areas are very reduced, in favor of the aesthetic of functional aspects.

Table 5.1. Production costs comparison of the Structural Member and one of the best aluminum frame for curtain walls available on the market (Metra).

	Structural Member for curtain walls GFRP		***METRA frame for curtain walls*** Aluminium
	C-section with 1 steel wire	Double-T section with 4 steel wires	Squared tubular section
Costs (euros/m)	35,00	90,00	20,00

With regard to sales prices, considering the high quality of *Structural Member*, some profit margins were assumed. However, the resulting prices are competitive with similar products available on the market.
- *Structural Member*, C-section with 1 steel wire: ***70 euro/m*** + IVA (production cost of 35 euro/ml);
- *Structural Member*, double-T section with 4 steel wires: ***180 euro/m*** + IVA (production cost of 90 euro/ml).

5.2. References

[1] M. Giampaoli, V. Terlizzi, P. Munafò. Risultanze di un processo di industrializzazione di un'idea brevettuale: finestra di solo vetro senza telaio "Full Glass". *Colloqui.AT.e* (2016) Artec:120-121.
[2] V. Terlizzi, M. Giampaoli, P. Munafò. Curtain wall made in pultruded profiles: technological and performance verification. G. Bernardini, E. Di Giuseppe, *"Colloqui.AT.e 2017.* DEMOLITION OR RECONSTRUCTION?", Edicom edizioni, Monfalcone (Gorizia), 2017.ISBN (e-book):978-88-96386-58-3; volume cartaceo (book of abstracts)978-88-96386-57-6.
[3] T. Alderucci, V. Terlizzi, P. Munafò. An innovative window with an invisible frame, *Tema 2017.* Vol. 3, No. 2 (2017), Issue 2-6, 61-71.
[4] G. B. Goffredo, V. Terlizzi, P. Munafò. Multifunctional TiO2-based hybrid coatings on limestone: initial performances and durability over time. *Journal of Building Engineering* 14 (2017) 134–149.
[5] www.puntodfv.it
[6] Ulisse Magazine. Il commercio mondiale di finestre e portefinestre in legno. 2013
[7] UNICMI. Rapporto sul mercato italiano dell'involucro edilizio. Uncsaal servizi srl. 2016.

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Chapter 6

Conclusion and unresolved issues

Thanks to the advantageous properties of the new innovative components, such as GFRP pultruded profiles and structural adhesives, can be used to lower the number of pieces of construction elements, as curtain wall. The analysis carried out through the present study demonstrates the feasibility of the “Technological Simplification” principle in the design of the components, which led to much easier production and installation phases and to the reduction of environmental impact thanks to lower CO_2 emissions.
In this work, also the applicability of a new *Structural Member* for curtain walls (patent application n. 102015000087569), is demonstrated.

The experimental studies demonstrated that:

(i) The state of the art evidences the development and the use of composite materials, thanks to the various advantages that they possess. Furthermore, the low elastic modulus and the consequent high deformability under loading conditions of the GFRP profiles impede the applications of this composite material in structures. For this reason, it is necessary to develop suitable approaches to improve the stiffness of the GFRP pultruded material with a steel laminated in order to reduce the deformations.

(ii) the patent idea behind the “Sistema per la realizzazione di facciate di edifici” designed by the research group allows the concept of technological simplification to overcome the disadvantages of the current curtain wall as the thermal property, due to the large size and the high thermal conductivity of the frames. Furthermore, the elevated number of components constituting the construction elements causes very high CO^2 emissions during all the curtain walls life cycle.

(iii) The compatibility between the GFRP and the steel profiles were stated and the method of hybridization resulted advantageous in the stiffness of GFRP profiles, even when the bonding system is exposed to adverse environmental conditions (high temperatures and moisture levels and after UV irradiation). **These results confirmed the reliability of the *Structural Member* for curtain walls basic principle.**

(iv) Until today, the results obtained demonstrate that hybrid profiles (GFRP-steel) can be used for continuous facades and can adequately contain deformations under load. The hybrid system also lends itself to a series production and the uprights thus designed allow a smooth and functional junction with the closing panels (glazed and non-stained). As far as the LCA study is concerned, there is evidence of a greater reduction of CO^2 emissions for the facade characterized from the mullion composite material.

(v) The *market trend analysis* and the *production costs evaluation* were carried out, demonstrating that the Structural Member is competitive with the analogous one, with higher mechanical and thermal performance.

The results obtained through experimental tests on GFRP profiles-steel bonded specimens, which is the basic principle of the structural member patent, were assessed and analysed. **The data showed that the bonded joints are able to withstand the maximum working stresses to which a curtain wall may be subjected, with an adequate coefficient of safety, also after the ageing treatments.**

After the validation of the patents basic systems, the research activity addressed the *industrialization process* of the curtain wall. The aim was to demonstrate the feasibility of the façade's series production, with the objective of its national and international commercialization.

In extreme summary, the research activity allowed to reach the main objective, i.e. to verify the feasibility of a research result transferred to the production world and, then, to the market. The industrialization process of the *Structural Member* for curtain walls will be the aim of the next phase.

It is currently being studied the possibility of applying a continuous facade type called "façade reported" in order to analyze the mechanical behaviour of the structural member, composite material, with components currently in the market to develop a gfrp-steel hybrid system with the best performance.

Appendix 1

Fibre Reinforced Polymers

Some contents of this chapter are extracted from the Fibreglass internet website: www.moldedfibreglass.com.

1.1 Composite materials – FRP and GFRP

Composite materials are a combination of two or more materials with significantly different physical or chemical properties, which remain separate and distinct within the finished structure. Composite properties are determined by chemical and mechanical interaction of the combined materials and the objective is usually to make a component that is strong and stiff, often with a low density.

Modern composites are usually made of two components, fibres, and matrix, known as *Fibre-Reinforced Polymers (FRP)*. The fibres are most often glass, but sometimes Kevlar, carbon fibre, or polyethylene. The matrix, which is weaker and less stiff than fibres, is usually an epoxy, vinyl ester or polyester thermosetting plastic. The fibres are embedded in the matrix in order to make the matrix stronger [1].

Figure 1.1. The combination of fibres and matrix in FRP composites.

The applications of FRP (Fig. 1.1) are:
- Marine transportation components.
- Architectural cladding components.
- Aerospace transportation and weapons components.
- Automotive components.
- Energy sector components (wind turbines).
- Static structural components (buildings/bridges).

Figure 1.2. Different applications of FRP composites

The most common fibre-reinforced polymer composites are based on glass fibres, mat, or roving embedded in a matrix of an epoxy or polyester resin. *Glass Fibre Reinforced Polymers (GFRP)* profiles were developed commercially after World War II and, since that time, their use has grown rapidly. This is because this advanced material combines excellent mechanical/physical performances and high cost- effectiveness, with environmental sustainability. The main advantages respect to metallic materials are the reduction in weight up to 60 %, the improved surface quality and the decrease in components by combining parts and forms into simpler molded shapes [1].

1.2 Benefits and features of FRP materials

The use of FRP materials led to numerous advantages and these beneficial properties should be considered in the design processes.

Corrosion resistance. FRP materials do not rust, corrode or rot, and they resist attack from most industrial and household chemicals. This quality has been responsible for applications in corrosive environments such as those found in the chemical processing and water treatment industries. Resistance to corrosion provides long life and low maintenance in marine applications from sailboats and minesweepers to seawalls and offshore oil platforms.

High strength, lightweight. FRP materials provide high strength to weight ratios exceeding those of aluminum or steel. High strength, lightweight FRP materials are a rational choice whenever weight savings are desired, such as components for the transportation industry.

Dimensional stability. FRP materials have high dimensional stability under varying physical, environmental, and thermal stresses. This is one of the most useful properties of FRP materials.

Parts consolidation and tooling minimization. A single FRP composite molding often replaces an assembly of several metal parts and associated fasteners, reducing assembly and handling time, simplifying inventory, and reducing manufacturing costs. A single FRP profile tool can replace several progressive tools required in metal stamping.

High dielectric strength and low moisture absorption. The excellent electrical insulating properties and low moisture absorption of FRP materials qualify them for use in primary support applications such as circuit breaker housings, and where low moisture absorption is required.

Minimum finishing required. FRP materials can be pigmented as part of the mixing operation or coated as part of the molding process, often eliminating the need for painting. This is particularly cost effective for large components such as tub/shower units. Also, on critical appearance components, a class “A” surface is achieved.

Low to moderate tooling costs. Regardless of the molding method selected, tooling for FRP materials usually represents a small part of the product cost. For either large-volume mass-production or limited runs, tooling cost is normally substantially lower than that of the multiple forming tools required to produce a similar finished part in metal.

Design flexibility. No other major material system offers the design flexibility of FRP materials. Present applications vary widely. They range from commercial fishing boat hulls and decks to truck fenders, from parabolic TV antennas to transit seating, and from the outdoor lamp, housings to seed hoppers. What the future holds depends on the imagination of today’s design engineers as they develop even more innovative applications for FRP materials.

1.3 Classification of FRP materials

There are two classification systems for composite materials. One of them is based on the matrix material and the second is based on the reinforcement material type and structure.

1.3.1. The matrix

The matrix or resin is the other major component of an FRP material. Resin systems are selected for their chemical, electrical and thermal properties. The two major classes of resins are thermosets and thermoplastics.

1.3.1.1. Thermoset resins

Thermosetting polymers are usually liquid or low melting point solids that can easily combine with fibres or fillers prior to curing. Thermosets feature cross-linked polymer chains that become solid during a chemical reaction or "cure" with the application of a catalyst and heat. The high level of cross-linking provides for reduced creep compared to thermoplastics. The thermoset reaction is essentially irreversible.

Among the thermoset resins for FRP materials, the family of unsaturated *polyesters* is by far the most widely used. These resins are suitable for practically every molding process available for thermosets. Polyesters offer ease of handling, low cost, dimensional stability, and a balance of good mechanical, chemical, and electrical properties. They can be formulated for high resistance to acids, weak alkalies, and organic solvents. They are not recommended for use with strong alkalis. Other formulations are designed for low or high-temperature processing, for room temperature or high-temperature cure, or for flexible or rigid end products.

Vinyl esters provide excellent resistance to water, organic solvents, and alkalis, but less resistance to acids than polyesters. Vinyl esters are stronger than polyesters and more resilient than epoxies. Molding conditions for vinyl esters are similar to those for polyesters.

Epoxies are another family of thermoset resins used in FRP materials. They have excellent adhesion properties and are suited for service at higher temperatures – some as high as 500ºF. Epoxy-matrix FRP materials are processed by any of the thermoset methods. Epoxies are more expensive than polyesters, and cure times are longer, but their extended range of properties can make them the cost/performance choice for critical applications. Epoxy/fibre structures have generally higher fatigue properties than polyesters.

Polyurethanes are a family of resins that offer very high toughness, high elongation, faster cure times and good coupling to a variety of reinforcements. Polyurethanes are easily foamed in a controlled process to produce a wide range of densities. Additives are easily incorporated into resin systems to provide pigmentation, flame retardance, weather resistance, superior surface finish, low shrinkage and other desirable properties.

Gel coats consisting of a special resin formulation provide an extremely smooth next-to-mold surface finish on FRP materials. They are commonly applied in hand lay-up and spray-up processes to produce a tough, resilient, weather-resistant surface. Gel coats, which may be pigmented, are sprayed onto the mold before the reinforcement and resin are introduced.

Other thermosetting resin systems, generally formulated with chopped strand or milled fibre reinforcement for compression or transfer molding are:

Phenolics: good acid resistance, good fire/smoke, and thermal properties.
Silicones: highest heat resistance, low water absorption, excellent dielectric properties.
Melamines: good heat resistance, high impact strength.
*Diallyl phthalates: g*ood electrical insulation, low water absorption.

1.3.1.2. Thermoplastic resins

Thermoplastic polymers can soften and become viscous liquids when heated for processing and then become solid when cooled. The process is reversible allowing a reasonable level of process waste and recycled material to be reused without significant effect on the end product. Thermoplastic resins allow for faster molding cycle times because there is no chemical reaction in the curing process. Parts may be formed as fast as heat can be transferred into and out of the molding compound.

Polypropylene and *polyethylene* are the most common thermoplastic resins used in FRP materials. They have excellent resistance to acids and alkalies and have good resistance to organic solvents. Their relatively low melting points allow for rapid processing at a lower cost.

Nylon and *Acetal* are highly resistant to organic solvents and may also be used where increased mechanical properties are required.

1.3.2. Reinforcements

Much of the strength of FRP materials is due to the type, amount and arrangement of the fibre reinforcement. While over 90% of the reinforcements in use are glass fibres, other reinforcements have established a critical niche.

The *glass* fibres are the most commonly used reinforcement type. It is strong, has good heat resistance, and high electrical properties.

Carbon fibres (graphite) are available in a wide range of properties and costs. These fibres combine light weight with very high strength and modulus of elasticity. The modulus of elasticity is a measure of the stiffness or rigidity in a material. For high stiffness applications, these reinforcements are hard to beat, with a modulus of elasticity that can equal steel. FRP materials with carbon fibre reinforcement also have excellent fatigue properties. The primary use of carbon fibres is in aircraft and aerospace, in which weight savings are a major objective. While its cost limits carbon's use in commercial applications, it is used extensively where material content is low, such as sporting equipment.

Aramid or aromatic polyamide fibres provide high strength and low density (40% lower than glass) as well as the high modulus. These fibres can be incorporated in many polymers and are extensively used in high impact applications, including ballistic resistance.

Natural fibres such as Sisal, Hemp and Flax have been used for many applications with low strength
requirements. They are limited to applications not requiring resistance to moisture or high humidity.

The *arrangement* of the glass fibres - how the individual strands are positioned – determines both direction and level of strength achieved in a molded FRP/Composite. The three basic arrangements of glass
fibre reinforcement are unidirectional, bidirectional and multidirectional.

Unidirectional arrangements provide the greatest strength in the direction of the fibres. Unidirectional fibres can be continuous or intermittent, depending on specific needs determined by part shape and process used. This arrangement permits very high reinforcement loading for maximum strengths.

The fibres in *a bidirectional* arrangement are in two directions – usually at 90^0 to each other, thus providing the highest strength in those directions. The same number of fibres need not necessarily be used in both directions. High fibre loading can be obtained in woven bidirectional reinforcements.

Multidirectional or random arrangements provide essentially equal strength in all directions of the finished part.

1.3.2.1. Reinforcement forms

Reinforcements are supplied in several basic forms to provide flexibility in cost, strength, compatibility with the resin system, and process requirements. Regardless of the final form, all fibre reinforcements originate as single filaments. A large number of filaments are formed simultaneously and gathered into a strand. A surface treatment is then applied to facilitate subsequent processing, maintain fibre integrity, and provide compatibility with specific resin systems. After this treatment, the strands are further processed into various forms of reinforcements for use in molding FRP materials.

Continuous strand roving. This basic form of reinforcement is supplied as untwisted strands wound into a cylindrical package for further processing. Continuous roving is typically chopped for spray-up, preform or sheet molding compounds. In the continuous form, it is used in pultrusion and filament winding processes.

Woven roving. Woven from continuous roving, this is a heavy, drapable fabric available in various widths, thicknesses, and weights. Woven roving costs less than conventional woven fabric and is used to provide high strength in large
structural components such as tanks and boat hulls. Woven roving is used primarily in hand lay-up processing.

Woven fabrics.Made from fibre yarns, woven fabrics are of a finer texture than woven roving. They are available in a broad range of sizes and in weights from 21/2 to 18 oz./sq. yd. Various strength orientations are also available.

Reinforcing mat. Made from either continuous strands laid down in a swirl pattern or from chopped strands, reinforcing mat is held together with a resinous binder or mechanically stitched. These mats are used for medium strength FRP materials. Combination mat, consisting of woven roving and chopped strand mat bonded together, is used to save time in hand lay-up operations. Hybrid mats of glass and carbon and aramid fibres are also available for higher-strength reinforced products.

*Surfacing mat***.** Surfacing mat or veil is a thin fibre mat made of monofilament and is not considered a reinforcing material. Rather, its purpose is to provide a good surface finish because of its effectiveness in blocking out the fibre pattern of the underlying mat or fabric. Surfacing mat is also used on the inside layer of corrosion-resistant FRP/Composite products to produce a smooth, resin-rich surface.

Chopped fibres. Chopped strands or fibres are available in lengths from 1/8” to 2” for blending with resins and additives to prepare molding compounds for compression or injection molding and other processes. Various surface treatments are applied to ensure optimum compatibility with different resin systems.

Figure 1.3. Continuous strand roving, woven roving and chopped fibres.

1.4 The surface interaction of fibre and resin

The mechanical performance of a composite material is highly dependent upon the quality of the fibre–matrix interface. This region is an anisotropic transition region which is required to provide chemical and physical bonding between the fibre and the polymer. The primary aim of a fibre reinforced matrix composite
material is to provide an average behaviour of the composite from the properties of the components which must act compositely for the material to be efficient. It is well known that the application of a coupling agent to a glass fibre surface will improve fibre–matrix adhesion in that composite but in addition, and to a greater degree, it is the mixing of the processing additives; this contribution to composite properties is not well understood. The interfacial region of the composite will, therefore, be affected not only by the composition of the coating but also by its distribution on the glass fibre surface and in the composite matrix [2].

1.5 The pultrusion process

The process whereby fibrous materials are bonded with the matrix is called the molding process. There are different forms of composites moldings, and one well-known method is the pultrusion, whereby industrialized profiles are realised. In this process, fibre bundles and slit fabrics are pulled through a wet bath of resin and formed into the rough part shape. The saturated material is extruded from a heated closed die curing while being continuously pulled through die. Some of the end products of the pultrusion process are structural shapes, i.e. beam, angle, channel and flat sheet. These materials can be used to create all sorts of fibre structures such as ladders, platforms, handrail systems tank, pipe, and pump supports [1].

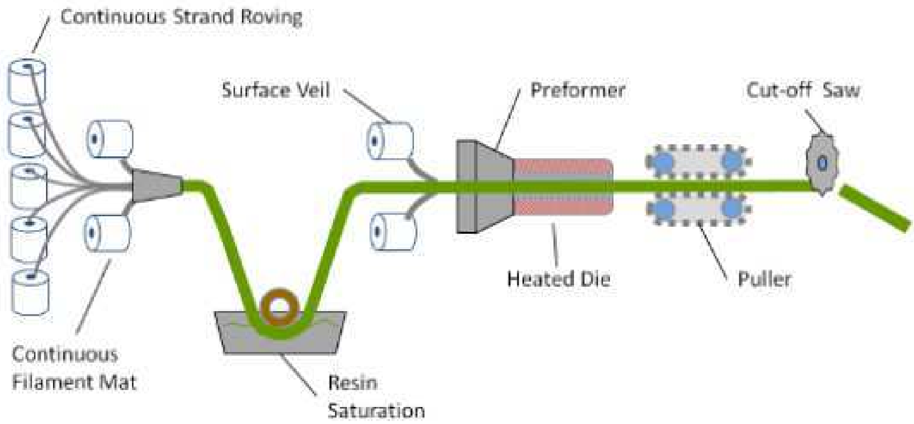

Figure 1.4. Scheme of the pultrusion process.

1.6 References

[1] Masuelli M. A. Introduction of Fibre-Reinforced Polymers – Polymers and Composites: Concepts, Properties and Processes. ISBN 978-953-51-0938-9, Argentina (2013).

[2] Hollaway L.C. A review of the present and future utilisation of FRP composites in the civil infrastructure with reference to their important in-service properties. *Construction and Building Materials* 24 (2010) 2419–2445

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Appendix 2

Adhesives

Some contents of this chapter are extracted from the Fibreglass internet website: www.adhesives.org.

2.1 Adhesives

An adhesive may be defined as a material which can join the surfaces together and resist their separation [1]. Recent advances in adhesive technology have led to a rapid growth in the use of adhesives in load-bearing joints, achieving structural performances and being used in civil engineering applications. The use of adhesives, in fact, can prove more convenient, less expensive, stronger, and more durable than traditional methods of joining [1].

Figure 2.1. The use of adhesives in the building/construction field.

2.2 Benefits of adhesives

The development of new materials with diverse applications puts additional challenges on processing technology. This is particularly so when different materials have to be joined to make components which retain their individual beneficial properties in the composite product. Traditional joining techniques have well-known disadvantages. With thermal techniques such as welding, the specific properties of the material alter within the heat-affected zone. Mechanical techniques such as riveting or the use of screws in their turn only allow force transfer at points; in addition, it is necessary to drill holes in the workpieces that are being joined, and this "damages" and hence weakens the materials. In contrast, bonding technology will assume an ever more important role in industry and the handicraft sector in the future. There are four key reasons for this:

1. *Material:* with the specialist application, bonding technology can be used to bond virtually any desired combination of materials with each other, creating long-lasting bonds.

2. *Processing:* the use of bonding technology in production processes, in general, allows the material properties of the substrates to be retained. Compared to welding and soldering/brazing, the bonding process requires relatively little heat input. No damage occurs, unlike when rivets or screws are used.

3. *Joining:* **i**n product manufacture, the two aforementioned considerations enable the specific material properties of substrates to be optimally utilized in components. This allows new construction methods to be employed.

4. *Design*: it is also possible to use bonding technology to introduce customized additional properties into the component via the actual joining. In addition, the use of bonding

technology in industrial production can lead to time savings, can accelerate the production process and hence give rise to specific economic benefits. In shipbuilding, for example, the inside decks can nowadays be bonded into the primary structure, so eliminating time-consuming straightening work that would be required if the inside decks were attached by welding.
Bonding technology also has the following *further advantages:*

- Transfer of high lap shear stresses due to the large bonding areas.
- Removal of unevenness on material surfaces; greater tolerances possible using gap-filling adhesives.
- Prevention of contact corrosion for metal bonds, in contrast to when rivets or screws are used (the adhesive functions as an insulator).

2.3 Classification of adhesives

There are a large number of adhesive types for various applications. They may be classified in a variety of ways depending on their chemistries, their form, their cure mechanism, or their load carrying capability.

2.3.1. Load carrying capacity

2.3.1.1. Structural

Structural adhesives refer to relatively strong adhesives that are normally used well below their glass transition temperature, an important property for polymeric materials, above which polymers are rubbery and below which they are glassy. Common examples of structural adhesives include epoxies, cyanoacrylates, and certain urethanes and acrylic adhesives. Such adhesives can carry significant stresses, and lend themselves to structural applications.

2.3.1.2. Semi-structural and non-structural

For many engineering applications, semi-structural (applications where failure would be less critical) and non-structural (applications of facades, etc. for aesthetic purposes) are also of significant interest to the design engineer and provide cost-effective means required for assembly of finished products. These include contact adhesives where a solution or emulsion containing an elastomeric adhesive is coated onto both adherents, the solvent is allowed to evaporate, and then the two adherents are brought into contact. Examples include rubber cement and adhesives used to bond laminates to countertops.

2.3.1.3. Pressure sensitive

Pressure sensitive adhesives are very low modulus elastomers, which deform easily under small pressures, permitting them to wet surfaces. When the substrate and adhesive are brought into intimate contact, van der Waals forces are sufficient to maintain the contact and can provide relatively durable bonds for lightly loaded applications. Pressure sensitive adhesives are normally purchased as tapes or labels for non-structural applications, although can also come as double-sided foam tapes which can be used in semi-structural applications. As the name implies, hot melts become liquid when heated, wetting the surfaces and then cooling into a solid polymer. These materials are increasing used in a wide array of engineering applications using more sophisticated versions of the glue guns widely used by consumers. Anaerobic adhesives cure within narrow spaces deprived of oxygen; such materials has been widely used in mechanical engineering applications to lock bolts or bearings in place. Cure in other adhesives may be induced by exposure to ultraviolet light or electron beams, or may be catalyzed by certain materials such as water, which are ubiquitous on many surfaces.

2.3.2. Cure mechanisms

2.3.2.1. Physically hardening

Physically hardening adhesives are adhesives which, on the application, are already present in their final chemical state. Only polymers that can be liquefied can be used for this category of adhesive, namely thermoplastics that can be melted, soluble thermoplastics or elastomers, or polymer dispersions. Although poorly crosslinked elastomers with good swelling properties are strictly speaking insoluble, they can still be used in certain cases to produce adhesives if they swell enough for the substrates to be wetted. Physically hardening adhesives provide a wide range of adhesive properties, generally good bond flexibility, and are used in a variety of applications. Four physically hardening adhesives are:

- Hot melts;
- Organic solvent adhesives;
- Plastisols;
- Water-based adhesives.

2.3.2.2. Chemically curing

Chemically curing adhesives are reactive materials that require a chemical reaction to convert them from the liquid (or thermoplastic) to solid. Once cured, these adhesives generally provide high strength, flexible to rigid bond lines that resist temperature, humidity, and many chemicals. They may be classified into two groups:

- Single component. With single component adhesives, the adhesive components are premixed in their final proportions. However, they are chemically blocked. As long as they are not subjected to the specific conditions, which activate the hardener, they will not bond. They require either high temperature or substances or media (light, humidity) from the surroundings to initiate the curing mechanism. The containers in which this type of adhesive are transported and stored must be carefully chosen to prevent any undesired reactions. These adhesives are usually 100% solid systems. The six major subclasses are Anaerobic, Cyanoacrylates, Heat Cure, Moisture Cure, Radiation Cure, Silicones.
- Two-component. Two-component adhesives are 100% solids systems that obtain their storage stability by separating the reactive components. They are supplied as "resin" and "hardener" in separate containers. It is important to maintain the prescribed ratio of the resin and hardener in order to obtain the desired cure and physical properties of the adhesive. The two components are only mixed together to form the adhesive a short time before application with cure occurring at room temperature. Since the reaction typically begins immediately upon mixing the two components, the viscosity of the mixed adhesive increases with time until the adhesive can no longer be applied to the substrate or bond strength is decreased due to diminished wetting of the substrate. Formulations are available with a variety of cure speeds providing various working times (work life) after mixing and rates of strength build-up after bonding. Final strength is reached in minutes to weeks after bonding depending on the formulation. Adhesive must be cleaned from mixing and application equipment before cure has progressed to the point where the adhesive is no longer soluble. Depending on work life, two component adhesives can be applied by trowel, bead or ribbon, spray, or roller. Assemblies are usually fixture until sufficient strength is obtained to allow further processing. If the faster rate of cure (strength build-up) is desired, heat can be used to accelerate the cure. This is particularly useful when parts need to be processed more quickly after bonding or additional work life is needed but a slower rate of strength build-up cannot be accommodated. When cured, two component adhesives are typically tough and rigid with good temperature and chemical resistance.

Two-component adhesives can be mixed and applied by hand for small applications. However, this requires considerable care to ensure the proper ratio of the components and sufficient mixing to ensure proper cure and performance. There is usually considerable waste involved in hand mixing as well. As a result, adhesive suppliers have developed packaging that allows the components to remain separate for storage and also provides a means for dispensing a mixed adhesive, e.g. side-by-side syringes, concentric cartridges. The package is typically inserted into an applicator handle and the adhesive is dispensed through a disposable mixing nozzle. The proper ratio of components is maintained by virtue of the design of the package and proper mixing is ensured by the use of the mixing nozzle. The adhesive can be dispensed from these packages multiple times provided the time between uses does not exceed the work life of the adhesive. If the work life is exceeded, a new mixing nozzle must be used. For larger applications, meter-mix equipment is available to meter, mix, and dispense adhesive packaged in containers ranging from quarts to drums. Four major types of two-component adhesives include: Epoxies, Methyl Methacrylates, Silicone Adhesives, Urethanes.

2.3.2.3. Pressure sensitive

The special feature of pressure sensitive adhesives is that they do not solidify to form a solid material, but remain viscous. As a result, they remain permanently tacky and have the ability to wet surfaces on contact. Bonds are made by bringing the adhesive film in contact with the substrate and applying pressure. If the inadequate pressure is applied or the processing temperature is too low, bonding faults such as bubbles or detachment can occur. Since these adhesives are not true solids, the strength of pressure sensitive adhesives decreases when the temperature is increased. Pressure sensitive adhesives also exhibit a tendency to undergo creep when subjected to loads. They are typically formulated from natural rubber, certain synthetic rubbers, and polyacrylates.

Pressure sensitive adhesives can be supplied dissolved in organic solvents, as an aqueous dispersion, as a hot melt, or coated on a release liner as tape. Liquid applied (solvent or water based, hot melt) pressure sensitive adhesives can be applied in bead or ribbon, sprayed, or roll coated. After coating (and drying of solvent or water based systems), parts can be bonded or the adhesive covered with release liner for bonding later. The adhesive can be coated in a pattern to provide bonded and unbounded areas, e.g. assembly of membrane switches, filter frames. Pressure sensitive adhesives are often used to temporarily hold components like gaskets in position during assembly.

2.3.3. Forms

Adhesives of various chemistries are available in many different forms as well. For structural applications, adhesives are available as pastes, liquids, films, and supported films. The latter are supported on loose knit or mat-scrim cloth to improve the handling properties and also to offer some measure of thickness control. Many of these adhesives produce little or no outgassing when cured, significantly reducing the likelihood of voids within the adhesive. It is important that these adhesives be kept dry, as absorbed moisture can create significant void problems.

Thermosetting structural adhesives are normally available in two-part forms that are mixed through carefully

controlled stoichiometry into a product that cures within the desired time window. One part forms are also available in which the resin and hardener (crosslinking agent) are already mixed together. These one part forms must be kept at sufficiently low temperature that the reaction does not occur prematurely, sometimes utilizing latent crosslinking agents that are not active at low temperatures. One part thermosetting adhesives often have limited shelf life, and often must be stored at low temperatures, but do offer very high-performance capabilities. Pot life refers to the time after a two-part adhesive is mixed during which it is workable and will still make a satisfactory bond. Materials with too short of a pot life will harden too fast, and do not give the workers sufficient time to assemble the product. An excessively long pot life may delay the cure time and slow the assembly process.

Adhesives may be applied in a variety of ways depending on the form it comes in. Adhesives may be spread on a surface manually, or may be dispensed using a variety of sophisticated nozzles and robotic equipment that is currently available. Maintaining adherent cleanliness, providing proper jigs and fixturing during cure, and providing adequate cure conditions may all be important considerations for certain types of adhesives.

2.4 Epoxy adhesives

Because of their ability to adhere to a wide variety of materials, their high strength, their resistance to chemicals and environments, and their ability to resist creep under sustained load, epoxies are the most widely used structural adhesive. They are available in one component, heat curing, and two-component, room temperature curing systems. Unmodified epoxies cure to hard, brittle solids. Most adhesive formulations include modifiers to increase flexibility or toughness of the cured adhesive. This results in bond lines that are able to resist more peel and cleavage stress as well as impact.

Figure 2.2. Application of epoxy adhesives in aircraft

One component systems typically cure at temperatures from 250 to 350ºF (120 to 175ºF). Cold storage is required to provide sufficient shelf life. They provide rigid but tough bond lines and have excellent adhesion to metals. Chemical and environmental resistance are excellent. Most formulations have a paste consistency and can be applied by trowel or extruded as beads. They easily fill gaps and provide excellent sealing properties particularly against harsh chemicals. They are often used as alternatives to welding and rivets. Some formulations can tolerate processing oil on the substrate and still obtain satisfactory bond strength.

One component heat curing film adhesives are typically based on epoxy resin formulated with curative and modifiers. They are very high-performance adhesives providing high strength, high fatigue resistance, and high-temperature resistance. These curing film adhesives require cold storage and have limited shelf-life after warming to room temperature. They are especially suited for bonding and laminating large areas. Epoxy film adhesives find most of their applications in the aerospace industry for assemblies of components such as aircraft panels and helicopter rotor blades. To obtain optimal performance and durability, aluminum substrates are usually chemically treated.

Two component epoxy adhesives are found in all market segments. The work life (time adhesive can be processed and bonded after mixing) can vary from a few minutes to several hours. Assemblies must be fixtured until the adhesive has cured sufficiently to have enough strength for handling and additional processing. Final cure and ultimate strength are obtained over hours to weeks depending on the formulation. High ambient temperature accelerates the rate of cure and shortens the work life. Low ambient temperature slows the rate of cure and extends the time before assemblies can be further processed. In general, adhesives that cure faster have lower final strength than those that cure more slowly. The major advantage of two component epoxy adhesives is that they are suitable for bonding nearly all substrates - metal, plastic, glass and ceramic, wood and wood products, and many types of rubber. In general, they have high resistance to physical and chemical influences and in addition, they have high long-term stability because they only have a limited tendency to undergo creep. Depending on the type, they can withstand continuous temperatures from 200oF (95°C) up to 390 ºF (200°C). Cured adhesives are typically hard and rigid and range from brittle to tough depending on the formulation.

Figure 2.3. One component and two component commercial epoxy adhesives.

2.5 Glass transition temperature

The glass transition temperature (T_g) is one of the most important properties of any polymer and refers to the temperature vicinity in which the amorphous portion of the polymer transitions from a hard, glassy material to soft, rubbery material. Although specific temperatures are often quoted for the glass transition temperature, it is important to remember that this transition temperature is a rate dependent process. For thermosetting structural adhesives, the glass transition temperature should normally be 50°C higher than the expected service temperature. Unless there are significant exotherms associated with the cure process, the glass transition temperature of an adhesive seldom exceeds the cure temperature. High-performance structural bonds often require an elevated temperature cure to provide a sufficiently high T_g in a reasonable cure time. One concern with such conditions, however, are the residual stresses which may develop with an assembled joint is cooled from the cure temperature to the service conditions.

2.6 Reference

[1] Mays G. C, Hutchinson A. R. Adhesives in Civil Engineering. ISBN 052132677X, Cambridge University Press (1992).

2.7 List of figures

Figure 2.1. The use of adhesives in the building/construction field.
Figure 2.2. Application of epoxy adhesives in aircraft.
Figure 2.3. One component and two component commercial epoxy adhesive

ANNEX 1

[19]中华人民共和国专利局

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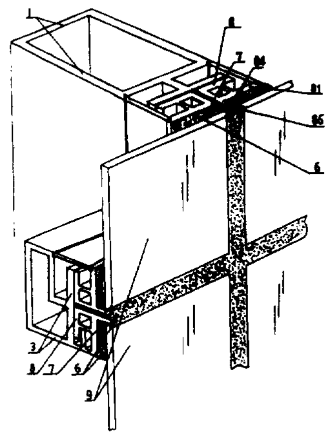
权利要求书 1 页 说明书 4 页 附图页数 2 页

[54]实用新型名称 隐固框玻璃幕墙的板块型材

[57]摘要

一种隐固框玻璃幕墙的板块型材，其设有前板、后板和连接前板、后板的侧板，侧板设有延伸部，顶端部设有向前板倾斜呈楔角形斜钩部，其内侧与延伸部内侧夹角为125度，前板外侧设有幕墙玻璃，周边制成与楔角形内侧匹配的斜面，板块型材构成的框型四周斜钩部钩扣住幕墙玻璃四周斜面上。幕墙玻璃四周斜面为与楔角形匹配的35度。其与幕墙玻璃间的连接除了结构胶等胶接外，还有前端斜钩部连接，使幕墙结构更牢固，具有结构简单、结合强度高、使用寿命长且使用安全的功效。



权 利 要 求 书

1、一种隐固框玻璃幕墙的板块型材，其设有前板、后板和连接前板、后板的侧板，其特征在于：该侧板向前方延伸设有一延伸部，该延伸部的顶端部设有一向前板倾斜的斜钩部。

2、根据权利要求1所述的隐固框玻璃幕墙的板块型材，其特征在于所述的延伸部上的斜钩部为呈楔角形。

3、根据权利要求2所述的隐固框玻璃幕墙的板块型材，其特征在于所述的延伸部上斜钩部的楔角形其内侧面与延伸部内侧面的夹角为125度，即与水平面的夹角为35度。

4、根据权利要求1、2或3中任一权利要求所述的隐固框玻璃幕墙的板块型材，其特征在于所述的板块型材的前板其外侧设有与其相连的幕墙玻璃，该幕墙玻璃的四周边缘制成与板块型材斜钩部的楔角形内侧角度相匹配的斜面边，板块型材构成的框型其四周的斜钩部刚好钩扣住幕墙玻璃四周外侧的斜面边上。

5、根据权利要求4所述的隐固框玻璃幕墙的板块型材，其特征在于所述的幕墙玻璃其四周外侧的斜面边制成与板块型材斜钩部的楔角形内侧角度相匹配的35度。

说　　明　　书

隐固框玻璃幕墙的板块型材

本实用新型涉及一种固定建筑物领域建筑物的装修工程构件，特别是涉及一种建筑物装修工程的隐固框玻璃幕墙的板块型材。

请参阅图4所示，现有的隐固框玻璃幕墙，其板块型材的组合结构主要包括主力杆骨架1、副骨架2、横杆骨架3、副横骨架4及若干块幕墙玻璃5，其中其组合结构为在主力杆骨架1上连设有一副骨架2，在横杆骨架3上连设有一副横骨架4，在副骨架2及副横骨架4的外侧设有幕墙玻璃5，该幕墙玻璃5与板块型材的副骨架2及副横骨架4之间设有结构胶6及不干胶7，主要靠该结构胶6将幕墙玻璃5与板块型材的副骨架2及副横骨架4 粘住而结合成为隐固框玻璃幕墙的整体。上述现有的隐固框玻璃幕墙，由于其是靠结构胶6将幕墙玻璃5与板块型材的副骨架2及副横骨架4粘住而结合成为一整体，其粘接强度有限，而使得幕墙玻璃5的固定强度不高，存在有令人担忧其强度的缺陷；另外，上述结构其使用的时间一般最长均不会超过20年，即会必然发生因结构胶6日久而造成幕墙玻璃5脱胶掉落的危险情形，实有改进的必要；再者，在上述情况下必须重新更换结构胶6及幕墙玻璃5，从而存在有会进一步造成既浪费人力又浪费财力物力的缺陷。

有鉴于上述传统隐固框玻璃幕墙存在的缺陷，本设计人基于多年的实务经验及丰富的专业知识，经过不断的研究、设计，并经过反复试作样品及改进后，终于创设出本实用新型。

本实用新型的主要目的在于，克服现有隐固框玻璃幕墙存在的缺陷，而提供一种新型结构的隐固框玻璃幕墙的板块型材，使其能与幕墙玻璃牢固地结合，具有结构简单、结合强度高、成本低、使用寿命长且使用安全的功效。

本实用新型的目的是由以下技术方案实现的。一种隐固框玻璃幕墙的板块型材，其设有前板、后板和连接前板、后板的侧板，其中该侧板向前方延伸设有一延伸部，该延伸部的顶端部设有一向前板倾斜的斜钩部。

本实用新型的目的还可以通过以下技术措施来进一步实现。前述的隐固框玻璃幕墙的板块型材，其中所述的延伸部上的斜钩部为呈楔角形。前述的隐固框玻璃幕墙的板块型材，其中所述的延伸部上斜钩部的楔角形其内侧面

与延伸部内侧面的夹角为125度，即与水平面的夹角为35度。前述的隐固框玻璃幕墙的板块型材，其中所述的板块型材的前板其外侧设有与其相连的幕墙玻璃，该幕墙玻璃的四周边缘制成与板块型材斜钩部的楔角形内侧角度相匹配的斜面边，板块型材构成的框型其四周的斜钩部刚好钩扣住幕墙玻璃四周外侧的斜面边上。 前述的隐固框玻璃幕墙的板块型材，其中所述幕墙玻璃其四周外侧的斜面边制成与板块型材斜钩部的楔角形内侧角度相匹配的35度。

本实用新型与现有技术相比具有明显的优点和积极效果。由以上的技术方案可知，本实用新型隐固框玻璃幕墙的板块型材其结构特征为板块型材的前端均制成斜钩部，与板块型材相连的幕墙玻璃其四周边缘均磨成与板块型材前端的斜钩部内侧角度相匹配的斜面边，使板块型材组成的板块型材框其四周的斜钩部刚好钩扣住幕墙玻璃四周的外侧斜面边上。本实用新型由于在现有的隐框玻璃幕墙的板块型材的前端制有斜钩部，因而板块型材组成的板块型材框与幕墙玻璃之间的连接，除了有结构胶等胶接连接外，还有板块型材前端的斜钩部扣合连接，因而使得制成的隐固框玻璃幕墙其结构更为牢固，且安全防震，使用寿命长。

综上所述，本实用新型隐固框玻璃幕墙的板块型材，其能够可靠地与幕墙玻璃牢固地结合，具有结构简单、结合强度高、成本低、使用寿命长且使用安全的功效，从而更加适于实用，其不论在结构上或功能上皆有较大改进，诚为一新颖、进步、实用的新设计。

本实用新型的具体结构由以下实施例及其附图详细给出。

图1 是本实用新型隐固框玻璃幕墙的板块型材与幕墙玻璃连接构成隐固框玻璃幕墙的组合结构示意图。

图2是本实用新型隐固框玻璃幕墙的板块型材的结构剖面示意图。

图3 是与本实用新型隐固框玻璃幕墙的板块型材相结合的幕墙玻璃的结构示意图。

图4是现有的隐固框玻璃幕墙的板块型材与幕墙玻璃的组合结构示意图。

以下结合附图及较佳实施例，对依据本实用新型提出的隐固框玻璃幕墙的板块型材其具体结构、特征及其功效，详细说明如后。

请首先参阅图2所示，本实用新型隐固框玻璃幕墙的板块型材8，其设有前板81、后板82和连接前板81、后板82的侧板83，侧板83向前方延伸设有一延伸部84，该延伸部84的顶端部设有一向前板81倾斜的斜钩部85，该斜钩部85为

呈楔角形，在本实施例中该楔角形的内侧面与延伸部84的内侧面的夹角设计为125度，即与水平面的夹角为35度。

请参阅图3所示，为与本实用新型隐固框玻璃幕墙的板块型材8与幕墙玻璃9相结合的组合结构，其与板块型材8斜钩部85的内侧面相接的斜面部91制成与板块型材8斜钩部85的内侧面倾斜角度相匹配的35度，且其四周均磨制成与板块型材8斜钩部85的内侧面倾斜角度相匹配的35度，使得由板块型材8相组合构成的板块型材框，其中位于其四周的板块型材8内侧的斜钩部85刚好均钩扣住幕墙玻璃9四周外侧的斜面部91上，而可将幕墙玻璃9牢固地结合。

请参阅图1所示，为本实用新型隐固框玻璃幕墙的板块型材8与幕墙玻璃9相连接构成新型结构的隐固框玻璃幕墙的组合结构。该组合的新型结构的隐固框玻璃幕墙，由本实用新型板块型材8与幕墙玻璃9相互连接而构成，其主要包括现有的主力杆骨架1、横杆骨架3，在主力杆骨架1、横杆骨架3上分别连接有本实用新型板块型材8及若干块幕墙玻璃9，其组合结构为在主力杆骨架1上对称各连接设有一板块型材8．在横杆骨架3上亦对称各连接设有一板块型材8，在相邻的板块型材8的外侧设有幕墙玻璃9，该幕墙玻璃9与其四周的板块型材8的前板81之间设有结构胶6及不干胶7，该等结构胶6及不干胶7将幕墙玻璃9与板块型材8的前板81粘合住而结合成为隐固框玻璃幕墙的整体。玻璃幕墙组合后，其主力杆骨架1和横杆骨架3构成隐固框玻璃幕墙的主体，四周的各板块型材8形成幕墙片框，以各板块型材8前端的斜钩部85进一步扣压并框住各幕墙玻璃9，使其牢固固定，若干个如上述结构所固定的幕墙玻璃9形成隐固框玻璃幕墙的整体。由于板块型材8的前端制有斜钩部85，因而板块型材8组成的板块型材框与幕墙玻璃9之间的连接，除了有结构胶6及不干胶7等胶接连接外，还有板块型材8前端的斜钩部85扣合连接，因而使得制成的隐固框玻璃幕墙其结构更为牢固，且安全防震，使用寿命长。一般板块型材8采用铝合金制成，且前端的斜钩部85内侧面的夹角制成为125度，幕墙玻璃9的四周边均磨制成与板块型材8斜钩部85 的内侧面倾斜角度相匹配配合连接的35度。本实用新型板块型材8与幕墙玻璃9的具体连接结构为：板块型材8前端的延伸部84及斜钩部85的内侧面打上防震胶，再与幕墙玻璃9的周边相连，使斜钩部85钩扣住幕墙玻璃9；板块型材8的前板81、侧板83与幕墙玻璃9背面的相对应处打上结构胶6及不干胶7，使其更牢固结合；然后在幕墙玻璃9之间的交接缝处打上胶，从而形成稳固连接的新型结构的隐固框玻璃幕墙。

以上所述，仅是本实用新型的较佳实施例而已，并非对本实用新型作任何限制，凡是依据本实用新型技术实质对以上实施例所作的任何简单修改、变更与等效结构变化，均仍属于本实用新型技术方案的范围内。

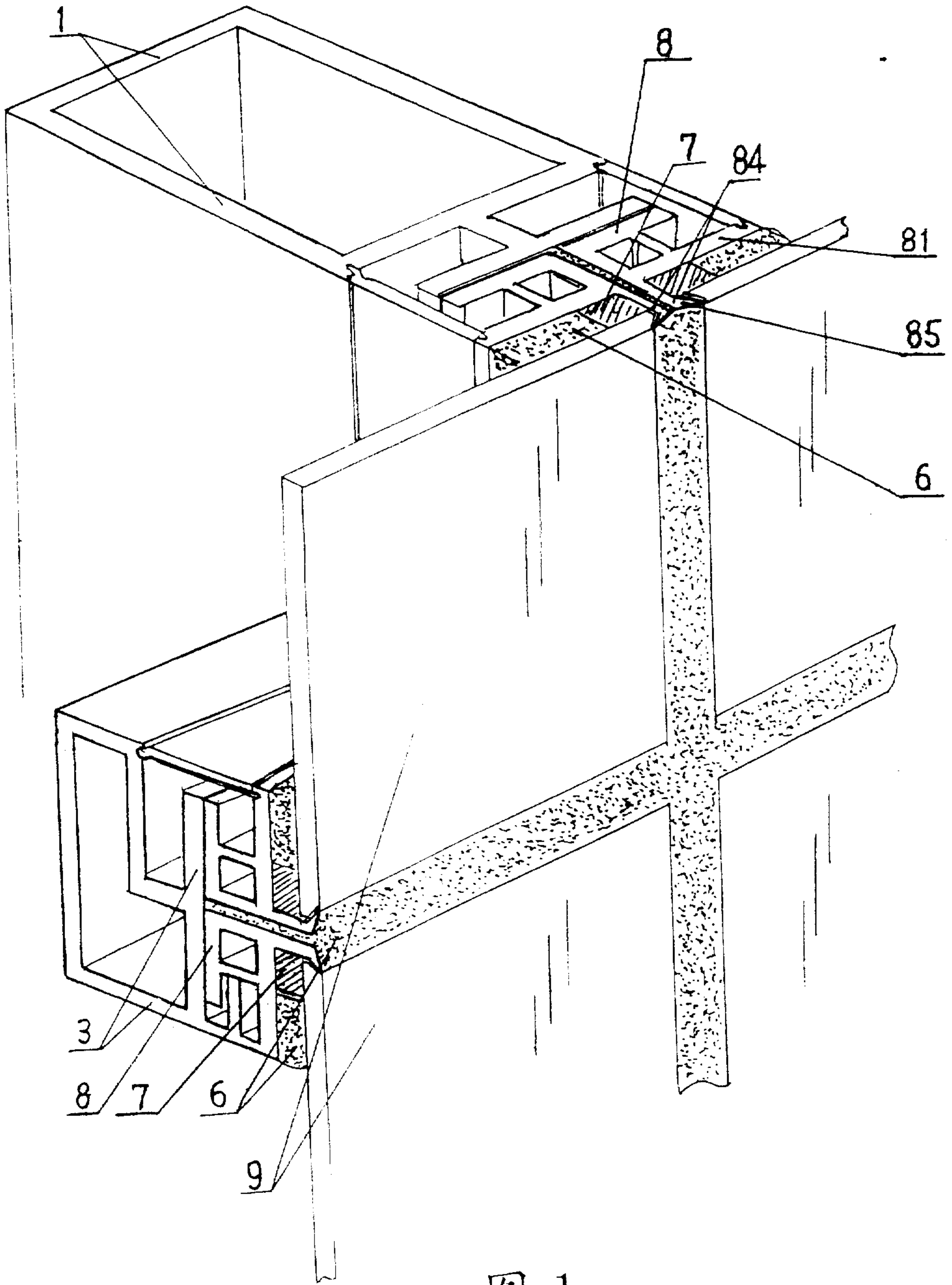


图 1

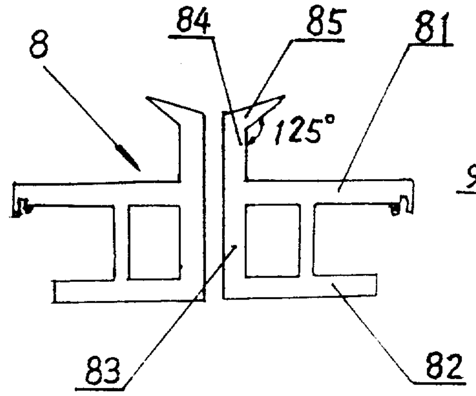


图 2

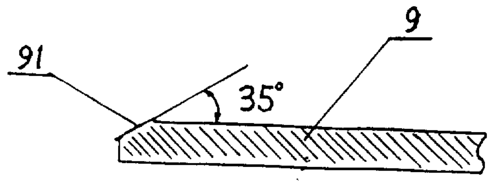


图 3

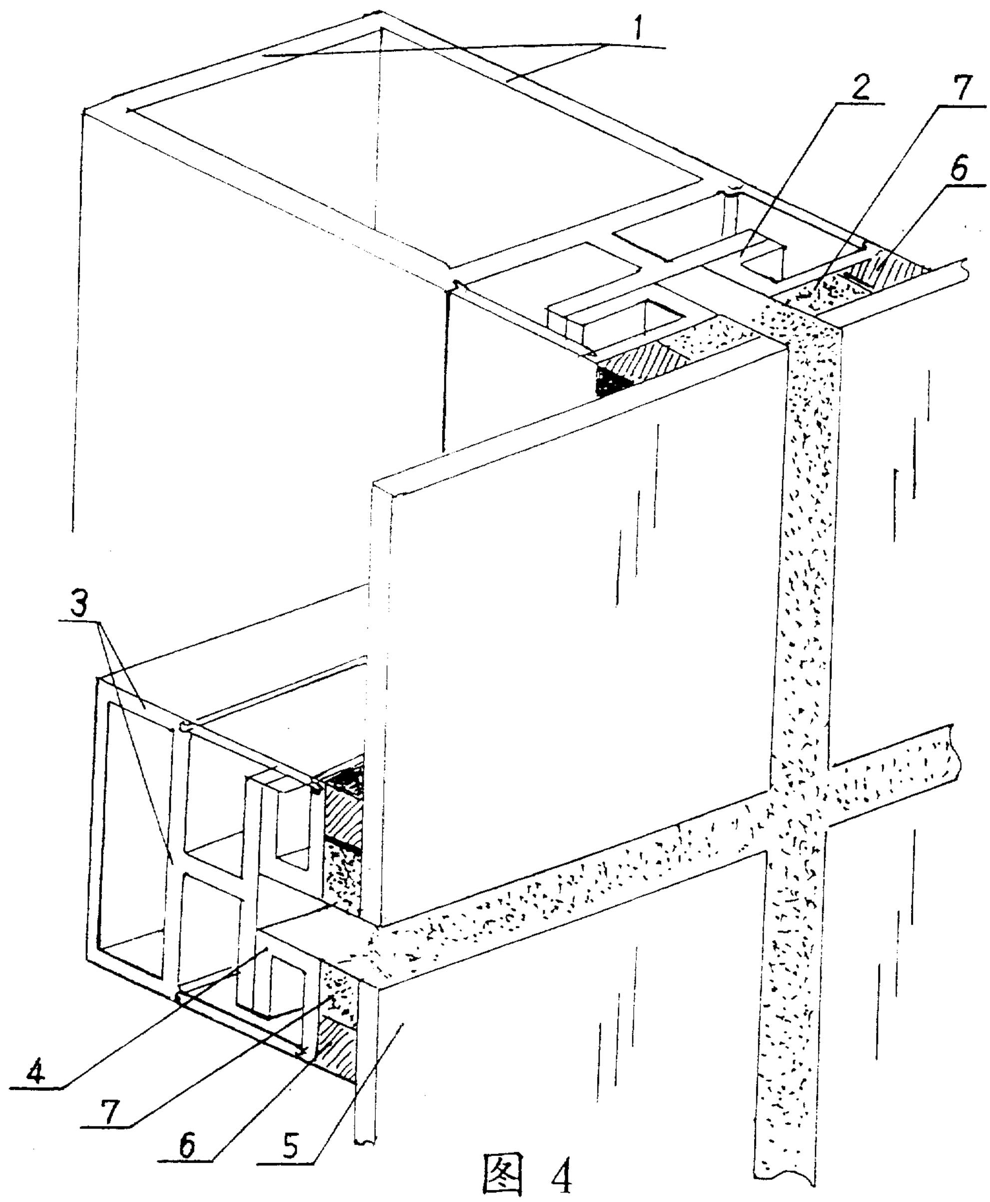


图 4

ANNEX 2

US005493831A

United States Patent [19]

Jansson

[11] **Patent Number: 5,493,831**

[45] **Date of Patent: Feb. 27, 1996**

[54] **METHOD AND ARRANGEMENT FOR SECURING GLASS FACADE ELEMENTS**

[76] Inventor: **Nils-Gunnar Jansson**, Grev Magnigatan 10, S-114 55 Stockholm, Sweden

[21] Appl. No.: **211,183**

[22] Filed: **Mar. 23, 1994**

[30] **Foreign Application Priority Data**

Sep. 24, 1991 [SE] Sweden 9102766

[51] **Int. Cl.**^{6} **E06B 3/54**

[52] **U.S. Cl.** **52/235**; 52/204.593; 52/489.1; 52/786.13

[58] **Field of Search** 52/235, 204.1, 52/208, 204.5, 204.57, 204.67, 396.07, 506.08, 506.06, 489.1, 788, 789, 172, 204.591, 204.593, 204.598

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,714,747	2/1973	Curran	52/489.1
3,871,150	3/1975	Murray et al.	52/506.08
4,110,948	9/1978	Maier, Jr.	52/489.1
4,475,325	10/1984	Veldhoen	52/235
4,552,790	11/1985	Francis	52/235
4,691,489	9/1987	Shea, Jr.	52/208
4,756,131	7/1988	Stoakes	52/235
4,961,975	10/1990	Bejnar	52/788
5,048,249	9/1991	Shreiner et al.	52/396.07
5,199,236	4/1993	Allen	52/235

FOREIGN PATENT DOCUMENTS

0250989	1/1988	European Pat. Off. .
3439436	4/1986	Germany .
3801826	8/1989	Germany .
9105924	5/1991	WIPO .

Primary Examiner—Carl D. Friedman
Assistant Examiner—Winnie S. Yip
Attorney, Agent, or Firm—Nies, Kurz, Bergert & Tamburro

[57] **ABSTRACT**

A method and an arrangement for securing glass facade elements comprised of sealed glazing units which include at least two parallel glass sheets separated by a spacer which extends between the glass sheets and terminates short of the outer edges of the sheets, wherein a glue layer is applied between the glass sheets but outwardly of the spacer, and wherein facade elements are secured to a frame structure and preferably a frame structure comprised of aluminum profiled sections and having a clip placed and penetrating the glue layer between the glass sheets of two neighboring facade elements.

10 Claims, 2 Drawing Sheets

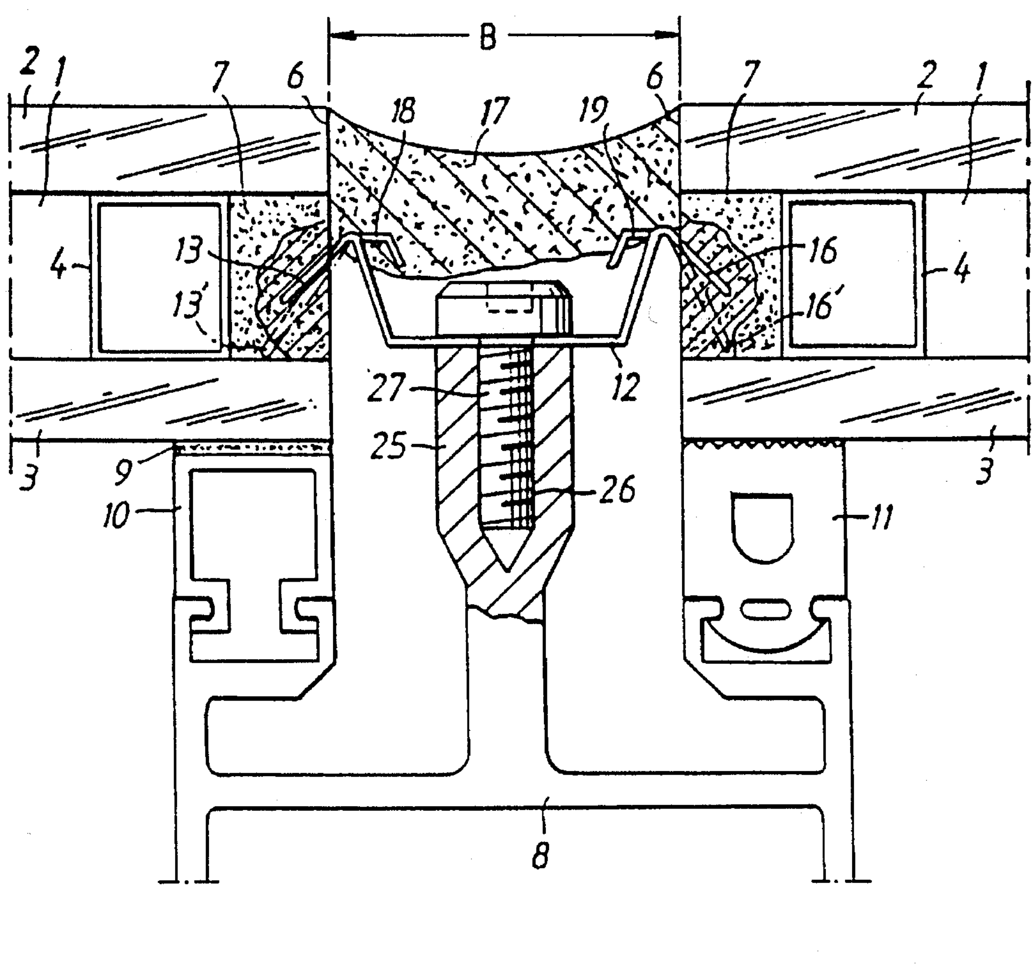


Fig. 1

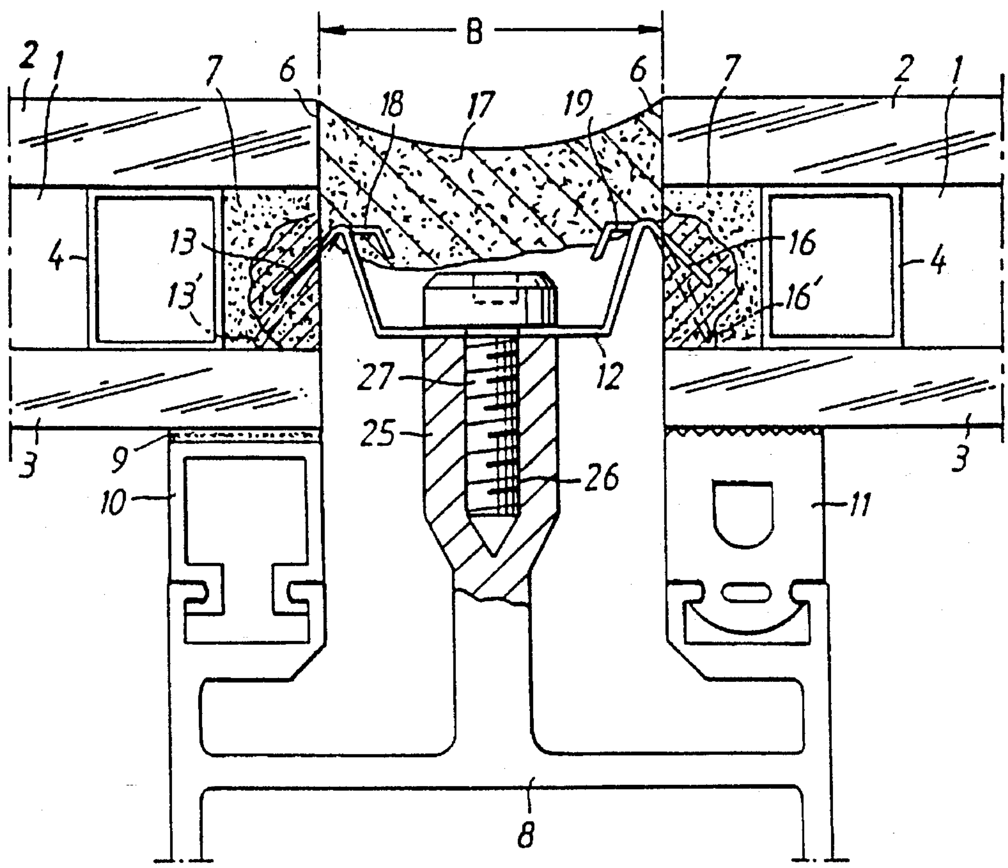

B
2
1
7
6
18
17
19
6
7
2
1
4
13
13'
16
16'
4
27
12
25
26
3
9
3
10
11
8

Fig. 2

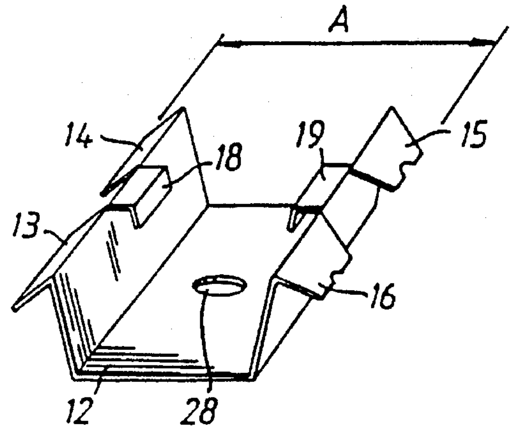

A
14
18
19
15
13
16
12
28

Fig.3a

Fig.3b

Fig.3c

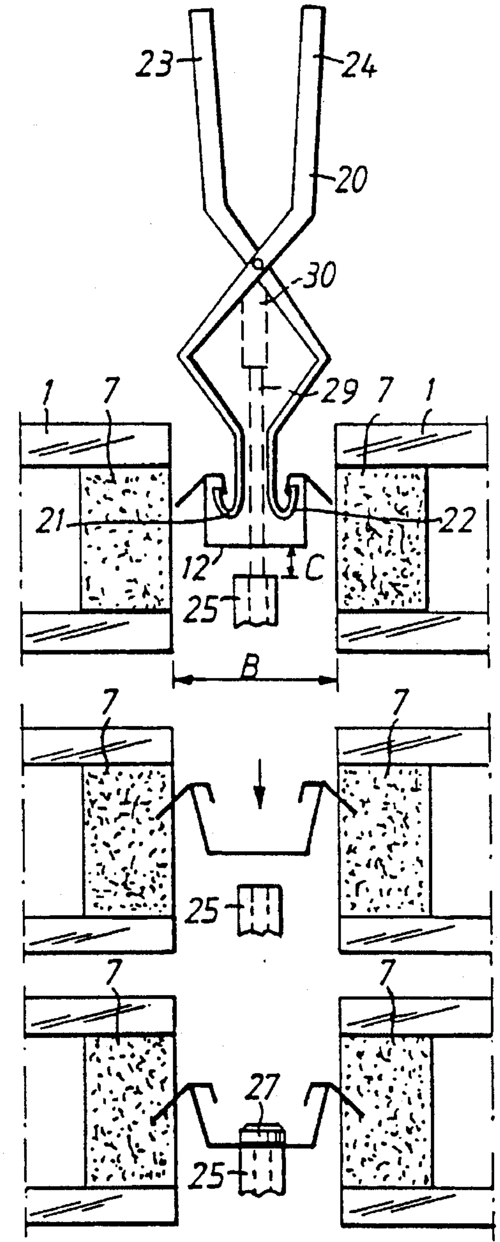
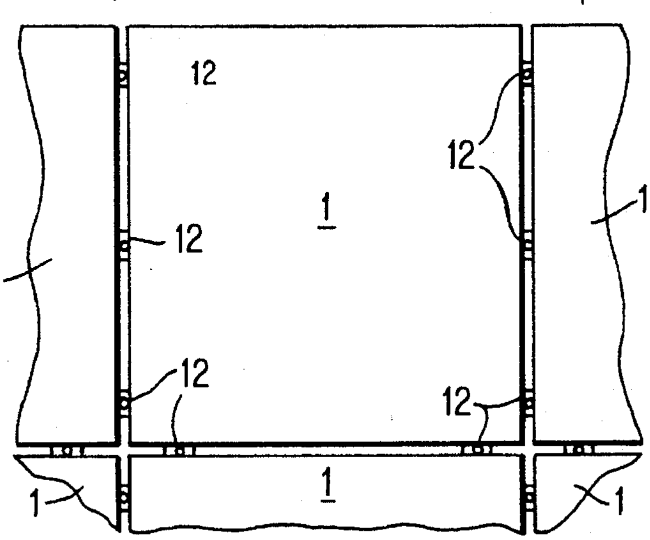


Fig.4



METHOD AND ARRANGEMENT FOR SECURING GLASS FACADE ELEMENTS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method and to an arrangement for securing glass facade elements. The invention is concerned primarily with facade elements in the form of glass sheets or panes which are glued to a frame structure. Such frame structures may be constructed from aluminium profiled sections.

2. Description of the Related Art

In recent times, it has become more and more usual to provide building structures, such as office buildings, with a full-covering glass facade. The glass sheets are herewith glued to a rearwardly-lying frame construction and the glue, or adhesive, used is load-carrying both with respect to positive and negative wind loads. Constructions are found in which the glass sheets are supported solely by the adhesive, although there are also found constructions in which, for instance, the bottom edges of the glass sheets rest on a frame part, so that the static load will be taken-up mechanically by the frame structure.

Glass facades of this kind are normally constructed with the aid of sealed double-glazing units. Sealed double-glazing insulating units are constructed with a spacer between the glass sheets, so as to hold the sheets at a given distance apart. An adhesive, or glue, is applied outside the spacer, but between the sheets. The purpose of the adhesive is to hold the glass sheets glued together, and also to form a seal between the surroundings and the space between the sheets. The adhesive used is normally a silicone glue. The glue is applied in the factory, under precise conditions, and consequently the glue joint will not loosen on the insulation unit fitted to the facades.

In the case of known facades of this kind, the known technique used involves gluing the glass sheets of the glazing units that lies closest to the frame structure directly onto said frame structure. This is carried out on the building site, and consequently the glue joints obtained are liable to vary in quality, among other things due to the weather conditions that prevail at that particular time.

It is obvious that a sealed glazing unit thus secured is liable to loosen and fall onto the ground below. It is also obvious that a falling sheet of glass can cause serious injury to people in the vicinity of the glass and also serious damage to property. However, with regard to the aesthetic appearance of the facade, it is important that no fastener devices are visible to the viewer, for instance extending in the joints between two adjacent glazing units and on the outside of said units. There is no doubt that a mechanical fastener arrangement would eliminate the risk of the unintentional release of a glazing unit, even if its glue bond with the frame structure should fail.

The problem solved by means of the present invention is thus that of securing glazing units with the aid of mechanical means without the use of surface-mounted fastener devices.

SUMMARY OF THE INVENTION

Accordingly, the present invention relates to a method for securing glass facade elements which are comprised of sealed glazing units which include at least two parallel glass sheets which are separated mutually by a spacer that extends between the glass sheets slightly and terminates short of the

outer edges thereof, where glue is applied between the glass sheets but outwardly of the spacer, said facade elements being fastened to a frame structure, preferably a frame structure comprises of aluminium profiled sections, and is characterized in that when assembling the facade elements a clip is fitted between two mutually adjacent elements and secured mechanically to the frame structure, said clip having two tongues which extend obliquely in mutually opposite directions towards the frame structure; in that when no load acts on the clip the distance between the free extremities of the tongues exceeds the distance between two mutually adjacent facade elements; and in that when fitting the clip, said clip is deformed elastically so as to bring the tongues closer together, whereafter the clip is placed between two mutually adjacent facade elements, whereafter the clip is subjected to load and secured in the frame structure as the tongues penetrate the glue layer applied between the glass sheets but outwardly of the spacer.

The invention also relates to a structural arrangement for securing a plurality of glass facade elements to a frame structure.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in more detail, partly with reference to exemplifying embodiments of the invention illustrated in the accompanying drawings, in which

FIG. 1 is a section view of an inventive arrangement mounted between two mutually adjacent glass facade elements;

FIG. 2 illustrates a clip used in accordance with the invention;

FIGS. 3*a*–3*c* illustrate fitting of the inventive arrangement and

FIG. 4 is a fragmentary elevational view showing a plurality of adjacent facade elements connected together.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 illustrates an arrangement for securing glass facade elements comprised of sealed glazing units that include at least two parallel glass sheets **2, 3**. The glass sheets are held separated by a spacer **4** which extends between the glass sheets **2, 3** and terminates short of the outer edges **6** of the glass sheets. Glue **7** is applied between the glass sheets **2, 3** but outwardly of the spacer **4**. Such sealed glazing units have long been known. The glue **7** is applied in the factory.

With regard to building constructions that have glass facades, the facade elements **1** are secured to a frame structure **8**, preferably a frame structure comprised of aluminum profiled sections, this frame structure in turn being secured to the building. Only a part of one such frame structure is illustrated in FIG. **1**.

Hitherto, glass facade elements **1** have been glued to the frame structure **8**. This is illustrated in the left-hand part of FIG. **1**, which shows the glass panes or sheets glued at **9** to a part **10** of the frame structure **8**. These glue joints are effected on the building site and, as previously mentioned, the quality of the glue joints may vary from one joint to the other and therewith, in some instances, result in the facade element **1** falling from the building.

A so-called weather seal **17**, i.e. a sealing compound, such as silicone, is provided between two neighbouring facade elements.

Shown in the right-hand part of FIG. **1** is another embodiment which is made possible by means of the present invention, namely an embodiment in which the facade element is not glued to the frame structure **8** at all, but simply rests on, e.g., a rubber strip **11** secured in said structure. Naturally, only one of the two embodiments illustrated in FIG. **1** are used in one and the same building.

The inventive arrangement includes a clip **12** which is intended to be fitted between two neighbouring facade elements **1**, said clip **12** being intended to be secured mechanically in the frame structure. FIG. **2** illustrates one embodiment of the clip. The clip **12** has two tongues which extend obliquely outwards in two mutually opposite directions. The clip shown in FIG. **2** has four such tongues **13**, **14**; **15**, **16**. When no load acts on the clip the distance A between the outer extremities of the tongues **13**, **16**; **14**, **15** exceeds the distance B between two neighbouring facade elements **1**. The clip **12** is elastically deformable, so that the tongues can be brought closer together and thereby enable the clip **12** to be placed between two neighbouring facade elements **1**, as illustrated in FIG. 3a. When the clip is subjected to load, the tongues **13–16** are able to penetrate the glue **7** between the glass panes or sheets **1**, **2**, see FIG. 3*b* and 3*c*.

According to one preferred embodiment, the clip **12** has a generally U-shape with the tongues **13–16** extending from the upper parts of the U and obliquely outwards and downwards, as illustrated in FIG. **2**. It will be understood, however, that the clip may be given a different configuration without changing its function.

According to one preferred embodiment, the clip is also provided with two further tongues **18**, **19**, which extend obliquely downwards and inwards from the upper parts of the U-form. When fitting the clip in position, these tongues **18**, **19** are intended to coact with a tool **20** such as to squeeze the clip together and therewith shorten the distance between the first mentioned tongues **13–16**, as before mentioned, and therewith enable the clip to be inserted between two neighbouring facade elements **1**.

The tool **20** is illustrated in FIG. **3** and comprises a pair of tongs having two rearwardly curved front parts **21**, **22** on respective legs, these rearwardly curved, or bent, parts being intended for insertion behind the further tongues **18**, **19**. The clip is squeezed together, so that it can be inserted between two neighbouring facade elements, by moving the handles **23**, **24** of the tongues towards one another.

According to one preferred embodiment, the clip **12** is made from stainless spring-steel sheet. A suitable sheet: thickness is 0.5 millimeter, for instance.

One or more clips are fastened on each side of a facade element. Preferably, a number of clips are fastened along each side. FIG. **4** shows several adjacent facade elements **1** that are each interconnected by a plurality of clips **12**.

When fitting the facade elements **1** in position, a clip **12** is placed between two neighbouring facade elements **1** and fastened mechanically in the frame structure **8**. When fitting the clip **12**, the clip is deformed elastically with the aid of the tool **20**, so that the tongues **13–16** will approach one another, whereafter the clip is placed in position between two neighbouring facade elements **1**. The clip **12** is then released and secured in the frame structure as the tongues penetrate the glue layer **7** between the glass sheets **1**, **2**, but outwardly of the spacer.

When fitting the clip **12**, the clip is placed initially a short distance from the frame structure **8**, so that the clip **12** will be located at a distance C from an outwardly-projecting part **25** of the frame structure **8**, see FIG. 3*a*. The outwardly-projecting part **25** has an axially-extending screw channel **26** in which a screw **27** is intended to be tightened. The screw **27** is intended to extend through a hole **28** in the clip. When the clip is positioned in the aforesaid manner and the load acting thereon is relieved, the first mentioned tongues **13–16** will lie against the glue layer **7**, see FIG. 3*b*. The clip is then screwed firmly to the frame structure **8** and is therewith displaced into abutment with the frame structure while the tongues spring outwards and penetrate the glue layer, see FIG. 3*c* and FIG. **1**.

Tongues **13**, **16** which have penetrated the glue layer **7** are shown in full lines in FIG. **1**, these tongues not being in abutment with a glass sheet or pane **3**. This embodiment of the tongues **13–16** is fully satisfactory when the facade elements are glued directly against the frame structure **8** by means of a glue joint **9**, as illustrated in the left-hand part of FIG. **1**. However, when the facade elements are not glued directly to the frame structure, but instead merely lie against a rubber strip **11**, the inventive arrangement can be used as the sole means of securing the facade elements to the frame structure. This is illustrated in FIG. **1** with the aid of the tongues **13'**, **16'** shown in broken lines. In this embodiment, the tongues have a length such that when the clip is tightened by means of the screw **27**, the tongues **13'**, **16'** will lie in abutment with the glass sheets **3**.

In order to facilitate positioning of the clip at the aforesaid distance C from the outwardly-projecting part: **25**, the tool **20** may be provided with a rod **29**, shown in broken lines in FIG. 3*a*, which extends through the hole **28** provided in the clip and projects from beneath the clip through a distance corresponding to the aforesaid distance C. The tool is therewith lowered until the forward end of the red **29** comes into contact with the outwardly-projecting part **25**, whereafter load is relieved from the clip by means of the tool and the tool withdrawn. According to one embodiment, the red **29** may be screwed into a sleeve **30** so as to enable the extent to which the rod **29** projects from the tool to be adjusted in accordance with the position of the outwardly-projecting part **25** in relation to the facade elements.

It will be evident that the present invention solves the problem mentioned in the introduction, in a simple and effective manner.

Although the invention has been described with reference to various embodiments thereof, it will be obvious to those skilled in this art that the construction of the arrangement can be varied without changing its function.

The present invention is therefore not restricted to the afore-described and illustrated embodiments thereof, since modifications can be made within the scope of the following claims.

I claim:

1. A method for securing glass facade elements which are comprised of sealed glazing units which include at least two parallel glass sheets (**2**, **3**) separated by a spacer (**4**) which extends between the glass sheets and terminates short of the outer edges of said sheets, wherein a glue layer (**7**) is applied between the glass sheets but outwardly of the spacer, and wherein facade elements are secured to a frame structure (**8**), preferably a frame structure comprised of aluminium profiled sections, characterized in that when fitting the facade element (**1**) a clip (**12**) is inserted between two adjacent neighbouring facade elements, said clip (**12**) being secured mechanically in the frame structure (**8**) and having two tongues (**13**, **16**; **14**, **15**) which project outwardly and obliquely in opposite directions on each opposite side of said clip towards the frame structure; in that when no load acts on the clip, the distance (A) between the free extremities of the tongues exceeds the distance (B) between two adjacent neighbouring facade elements (**1**); and in that when fitting the clip (**12**) in position, said clip being loaded, the tongues (**13**, **16**; **14**, **15**) are deformed elastically and caused to approach one another, whereafter the clip is placed between two adjacent neighbouring facade elements and the load on the clip is removed, therewith securing the clip in the frame structure (**8**) with the tongues (**13–16**) penetrating said glue layer (**7**) between the glass sheets, but outwardly of the spacer (**4**).

2. A method according to claim **1**, including providing a generally U-shape to the clip and extending said tongues, from the upper parts of the U-shape of the clip, obliquely outwards and downwards away from the center portion of the clip.

3. A method according to claim **2**, characterized in that the clip (**12**) is provided with two further tongues (**18**, **19**) which extend obliquely downwards and inwards from the upper parts of the U-shape and which, when fitting the clip, are caused to coact with a tool for squeezing the clip (**12**) together so that said distance (A) between the first mentioned tongues is decreased and therewith enable the clip to be inserted between two neighbouring adjacent facade elements, as before mentioned.

4. A method according to claim **1**, characterized in that when fitting the clip (**12**), the clip is placed initially at a distance (C) from the frame structure (**8**), such that the first mentioned tongues (**13–16**) will lie against the glue layer (**7**); and in that the clip is then screwed in the frame structure, said clip being displaced into abutment with the frame structure and the tongues (**13–16**) being caused to penetrate the glue layer (**7**).

5. A method according to claim **1**, characterized in that one or more clips (**12**) are fastened at each side of a facade element (**1**).

6. An arrangement for securing glass facade elements comprised of two separated sealed glazing units which each of said units includes at least two parallel glass sheets (**2**, **3**) separated by a spacer (**4**) which extends between the glass sheets and terminates short of the outer edges of said sheets, wherein a glue layer (**7**) is provided between the glass sheets and outwardly of the spacer, and wherein facade elements (**1**) are fastened to a frame structure (**8**), preferably a frame structure comprised of aluminium profiled sections, characterized: in that the arrangement includes an elastically deformable clip (**12**) which is intended to be fitted between two adjacent neighbouring facade elements (**1**) and fastened mechanically to the frame structure; in that the clip has a center portion with a U-shaped cross-section having two sides, each side having two tongues (**13**, **16**; **14**, **15**) which project outwardly from the said center portion in opposite directions and obliquely in towards the frame structure (**8**); in that, when the clip is not deformed by loading forces, a distance (A) between the free outer extremities of the tongues (**13**, **16**; **14**, **15**) exceeds a distance (B) between two neighbouring adjacent facade elements (**1**); and in that the clip (**12**) is elastically deformable, under loading when fitted between two adjacent facade elements, so that the tongues are able to approach one another and therewith enable the clip to be inserted between two neighbouring adjacent facade elements and so that, when the loading acting on the clip (**12**) is relieved, the clip (**12**) will spring-back essentially to its unloaded condition so that the tongues (**13–16**) are able to penetrate the glue layer (**7**) between the glass sheets, and outwardly of the spacer (**4**).

7. An arrangement according to claim **6**, wherein the tongues (**13–16**), extend outward from the sides of the clip and obliquely in a direction toward the center portion of the clip.

8. An arrangement according to claim **7**, characterized in that the clip (**12**) is provided with two further tongues (**18**, **19**) which extend obliquely downwards and inwards from the upper parts of the U-shape, said further tongues (**18**, **19**), when fitting the clip, being intended to coact with a tool which functions to squeeze the clip (**12**) together so that, as before mentioned, the distance (A) between the first mentioned tongues is decreased and therewith enables the clip to be inserted between two neighbouring adjacent facade elements.

9. An arrangement according to claim **6**, characterized in that one or more clips (**12**) are fitted on adjacent sides of adjacent elements.

10. An arrangement according to claim **6**, characterized in that the clip (**12**) is made of stainless spring steel.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,493,831

DATED : February 27, 1996

INVENTOR(S) : NILS-GUNNAR JANSSON

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

On the Title page, correct item [22] to read:

[22] PCT filed: September 24, 1992

On the COVER PAGE, add the following item:

[63] Filed as PCT/SE92/00663 on March 23, 1994.

Signed and Sealed this

Eleventh Day of June, 1996

Attest:

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks

ANNEX 3

MODULARIO
INDUSTRIA, COMMERCIO
E ARTIGIANATO 170

MOD. I - 48 TER

MINISTERO DELL'INDUSTRIA DEL COMMERCIO E DELL'ARTIGIANATO

D. G. P. I. – UFFICIO CENTRALE BREVETTI

BREVETTO PER INVENZIONE INDUSTRIALE

N. 200185

Il presente brevetto viene concesso per l'invenzione oggetto della domanda sotto specificata:

N. DOMANDA	Anno
03475	86

Cod. Prov.	U.P.I.C.A.		CODICI	DATA PRES. DOMANDA G	M	A	H	M			P
37	BOLOGNA		21040	01	08	86	00	00	0	0	0

TITOLARE FOCCHI GIUSEPPE DI FOCCHI UGO & C.
S.P.A.
A RIMINI FO

TITOLO VETRATA COMPOSITA PER FACCIATE
CONTINUE DI CASE E PALAZZI

INV. DES. UGO FOCCHI

Roma, li – 5 GEN. 1989

IL DIRETTORE

Protocollo N. 3475 A/86

Registro A

UFFICIO PROVINCIALE DELL'INDUSTRIA DEL COMMERCIO E DELL'ARTIGIANATO DI BOLOGNA

Copia del Verbale di deposito della domanda di brevetto d'invenzione industriale

*L'anno 19*86 *il giorno* UNO *del mese di* AGOSTO

la Ditta FOCCHI GIUSEPPE DI FOCCHI UGO & C. S.P.A.

~~Signor~~ *di nazionalità* italiana *con sede* ~~residente~~ *a* RIMINI (FO)

Via Circonvallazione Ovest *n.* 9, *a mezzo mandatario* ING.MAURIZIO NARDI, ING.LUCIANO LANZONI *elettivamente domiciliato agli effetti di legge a* Bologna

Via Farini *n.* 37, *presso* BUGNION S.P.A.

ha presentato a me sottoscritto:

Domanda in bollo per la concessione di un **BREVETTO PER INVENZIONE INDUSTRIALE**

avente per TITOLO:

VETRATA COMPOSITA PER FACCIATE CONTINUE DI CASE E PALAZZI.

Inventore designato Sig. UGO FOCCHI

Priorità della domanda di brevetto/modello *depositata in* ......

il ...... *N.* ......

corredata di:

a) *descrizione in duplo di n.* 13 *pagine di scrittura;*

b) *disegni, tavole n.* una *in duplo;*

c) *lettera d'incarico* - ~~Dichiarazione riferimento ad Atto di procura~~;

d) ~~documento di priorità e traduzione italiana~~;

e) ~~autorizzazione o atto di cessione~~;

f) ~~dichiarazione di consenso dell'inventore per essere menzionato nel brevetto~~;

g) *allest. di vers. sul c/c post. n. 00668004 intestato all'Uffic. Registro per Tasse Concessioni Governative - Roma, di L.* 174.000= *emessa dall'Uff. Post. di Bologna* VR *il* 1/8/86 *n.* 314;

Per questa domanda viene presentata contemporanea domanda di eventuale Modello di Utilità n. 4956/B/86 Art.4 R.D. 25/08/40 N.1411

La domanda, le descrizioni ed i disegni sopra elencati sono stati firmati dal richiedente e da me controfirmati e bollati col timbro d'ufficio.

Copia del presente verbale è stata da me sottoscritta e consegnata alla parte interessata.

Il Depositante | **L'UFFICIALE ROGANTE**

F.to VALERIA LIPPARINI | *F.to* G. SANTOPIETRO

IL DIRETTORE (Dr. Giovanni Santopietro)

La presente copia è conforme all'originale.

Bologna, lì 1 AGOSTO 1986

(Spazio riservato all'Ufficio Centrale Brevetti)

3475A/86 - 1986

ON.LE MINISTERO INDUSTRIA COMMERCIO E ARTIGIANATO

UFFICIO CENTRALE BREVETTI - ROMA -

La richiedente FOCCHI GIUSEPPE DI FOCCHI UGO & C. S.P.A., di nazionalità italiana, in persona del Presidente, Sig. FOCCHI UGO, con sede in RIMINI (FO), Via Circonvallazione Ovest, 9 ed elettivamente domiciliata in BOLOGNA, Via Farini, 37 presso i mandatari ING. MAURIZIO NARDI, ING. LUCIANO LANZONI C/O BUGNION S.P.A., fa domanda di un attestato di brevetto per INVENZIONE INDUSTRIALE dal titolo:

VETRATA COMPOSITA PER FACCIATE CONTINUE DI CASE E PALAZZI.

Per questa Invenzione si designa quale Inventore il Sig. FOCCHI UGO, di nazionalità italiana, nato a RIMINI il 01/05/1924 ed ivi residente, in Via Roma, 40.

Per questa domanda viene presentata contemporanea domanda di eventuale Modello di Utilità N. 49568/86 Art. 4 R.D. 25/08/40 N. 1411.

Altresì si richiede che, in considerazione della particolare complessità di valutazione del tipo di tutela brevettuale spettante alla domanda in oggetto, l'esame delle rispettive divisioni Invenzioni e Modelli venga effettuato collegialmente, al fine di un maggiore, reciproco contributo alla valutazio

COR

ne medesima.

A tale scopo, si allegano:

1) descrizione del trovato, in duplo, di n. 13 pagine di scrittura;

2) n. 1 tavola di disegni, in duplo;

3) lettera d'incarico;

4) attestazione versamento c/c postale N.00668004 di Lit. 174.000.=.

Bologna, 01/08/1986

In Fede

I Mandatari

Ing. Luciano LANZONI
ALBO - prot. n. 217

Ing. Maurizio NARDI
ALBO - prot. n. 288

UFFICIO PROVINCIALE INDUSTRIA
COMMERCIO ARTIGIANATO - BOLOGNA
VISTO: L'Ufficiale Rogante
(Dr. Giovanni Santopietro)

61/MN/LC
F3253.12/42.IT.2

3475 A/86

UFFICIO PROVINCIALE INDUSTRIA COMMERCIO E ARTIGIANATO DI BOLOGNA UFFICIO BREVETTI L'IMPIEGATO

DESCRIZIONE

annessa a domanda di brevetto per INVENZIONE INDUSTRIALE dal titolo:

VETRATA COMPOSITA PER FACCIATE CONTINUE DI CASE E PALAZZI.

a nome: **FOCCHI GIUSEPPE di FOCCHI UGO & C. S.p.A.**, di nazionalità italiana, con sede in Rimini (FO), Via Circonvallazione Ovest, 9;

Inventore Designato: Sig. FOCCHI UGO;

i Mandatari: Ing. Maurizio NARDI - Ing. Luciano LANZONI c/o BUGNION S.p.A., Via Farini, 37, 40124 BOLOGNA.

Depositata il 1 AGO. 1986 al N.

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Ing. Maurizio NARDI
Albo - prot. n. 288

RIASSUNTO

La vetrata composita secondo il presente trovato prevede che i telai (32) di ogni vetrata (1), corredata da un vetro esterno (15) ed uno interno (24), portino una guarnizione periferica (18) di tenuta a contatto con una guarnizione (8) sostenuta dal reticolo di facciata (31) a copertura della sua zona più esterna, e prevede altresì che il vetro interno (24) sia apribile rispetto al vetro esterno (15) e che al telaio (32) di ciascuna vetrata (1) sia associato un elemento tubolare (30) sviluppantesi dal basso per una lunghezza tale da impedire alla pioggia di penetrare nel vano compreso tra i vetri interno (24) ed

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esterno (15) della relativa vetrata (1) indipendentemente dalla violenza del vento.

* * * * *

DESCRIZIONE

Forma oggetto del presente trovato una vetrata composita per facciate continue di case e palazzi, detta vetrata composita essendo costituita da una pluralità di vetrate supportate da un reticolo di facciata associato alla struttura portante del palazzo, ciascuna vetrata essendo costituita da un vetro interno e da un vetro esterno sostenuti da un telaio supportato in modo apribile dal detto reticolo di facciata.

É perfettamente noto l'impiego di siffatte vetrate per la costruzione delle pareti esterne dei moderni palazzi onde consentire una maggiore luminosità interna.

Tali vetrate devono soddisfare contemporaneamente diverse esigenze, quali l'isolamento termico ed acustico ed il fatto di non creare fenomeni di condensa.

Il problema dell'isolamento termico ed acustico viene parzialmente risolto prevedendo l'impiego di vetri-camera, cioè di coppie di vetri monolitici tra i quali viene praticamente prodotto il vuoto.

In realtà, il problema non viene risolto completamente poichè il reticolo di facciata che sostiene le singole vetrate è di materiale metallico, solitamente

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Ing. Maurizio NARDI
ALBO - prot. n. 283

alluminio in quanto più resistente alla corrosione, e vi erano zone a contatto sia con l'ambiente interno che con quello esterno così da costituire un ponte termico tra gli stessi ambienti.

Il problema della condensa viene solitamente risolto parzialmente predisponendo dei sali igroscopici nella zona compresa tra il vetro interno e quello esterno prima dell'assemblaggio della vetrata stessa.

Per risolvere in modo più efficace questo problema della condensa, la stessa Richiedente ha proposto, in una sua precedente Domanda di Brevetto, di prevedere, alla base di ciascuna vetrata singola, dei canali di comunicazione con l'esterno della zona tra i vetri interno ed esterno, così da consentire una certa aerazione in tale zona.

Questi canali sono stati ora ulteriormente migliorati con modifiche strutturali e dimensionali opportune, al fine di inibire anche in situazioni atmosferiche estreme qualsiasi infiltrazione di umidità.

Un altro problema riscontrato dalle vetrate composite note è quello della impossibilità di pulizia della superficie interna dei vetri interno ed esterno poichè gli stessi sono solidali ad uno stesso telaio.

Lo scopo del presente trovato è pertanto quello di eliminare gli inconvenienti ora menzionati. Il trovato,

Ing. Maurizio NARDI
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quale esso è caratterizzato dalle rivendicazioni, risolve il problema affrontato.

Uno dei vantaggi qui presenti, consiste essenzialmente nella possibilità di interrompere il ponte termico tra ambiente esterno ed ambiente interno.

Un altro vantaggio del presente trovato è la praticità della vetrata composita proposta che prevede l'accesso alla zona compresa tra i vetri interno ed esterno di ciascuna vetrata singola per la pulizia degli stessi.

Particolarmente vantaggioso risulta l'aver previsto, in corrispondenza di un lato verticale di ciascuna vetrata singola, un elemento tubolare obliquo di lunghezza tale da impedire l'ingresso di pioggia nella zona compresa tra i vetri interno ed esterno indipendentemente dalla violenza del vento.

Un ulteriore vantaggio ancora del presente trovato è la sua sicurezza conseguente all'aver previsto che il collante, oltre ad essere insensibile ai raggi ultravioletti, sia anche completamente protetto dalla atmosfera e pertanto completamente isolato.

Il trovato è esposto più in dettaglio nel seguito con l'aiuto del disegno allegato che ne rappresenta una forma di realizzazione puramente esemplificativa e non limitativa in vista prospettica con alcune parti asportate ed altre sezionate per viasualizzarne altre ancora.

La vetrata composita è costituita da una serie di vetrate singole 1 vincolate ad un reticolato di facciata 31 solidale alla struttura portante del palazzo al quale viene applicata la vetrata composita.

Ciascuna vetrata 1 è costituita da un vetro interno 24, e da un vetro esterno 15 reciprocamente vincolati da un telaio 32.

Ciascun telaio 32 è supportato dal reticolo di facciata 31 e può risultare apribile verso l'esterno a mezzo di opportuni accessori.

Il reticolo di facciata 31 della vetrata secondo il presente trovato viene ricavato da una coppia di profilati a "T" 2 e 3.

Tali profilati 2 e 3 presentano, in corrispondenza della estremità libera del tratto verticale 4 ed in corrispondenza dei bracci orizzontali 5 della loro conformazione a "T", delle sedi 6 e rispettivamente 7 longitudinali ed aperte verso l'esterno del palazzo. Le sedi 6 e 7 sono destinate ad impegnare relative guarnizioni 8 e 9, la prima delle quali, associata alla estremità libera del tratto verticale 4 della conformazione a "T" dei profilati 2 e 3, ha una larghezza pari almeno alla larghezza di tale tratto verticale 4 così da coprirlo completamente.

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Il telaio 32 delle vetrate singole 1 viene ricavato da un profilato 10 od 11 rettangolari allungati.

Il primo è destinato a costituire il supporto della vera e propria vetrata 1, il secondo è usato per l'accoppiamento con pannelli 12 isolanti dell'interno -vano, al posto del vetro interno 24.

In corrispondenza di un loro lato longitudinale più stretto, i profilati 10 ed 11 presentano una sede longitudinale 13 di impegno di una guarnizione di tenuta 14 a battuta contro il vetro esterno 15. I profilati 10 ed 11 comportano anche, a partire da questa sede 13, un'ala 16 definente una sede 17 di impegno di una relativa guarnizione di tenuta 18 a battuta contro la guarnizione 8 portata dai profilati 2 e 3.

Le superfici di contatto reciproco delle guarnizioni 8 e 18 sono frontali e longitudinalmente e corrispondentemente dentellate così da aumentare la loro superficie di contatto per una migliore tenuta.

Il lato longitudinale opposto del profilato 10 od 11 è a battuta contro la guarnizione 9 portata dal reticolo di facciata 31.

La guarnizione 18 si prolunga verso l'esterno fino a contatto col bordo del vetro esterno 15. La guarnizione 18 definisce, in combinazione con la guarnizione 14, l'ala 16 ed il vetro esterno 15, un vano nel quale viene introdotto del collante 19 insensibile ai raggi ultravioletti destinato a rendere il vetro esterno 15 solidale al relativo telaio 32. Ovviamente, il materiale delle guarnizioni 14 e 18 è compatibile col collante 19 che, ad esempio, è costituito da silicone strutturale.

I profilati 10 ed 11 differiscono per il fatto che il primo comporta un'ala 20 dotata di una sede 21 per una guarnizione di tenuta 22 come si vedrà meglio in seguito. Il profilato 11 presenta invece, in corrispondenza dello stesso lato, due alette 25 di contenimento e trattenimento del pannello isolante 12.

Il vetro interno 24 di ciascuna vetrata singola 1 è sostenuto, conformemente al presente trovato, da un rispettivo telaio 23 ricavato da un profilato tubolare 26 che definisce altresì una sede 27 nella quale trova alloggiamento il vetro interno 24. La dimensione della sede 27 è tale che essa può alloggiare un vetro interno 24 di tipo monolitico o di tipo vetro-camera con relative guarnizioni di tenuta. Il profilato 26 di uno dei montanti del telaio 23 è attraversato da una coppia di perni di rotazione coassiali 28 associati a rispettivi angolari 29 utilizzati per vincolare reciprocamente i profilati 10 del telaio 32 al quale il telaio 23 è associato. I perni di rotazione 28 vengono posizionati in modo che il telaio 23, nella sua configurazione in cui il vetro interno 24 è chiuso, sia a contatto con la guarnizione di tenuta 22.

Su un lato verticale di ciascun telaio 32 è previsto un elemento tubolare 30 di materiale compatibile col collante 19 sfociante entro il vano delimitato dai vetri interno 24 ed esterno 15 e dal relativo telaio 32.

Sull'altro lato verticale di ciascun telaio 31 e diagonalmente opposto, è disposto un ulteriore elemento tubolare 30, per favorire al meglio il movimento convettivo all'aria.

L'elemento tubolare 30 è obliquo verso l'alto ed attraversa le guarnizioni 14 e 18 ed il collante 19. La lunghezza di questo elemento tubolare 30 viene scelta in modo che la pioggia non sia in grado di risalirlo interamente fino ad entrare nel detto vano delimitato dai vetri interno 24 ed esterno 15 e dal relativo telaio 32 qualunque sia la violenza del vento.

In corrispondenza della sua estremità esterna ed inferiore, l'elemento tubolare 30 è provvisto di un reticolo 33 capace di impedire l'ingresso degli insetti entro lo stesso elemento tubolare 30.

Nella figura allegata non sono stati illustrati per semplicità (in quanto di applicazione nota) gli elementi utilizzati per l'apertura dei telai 32 e per la chiusura dei telai 23.

La vetrata composita secondo il presente trovato qui

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Ing. Maurizio NARDI
ALBO - prot. n. 288

descritta raggiunge perfettamente gli scopi prefissatisi, in particolare:

- il ponte termico tra ambiente esterno ed ambiente interno viene abbattuto per il fatto che, a vetrate 1 chiuse, nessun profilato è a contatto con l'ambiente esterno;

- il collante 19 è egregiamente protetto dall'aria in quanto contenuto in un vano chiuso definito dalle guarnizioni 14 e 18, dal vetro esterno 15 e dall'ala 16 dei profilati 10 ed 11;

- vengono impediti fenomeni di condensa nel vano compreso tra il vetro esterno 15 e quello interno 24 grazie alla presenza dell'elemento tubolare 30 comunicante con l'esterno per mantenere l'aria contenuta nel medesimo vano alla stessa temperatura di quella esterna. Inoltre, questo elemento tubolare 30 ha una lunghezza tale da impedire l'ingresso della pioggia in questo vano indipendentemente dalla violenza del vento;

- il vetro interno 24 può essere aperto rispetto al telaio 32 di ciascuna vetrata singola 1 così da consentire l'ispezione e quindi la pulizia del vano compreso tra il vetro interno 24 e quello esterno 15.

Il trovato così concepito è suscettibile di numerose modifiche e varianti, tutte rientranti nell'ambito del concetto inventivo. Inoltre, tutti i dettagli possono essere sostituiti da elementi tecnicamente equivalenti.

RIVENDICAZIONI

1. Vetrata composita per facciate continue di case e palazzi, del tipo costituita da una pluralità di vetrate (1) supportate da un reticolo di facciata (31) associato alla struttura portante del palazzo, ciascuna vetrata (1) essendo costituita da un vetro interno (24) e da un vetro esterno (15) sostenuti da un telaio (32) supportato in modo apribile dal detto reticolo di facciata (31), **caratterizzata dal fatto** che il detto vetro interno (24) di ciascuna vetrata (1) è sostenuto da un proprio telaio (23) articolato al detto telaio (32) della rispettiva vetrata (1) attraverso perni di articolazione (28) e **dal fatto** che ciascun detto telaio (32) delle dette vetrate (1) è dotato di una guarnizione di tenuta perimetrale (18) destinata a fare battuta contro una guarnizione frontale di tenuta (8) associata al detto reticolo di facciata (31) ed è altresì dotato di almeno una coppia di elementi tubolari (30), disposti a quota diversa e sviluppantisi dal basso verso l'alto all'interno del vano compreso tra i detti vetri interno (24) ed esterno (15) e di lunghezza tale da impedire comunque l'ingresso della pioggia o dell'umidità nella zona compresa tra i detti vetri interno (24) ed esterno (15); ciascun detto vetro esterno (15) essendo vincolato al rispettivo detto

telaio (32) tramite un collante (19) insensibile ai raggi ultravioletti ed isolato dall'esterno attraverso dette guarnizioni perimetrali 18.

2. Vetrata composita secondo la rivendicazione 1, **caratterizzata dal fatto** che il detto telaio (32) di ciascuna vetrata (1) è dotato internamente di una sede (21) di impegno di un guarnizione di tenuta (22) a battuta contro il detto telaio (23) del relativo detto vetro interno (24) ed è destinato a riscontrare una seconda guarnizione di tenuta (9) vincolata frontalmente al detto reticolo di facciata (31).

3. Vetrata composita secondo la rivendicazione 1, **caratterizzata dal fatto** che il detto telaio (32) di ciascuna vetrata (1) è dotato anteriormente di un sede (13) di impegno di una relativa guarnizione di tenuta (14) destinata a riscontrare il relativo vetro esterno (15) ed a definire, in combinazione con l'altra detta guarnizione di tenuta perimetrale (18) sostenuta dal medesimo telaio (32), con quest'ultimo e col relativo detto vetro esterno (15), una camera anulare di contenimento del detto collante (19) insensibile ai raggi ultravioletti.

4. Vetrata composita secondo la rivendicazione 1, **caratterizzata dal fatto** che il detto telaio (23) di supporto del detto vetro interno (24) viene ricavato da un profilato tubolare (26) definente una sede (27) di impegno del

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detto vetro interno (24), uno dei detti profilati tubolari (26) essendo liberamente attraversato dai detti perni di rotazione (28).

5. Vetrata composita secondo la rivendicazione 1, **caratterizzata dal fatto** che ciascun detto elemento tubolare (30) è dotato, in corrispondenza della sua estremità di ingresso, di un elemento reticolare (33) atto ad impedire l'ingresso degli insetti e di impurità nella zona compresa tra i detti vetri interno (24) ed esterno (15).

6. Vetrata composita secondo la rivendicazione 1, **caratterizzata dal fatto** che le superfici di reciproco contatto della detta guarnizione di tenuta (18) sostenuta dai detti telai (32) delle dette vetrate (1) e della detta guarnizione di tenuta (8) sostenuta dal detto reticolo di facciata (31) sono corrispondentemente dentellate a costituire una maggiore superficie di contatto.

7. Vetrata composita secondo la rivendicazione 1, **caratterizzata dal fatto** che il detto elemento tubolare (30) è di materiale compatibile col detto collante (19) insensibile ai detti raggi ultravioletti.

8. Vetrata composita secondo la rivendicazione 1, **caratterizzata dal fatto** che il detto vetro interno (24) è un vetro-camera.

9. Vetrata composita secondo le rivendicazioni precedenti e secondo quanto descritto ed illustrato con

riferimento alla figura dell'unito disegno e per gli accennati scopi.

Bologna, 31/07/86

In fede

Il Mandatario

Ing. Maurizio NARDI

ALBO - prot. n. 283

UFFICIO PROVINCIALE INDUSTRIA COMMERCIO E ARTIGIANATO DI BOLOGNA
UFFICIO BREVETTI
L'IMPIEGATO

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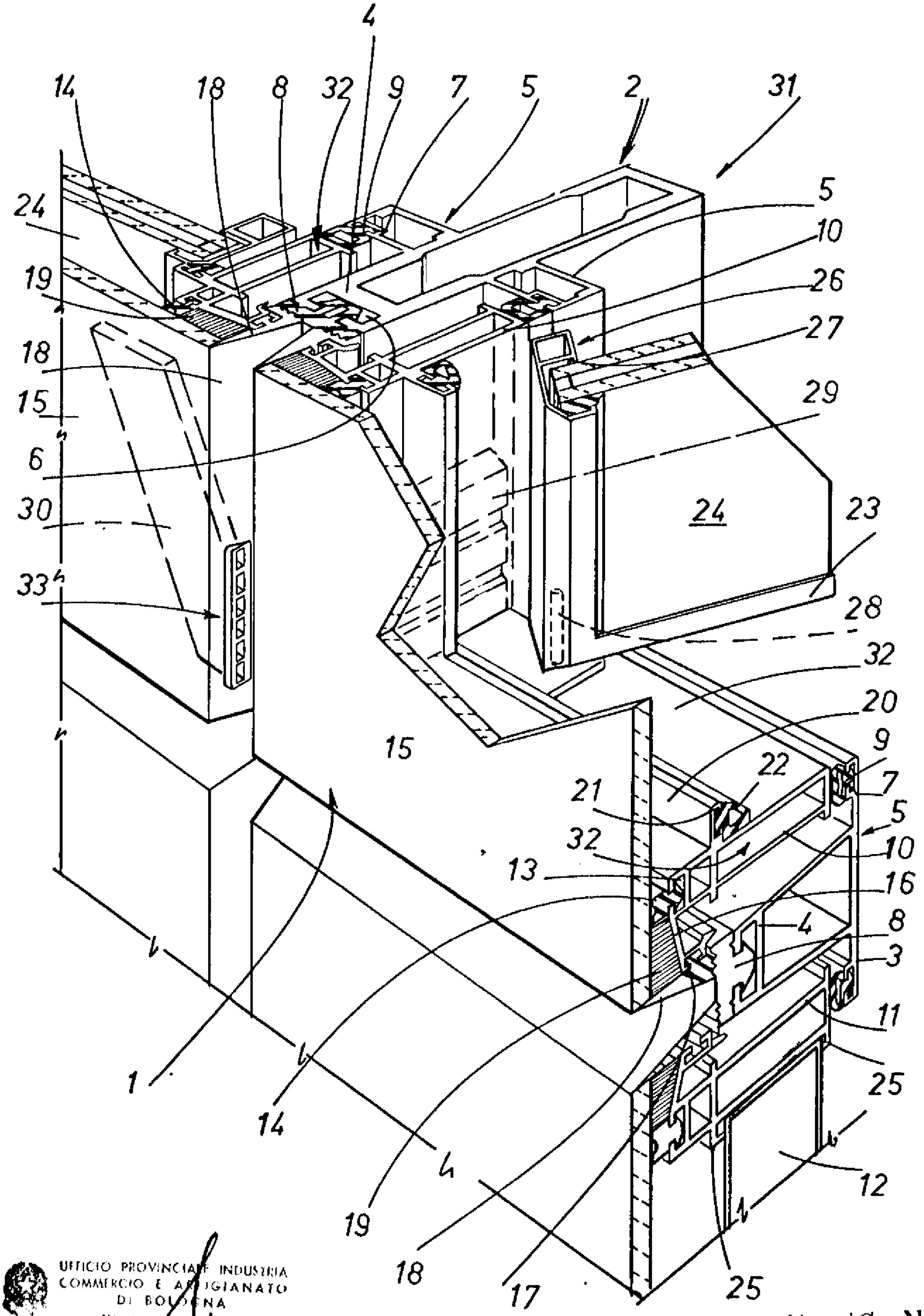


Ing. Maurizio NARDI
ALBO - prot. n. 288

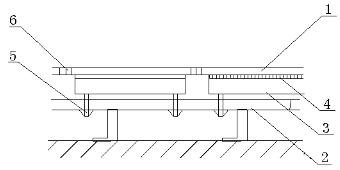
ANNEX 4

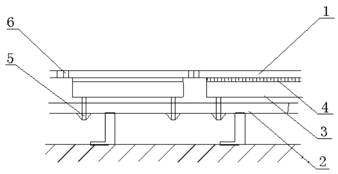
Aluminum alloy thermal insulation curtain wall and manufacturing process thereof

CN103206036

- **Patent Assignee**
  CHENGDU SUNSHINE ALUMINIUM
- **Inventor**
  LIAO JIAN
- **International Patent Classification**
  E04B-002/90; E04B-002/92; E04G-021/00
- **Publication Information**
  CN103206036 A 2013-07-17 [CN103206036]
- **Priority Details**
  2013CN-0101736 2013-03-27
- **Fampat family**
  CN103206036 A 2013-07-17 [CN103206036]

- **Abstract:**
  (CN103206036)
  The invention discloses an aluminum alloy thermal insulation **curtain wall** and a manufacturing process thereof. The aluminum alloy thermal insulation **curtain wall** comprises glass (1) and an aluminum alloy **frame** system (2). The aluminum alloy **frame** system (2) is fixed on the surface of a building outer wall. The glass (1) is adhered to the surface of a glass **frame** (3) through structural **adhesives**. The glass **frame** (3) is fixedly mounted on the aluminum alloy **frame** system (2) through bolts (5). Rubber strips (6) for sealing and damping are mounted on the periphery of the glass (1). The manufacturing process includes: manufacturing thermal insulation section bars; manufacturing the glass **frame**; adhering the glass; and mounting the **frame** system and the glass **frame**. The glass is double-layer hollow coated glass, so that solar radiation, far-infrared radiation, and heat transfer inside and outside a building are reduced effectively. The glass **frame** is made of honeycomb aluminum alloy thermal insulation section bars which are lightweight, high in hardness and capable of forming a continuous thermal insulation area inside and outside the building, and accordingly thermal insulation effect of the glass **curtain wall** is enhanced greatly.





English Claims:

(CN103206036)

(Claims machine translated from Chinese)

1. The aluminum alloy heat insulation heat preservation curtain wall, its characteristic lies in: It including the glass (1) and aluminum alloy Sash system (2), the aluminum alloy Sash system that states (2) fixes in the building outer wall surface, the glass (1) through the structure rubber (4) glue in the instrument bezel (3) surface, the instrument bezel (3) through the bolt (5) fixed installment in the aluminum alloy Sash system (2), the glass (1) all around is loaded with peacefully for sealing the absorption of shock rubber strip (6).

2. The aluminum alloy heat insulation heat preservation curtain wall that according to claim 1 station, its characteristic lies in: Glass that stated for double-decked midheaven coating glass.

3. The aluminum alloy heat insulation heat preservation curtain wall that according to claim 1 station, its characteristic lies in: Structure rubber that stated for silicone sealant.

4. The aluminum alloy heat insulation heat preservation curtain wall that according to claim 1 station, its characteristic lies in: Instrument bezel that stated for the honeycomb aluminum alloy heat insulation Duanqiao molding.

5. The aluminum alloy heat insulation heat preservation curtain wall that according to claim 1 station, its characteristic lies in: The rubber strip that stated was the [Sanyuanyibing] rubber.

6. The aluminum alloy heat insulation heat preservation curtain wall and fabrication technology, its characteristic lies in: It including the following step:

S1: System heat insulation Duanqiao molding: The aluminum alloy ingot casting hewing dowel, 560.deg.C maintains 4.5h the dowel uniformization preheating temperature, then carries on the extrusion manufacture honeycomb aluminum sheet on the extrusion unit, makes the heat insulation Duanqiao molding the honeycomb aluminum sheet;

S2: Makes the instrument bezel: Takes heat insulation Duanqiao molding system instrument bezel that the step S1 system results in;

S3: Glue glass: With the structure rubber the glass glue on the instrument bezel, and installs long the rubber strip, the rubber strip length compared to the frame notch around the glass 1.5% to 2%;

S4: Installs Sash system: Installs the aluminum alloy Sash system in the construction periphery;

S5: Installment instrument bezel: Fixes the instrument bezel in the aluminum alloy Sash system that on the wall the vertical post and cross rod compose and ensure the same plane the glass smoothness must control in 3mm, the caulked joint width error also controls in 2mm.

Description:

(CN103206036)
(Description machine translated from Chinese)
Aluminum alloy heat insulation heat preservation curtain wall and fabrication technology
Area of technology
This invention involves one kind of aluminum alloy heat insulation heat preservation curtain wall and fabrication technology.
Background technology
The glass curtain wall becomes the metal frame by other aluminum alloys or light quality metal rollings, prefabricates the module with the function glass, then installs fixedly in the construction periphery's structural support, construction enclosure or decoration structure that forms. The glass curtain wall forms the smooth big area continual wall in the construction periphery, what because uses is the coating glass, therefore cannot see behind from outside the glass, can only see the big area mirror surface effect that the entire wall forms, forms very beautiful one side big mirror, maps the sky and environment's scenery, when ray change, the phantom is colorful, countless changes, very artistic novel, under the reflection of ray, the indoor was not shone by the glare, the vision is gentle, it will construct esthetics, the building function, the construction structure and other factor organic unifications, is the modernism high-rise construction time dominant character. But glass curtain wall heat insulation heat preservation difference, in the cold winter, indoor temperature is higher than outdoor temperature, therefore indoor quantity of heat transmits fast after the glass curtain wall's aluminum alloy molding and glass outside, causes the indoor temperature to drop suddenly, in the burning hot summer, outdoor temperature is higher than the indoor temperature, the aluminum alloy molding's heat transfer effect is obvious, the indoor temperature promotion is also quick, to guarantee indoor has a comfortable environment, the people have to open the air-conditioning system to come to the temperature to adjust, causes the glass curtain wall construction the air conditioning energy consumption to be huge.
Invention content
This invention's point lies in overcomes the existing technical the insufficiency, provides one kind of glass for the double-decked midheaven coating glass, reduced the solar radiation and far infrared effectively radiates as well as constructs the inside and outside heat transfers, the instrument bezel for the honeycomb aluminum alloy heat insulation Duanqiao molding, the quality light degree of hardness is high, and can form a continual heat insulation area inside and outside the building, greatly strengthened the glass curtain wall heat insulation heat preservation effect aluminum alloy heat insulation heat preservation curtain wall and fabrication technology.
Goal of this invention approves the following technical program to realize: Aluminum alloy heat insulation heat preservation curtain wall, it including the glass and aluminum alloy Sash system, the aluminum alloy Sash system that states fixes in the building outer wall surface, the glass through the structure rubber glue in the instrument bezel surface, the instrument bezel through the bolt fixed installment in the aluminum alloy Sash system, around the glass is loaded with peacefully for sealing the absorption of shock rubber strip.
Glass that stated for double-decked midheaven coating glass.
Structure rubber that stated for silicone sealant.
Instrument bezel that stated for the honeycomb aluminum alloy heat insulation Duanqiao molding.
The rubber strip that stated was the [Sanyuanyibing] rubber.
Aluminum alloy heat insulation heat preservation curtain wall and fabrication technology, its characteristic lies in: It including the following step:
S1: System heat insulation Duanqiao molding: The aluminum alloy ingot casting hewing dowel, 560.deg.C maintains 4.5h the dowel uniformization preheating temperature, then carries on the extrusion manufacture honeycomb aluminum sheet on the extrusion unit, makes the heat insulation Duanqiao molding the honeycomb aluminum sheet;
S2: Makes the instrument bezel: Takes heat insulation Duanqiao molding system instrument bezel that the step S1 system results in;
S3: Glue glass: With the structure rubber the glass glue on the instrument bezel, and installs long the rubber strip, the rubber strip length compared to the frame notch around the glass 1.5% to 2%;
S4: Installs Sash system: Installs the aluminum alloy Sash system in the construction periphery;
S5: Installment instrument bezel: Fixes the instrument bezel in the aluminum alloy Sash system that on the wall the vertical post and cross rod compose and ensure the same plane the glass smoothness must control in 3mm, the caulked joint width error also controls in 2mm.
The beneficial effect of this invention is:
(1) the glass of this invention for the double-decked midheaven coating glass, in the glass the dead level can effectively reduce the hot heat transfer coefficient, the glass coating level can limit the solar

radiation and far infrared heat radiation effectively, reduced the solar radiation and far infrared effectively radiates as well as constructs the inside and outside heat transfers;
(2) not only this invention's instrument bezel for the honeycomb aluminum alloy heat insulation Duanqiao molding, the honeycomb aluminum material the quality light degree of hardness is high. Moreover the heat insulation heat preservation performance is very strong, the heat insulation Duanqiao structure can form a continual heat insulation area inside and outside the building, its 0.3W/(*K) heat transfer coefficient by far is smaller than the ordinary aluminum alloy 210W/(*K) heat transfer coefficient, greatly strengthened the glass curtain wall heat insulation heat preservation effect.
Attached figure explanation
Figure 1 is this invention structure schematic drawing;
In chart, 1- glasses, 2- aluminum alloy Sash systems, 3- instrument bezels, 4- structure rubber, 5- bolts, 6- rubber strip.
Implements the way specifically
Following further in detail described the technical program of this invention in light of the attached figure:
As shown in Figure 1, the aluminum alloy heat insulation heat preservation curtain wall, it including the glass 1 and aluminum alloy Sash system 2, the aluminum alloy Sash system that states 2 fixes in the building outer wall surface, the glass 1 through the structure rubber 4 glues in the instrument bezel 3 surfaces, the instrument bezel 3 through the bolt 5 fixed installments in the aluminum alloy Sash system 2, the glass 1 all around is loaded with peacefully for sealing the absorption of shock rubber strip 6.
The glass that stated 1 was the double-decked midheaven coating glass.
The structure rubber that stated 4 were the silicone sealants.
The instrument bezel that stated 3 were the honeycomb aluminum alloy heat insulation Duanqiao moldings.
The rubber strip that stated 6 were the [Sanyuanyibing] rubbers.
Aluminum alloy heat insulation heat preservation curtain wall and fabrication technology, its characteristic lies in: It including the following step:
S1: System heat insulation Duanqiao molding: The aluminum alloy ingot casting hewing dowel, 560.deg.C maintains 4.5h the dowel uniformization preheating temperature, then carries on the extrusion manufacture honeycomb aluminum sheet on the extrusion unit, makes the heat insulation Duanqiao molding the honeycomb aluminum sheet;
S2: Makes the instrument bezel: Takes heat insulation Duanqiao molding system instrument bezel that the step S1 system results in;
S3: Glue glass: With the structure rubber the glass glue on the instrument bezel, and installs long the rubber strip, the rubber strip length compared to the frame notch around the glass 1.5% to 2%;
S4: Installs Sash system: Installs the aluminum alloy Sash system in the construction periphery;
S5: Installment instrument bezel: Fixes the instrument bezel in the aluminum alloy Sash system that on the wall the vertical post and cross rod compose and ensure the same plane the glass smoothness must control in 3mm, the caulked joint width error also controls in 2mm.

CN102953466

- **Patent Assignee**
  SHANGHAI MEITE CURTAIN WALL

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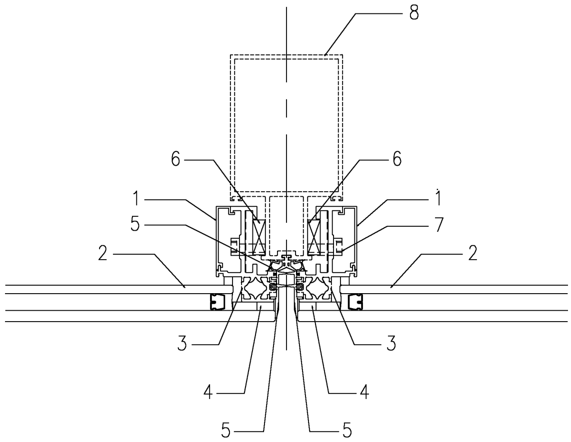
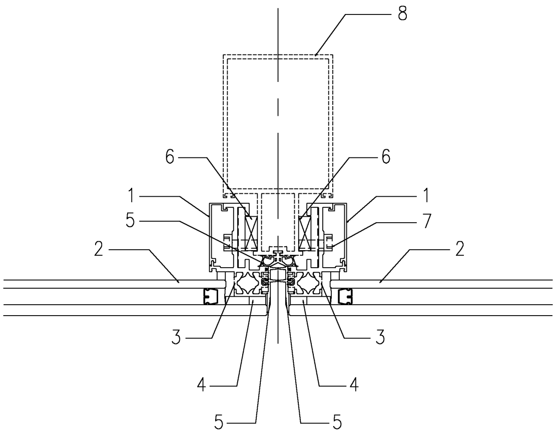
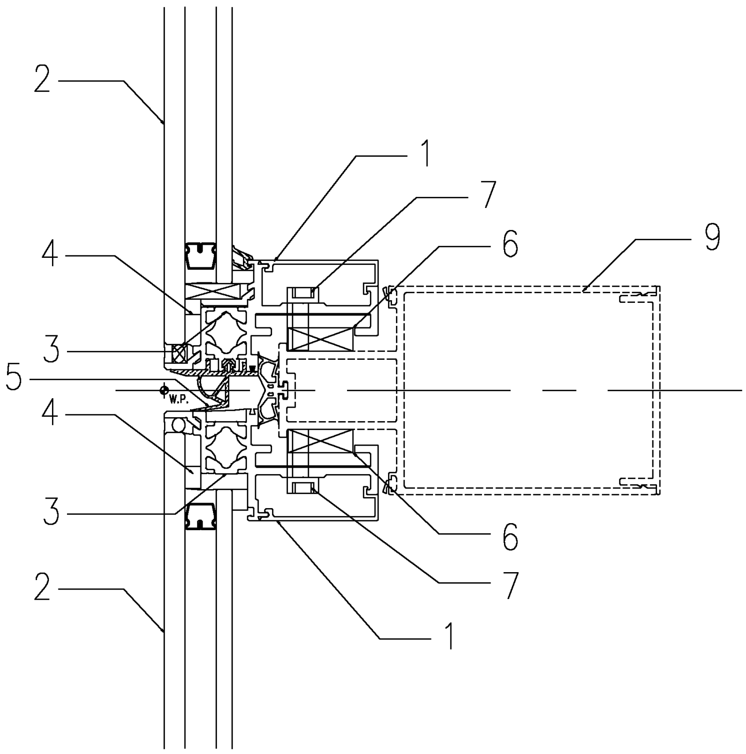
- **Fampat family**
  CN102953466 A 2013-03-06 [CN102953466]

- **Abstract:**
  (CN102953466)
  The invention relates to a half-unit **curtain wall** system which comprises glass, structural **adhesives**, an auxiliary **frame**, a mullion, a transom and fasteners. The glass is connected with the auxiliary **frame** through the structural **adhesives**, and the auxiliary **frame** is connected with the mullion or the transom through the fasteners. Compared with the prior art, the half-unit **curtain wall** system has the advantages of novel connection mode, convenience and rapidness in mounting and maintenance, high tightness and high adaptability and the like.



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English Claims:

(CN102953466)

(Claims machine translated from Chinese)

1. 1-and-a-half unit curtain wall system, including glass, structure rubber, vice-frame, vertical stroke material and cross member, its characteristic in
In, but also includes the card buckle, the glass that states connects the vice-frame through the structure rubber, the vice-frame that states connects the vertical material through the card buckle
Or cross member.

2. One-and-a-half unit curtain wall system that according to claim 1 station, its characteristic lies, the card that states buckles one
The end fixes through the bolt between vice-frame and vertical stroke material or cross member, another end may circle the bolt rotation, causes the vice-frame card to meet in the vertical stroke
On the material or the cross member locks, or rotation unlocking.

3. One-and-a-half unit curtain wall system that according to claim 1 station, its characteristic lies, the vice-frame that states is
Aluminum alloy molding board unit vice-frame.

4. One-and-a-half unit curtain wall system that according to claim 1 station, its characteristic lies, structure rubber that states
Including establishing with vice-frames, cakes the vice-frame and glass two-sided block glues in glass's heat insulation strip, with establishing is neighboring
[Sanyuanyibing] rubber between glasses and vice-frames.

5. One-and-a-half unit curtain wall system that according to claim 1 station, its characteristic lies, glass package that states
Includes the midheaven glass, the armored glass, the doubling glass or the wire-reinforced glass.

Description:

(CN102953466)
(Description machine translated from Chinese)
One-and-a-half unit curtain wall system
Area of technology
This invention involves one curtain wall system, particularly involves one-and-a-half unit curtain wall system.
Background technology
Along with the development of repair industry, curtain wall more and more widely served as the exterior envelope of building, the curtain wall installment
Conveniently and quickly, as well as the security reliability of structure also more and more brings to the attention of people. Traditional curtain wall system
Mainly has frame and unit two structural styles. The frame curtain wall system architecture is simple, the construction is convenient,
But the majority of work proceed at the scene, the processing and assembly quality are hard to guarantee, among the tectonic plates the slit place must hit the rubber, the curtain wall
Constructs by the limit of climatic conditions, compatible insufficient. The unit curtain wall will process various good kind of constructions in the workshop
After the middle and facing material assembles, transports carries on the integral hoisting to the work site, the majority works in the factory carries on, can guarantee
Card processing and assembly quality, and may the arrangement construction plan, can greatly reduce the time, but because the glass tectonic plate is heavy
The quantity is big, in lifting and installment to construction process proposed very high request, needs special-purpose lifting and installs peacefully
Prepares, and cost is high.
Invention content
Goal of this invention is provides one connection mode to be new for the flaw that to overcome the above existing technology has
Ying, the installment service convenience, leak-proof quality is quickly good, compatible strong half unit curtain wall system.
Goal of this invention may approve the following technical program to realize: One-and-a-half unit curtain wall system, including glass,
The structure rubber, the vice-frame, the vertical stroke material and cross member, its characteristic lies, but also includes the card buckle, the glass that states passes the structure joined together
Meets the vice-frame, the vice-frame that states buckles the connection to set upright the material or the cross member through the card.
The card that stated buckled an end to fix through the bolt between the vice-frame and vertical stroke material or the cross member, another end may circle the bolt extension
Moves, causes the vice-frame card to meet in setting upright on the material or the cross member locks, or rotation unlocking.
Vice-frame that stated for aluminum alloy molding board unit vice-frame.
The structure rubber that stated including establishing with vice-frames, caked the vice-frame and glass two-sided rubber in glass's heat insulation strip
Strip, with establishing and vice-frames in neighboring the [Sanyuanyibing] rubber between glasses.
Glass that stated including midheaven glass, armored glass, doubling glass or wire-reinforced glass.
Compares with the existing technology, this invention has the following merit:
(1) the installment and service convenience are quick, when may realize the disorderly installment, the service, may carry on the indoor alone
Trades the slab, and slab interchangeable;
(2) the leak-proof quality is good, uses the [Sanyuanyibing] rubber strip to carry on the seal, the waterproof performance enhancement of curtain wall;
(3) compatible, the curtain wall construction was not affected by the climate;
(4) the construction efficiency is high, saves cost.
Attached figure explanation
Figure 1 is this invention sets upright the material department to divide in half the unit curtain wall system structure schematic drawing;
Figure 2 is this invention cross member department divides in half the unit curtain wall system structure schematic drawing.
Implements the way specifically
Following carries on the detail to this invention in light of the attached figure and concrete

implementation example.
Implementation example
As shown in Figure 1, one-and-a-half unit curtain wall system, including midheaven glass 2, structure rubber and vice-frame 1, vertical material
8 and cross member 9, but also includes the card to buckle 6, the vice-frame 1 is the traditional aluminum alloy molding board unit vice-frame, the structure rubber is the biography
Series structure rubber, including establishing 1 3, cakes the vice-frame with the vice-frame 2 between heat insulation strip in the midheaven glass 2 and midheaven
Glass 2 two-sided block glues 4, with establishing in neighboring midheaven glass 2 and vice-frame 1 [Sanyuanyibing] rubber 5. Institute
Midheaven glass that stated 2 connected the vice-frame through the structure rubber 1, the vice-frame that states 1 buckled 6 to connect the vertical material through the card 8.
The card that stated buckled a 6 end 7 to fix through the bolt in the vice-frame 1 with setting upright the material eights, another end may circle the bolt 7
The rotation, causes vice-frame 1 calorie to meet in setting upright the material 8 on locks, or the rotation unlocking, the installment and service convenience are quick.
As shown in Figure 2, cross member 9 high and low buckle 6 calories to meet the aluminum alloy molding vice-frame through the card respectively 1, vice-frame 1 through knot
Construction rubber caking midheaven glass 2.
The above vertical stroke material part and cross member in the traditional frame curtain wall system's foundation, pass the glass partially the vice-frame
Or the vertical material connection with the cross member, its connection mode is novel, only needs to take away the machinery through the card fixedly then, installs the side
Then when quickly, may realize disorderly installment, the service, may carry on the indoor alone with trading half unit curtain wall slab.
The above midheaven glass may also replace for the armored glass, the doubling glass or the wire-reinforced glass.

ANNEX 6

(19)中华人民共和国国家知识产权局

(12)实用新型专利

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(51)Int.Cl.

E04B 2/88(2006.01)

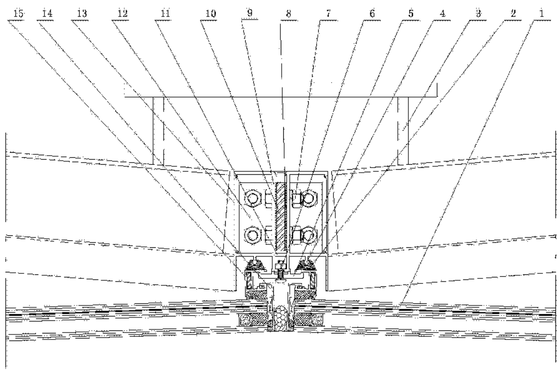
权利要求书 1 页 说明书 2 页 附图 2 页

(54)实用新型名称

一种异面幕墙连接结构

(57)摘要

一种异面幕墙连接结构属于幕墙连接结构技术领域，尤其涉及一种异面幕墙连接结构。本实用新型提供一种便于调节玻璃板块的角度、连接方便的异面幕墙连接结构。本实用新型包括压板，压板两端均设置有副框，压板与其上方的连接型材下端通过第一紧固件相紧固，并挤压副框，副框下端通过结构胶与玻璃板块相固定；其结构要点连接型材下端两侧均设置有转轴，转轴与固定于副框上端的密封胶条相套接；连接型材通过其上部的凹槽套接在龙骨上，并通过第二紧固件紧固。



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1. 一种异面幕墙连接结构，包括压板（5），压板（5）两端均设置有副框（15），压板（5）与其上方的连接型材（11）下端通过第一紧固件（6）相紧固，并挤压副框（15），副框（15）下端通过结构胶与玻璃板块（1）相固定；其特征在于连接型材（11）下端两侧均设置有转轴（4），转轴（4）与固定于副框（15）上端的密封胶条（2）相套接；连接型材（11）通过其上部的凹槽套接在龙骨（10）上，并通过第二紧固件（7）紧固。

2. 根据权利要求 1 所述一种异面幕墙连接结构，其特征在于所述凹槽由两个对称设置的，纵截面为倒 L 形体（9）组成，倒 L 形体（9）端部卡接有扣边（13）。

3. 根据权利要求 1 所述一种异面幕墙连接结构，其特征在于所述玻璃板块（1）为中空夹胶玻璃板块。

4. 根据权利要求 1 所述一种异面幕墙连接结构，其特征在于所述结构胶为硅酮结构胶。

5. 根据权利要求 1 所述一种异面幕墙连接结构，其特征在于所述第一紧固件（6）和第二紧固件（7）均采用不锈钢螺栓。

6. 根据权利要求 1 所述一种异面幕墙连接结构，其特征在于所述玻璃板块（1）端部设置有护边（14），护边（14）与副框（15）卡接。

7. 根据权利要求 1 所述一种异面幕墙连接结构，其特征在于所述压板（5）为铝合金压板，副框（15）为铝合金副框，连接型材（11）为铝合金连接型材，龙骨（10）为钢龙骨；连接型材（11）与龙骨（10）之间设置有隔离垫（8）。

一种异面幕墙连接结构

技术领域

[0001] 本实用新型属于幕墙连接结构技术领域，尤其涉及一种异面幕墙连接结构。

背景技术

[0002] 近年来，随着建筑业的不断发展，国内、外的新建筑、新工艺、新材料、新工艺不断涌现，建筑幕墙设计也日益多样化，建筑幕墙的形式也越来越多。许多形式独特的建筑幕墙采用了多种角度的幕墙面结构。为了满足这种多角度转角异面幕墙结构的连接要求，经常需要制作特殊型材。由于制作特殊型材费时费力，且成本高；因此需要一种能同时适应多种建筑物墙面的异面幕墙连接结构。

发明内容

[0003] 本实用新型就是针对上述问题，提供一种便于调节玻璃板块的角度、连接方便的异面幕墙连接结构。

[0004] 为实现上述目的，本实用新型采用如下技术方案，本实用新型包括压板，压板两端均设置有副框，压板与其上方的连接型材下端通过第一紧固件相紧固，并挤压副框，副框下端通过结构胶与玻璃板块相固定；其结构要点连接型材下端两侧均设置有转轴，转轴与固定于副框上端的密封胶条相套接；连接型材通过其上部的凹槽套接在龙骨上，并通过第二紧固件紧固。

[0005] 作为一种优选方案，本实用新型所述凹槽由两个对称设置的，纵截面为倒 L 形体组成，倒 L 形体端部卡接有扣边。

[0006] 作为另一种优选方案，本实用新型所述玻璃板块为中空夹胶玻璃板块。

[0007] 作为另一种优选方案，本实用新型所述结构胶为硅酮结构胶。

[0008] 作为另一种优选方案，本实用新型所述第一紧固件和第二紧固件均采用不锈钢螺栓。

[0009] 其次，本实用新型所述玻璃板块端部设置有护边，护边与副框卡接。

[0010] 另外，本实用新型所述压板为铝合金压板，副框为铝合金副框，连接型材为铝合金连接型材，龙骨为钢龙骨；连接型材与龙骨之间设置有隔离垫。

[0011] 本实用新型有益效果：本实用新型连接型材下端两侧均设置有转轴，转轴与固定于副框上端的密封胶条相套接；密封胶条可绕转轴旋转，便于玻璃板块角度的调节。另外，连接型材通过其上部的凹槽套接在龙骨上，并通过第二紧固件紧固；便于连接型材与龙骨的连接固定。

附图说明

[0012] 下面结合附图和具体实施方式对本实用新型做进一步说明。本实用新型保护范围不仅局限于以下内容的表述。

[0013] 图 1 是本实用新型结构示意图。

[0014] 图 2 本实用新型连接型材结构示意图。

[0015] 图中，1 为玻璃板块、2 为密封胶条、3 为墙体钢结构、4 为转轴、5 为压板、6 为第一紧固件、7 为第二紧固件、8 为隔离垫、9 为倒 L 形体、10 为龙骨、11 为连接型材、12 为钢制连接件、13 为扣边、14 为护边、15 为副框。

具体实施方式

[0016] 如图所示，本实用新型包括压板 5，压板 5 两端均设置有副框 15，压板 5 与其上方的连接型材 11 下端通过第一紧固件 6 相紧固，并挤压副框 15，副框 15 下端通过结构胶与玻璃板块 1 相固定；连接型材 11 下端两侧均设置有转轴 4，转轴 4 与固定于副框 15 上端的密封胶条 2 相套接；连接型材 11 通过其上部的凹槽套接在龙骨 10 上，并通过第二紧固件 7 紧固。

[0017] 所述凹槽由两个对称设置的，纵截面为倒 L 形体 9 组成，倒 L 形体 9 端部卡接有扣边 13。采用两个对称设置的倒 L 形体 9，便于连接型材 11 与龙骨 10 连接和卡接扣边 13；扣边 13 可采用铝合金扣边 13。

[0018] 所述玻璃板块 1 为中空夹胶玻璃板块。

[0019] 所述结构胶为硅酮结构胶。硅酮结构胶粘结性好、耐老化性好。

[0020] 所述第一紧固件 6 和第二紧固件 7 均采用不锈钢螺栓；连接方便、耐用。

[0021] 所述玻璃板块 1 端部设置有护边 14，护边 14 与副框 15 卡接。护边 14 可加强对玻璃板块 1 的保护。

[0022] 所述压板 5 为铝合金压板，副框 15 为铝合金副框，连接型材 11 为铝合金连接型材，龙骨 10 为钢龙骨；连接型材 11 与龙骨 10 之间设置有隔离垫 8；避免双金属腐蚀。

[0023] 下面结合附图说明本实用新型的安装过程：首先将龙骨 10 通过钢制连接件 12 和不锈钢螺栓与墙体钢结构 3 固定连接；然后将连接型材 11 套接在龙骨 10 上，调整好后，用第一紧固件 6 固定连接；将扣边 13 扣于连接型材 11 两侧面，连接型材 11 与龙骨 10 之间加隔离垫 8。

[0024] 玻璃板块 1 与副框 15 之间的连接可在工厂加工完成。玻璃板块 1 与副框 15 通过结构胶粘接固定，之后将护边 14 钩于副框 15 上，护边 14 与玻璃板块 1 之间加垫块后打胶密封。当完成玻璃板块 1 四边与副框 15、护边 14 的连接后，将组装好的玻璃板块 1 运往施工现场。下面可以开始进行玻璃板块 1 与龙骨 10 的现场安装，先将组装好的玻璃板块 1 置于连接型材 11 之上，通过密封胶条 2 连接副框 15 与转轴 4；然后通过转轴 4 调节玻璃板块 1 成不同角度，调整好后，拧紧第一紧固件 6 使压板 5 压紧副框 15 将玻璃板块 1 与龙骨 10 固定连接；最后加设圆泡沫条并灌注耐候密封胶完成密封。

[0025] 可以理解的是，以上关于本实用新型的具体描述，仅用于说明本实用新型而并非受限于本实用新型实施例所描述的技术方案，本领域的普通技术人员应当理解，仍然可以对本实用新型进行修改或等同替换，以达到相同的技术效果；只要满足使用需要，都在本实用新型的保护范围之内。

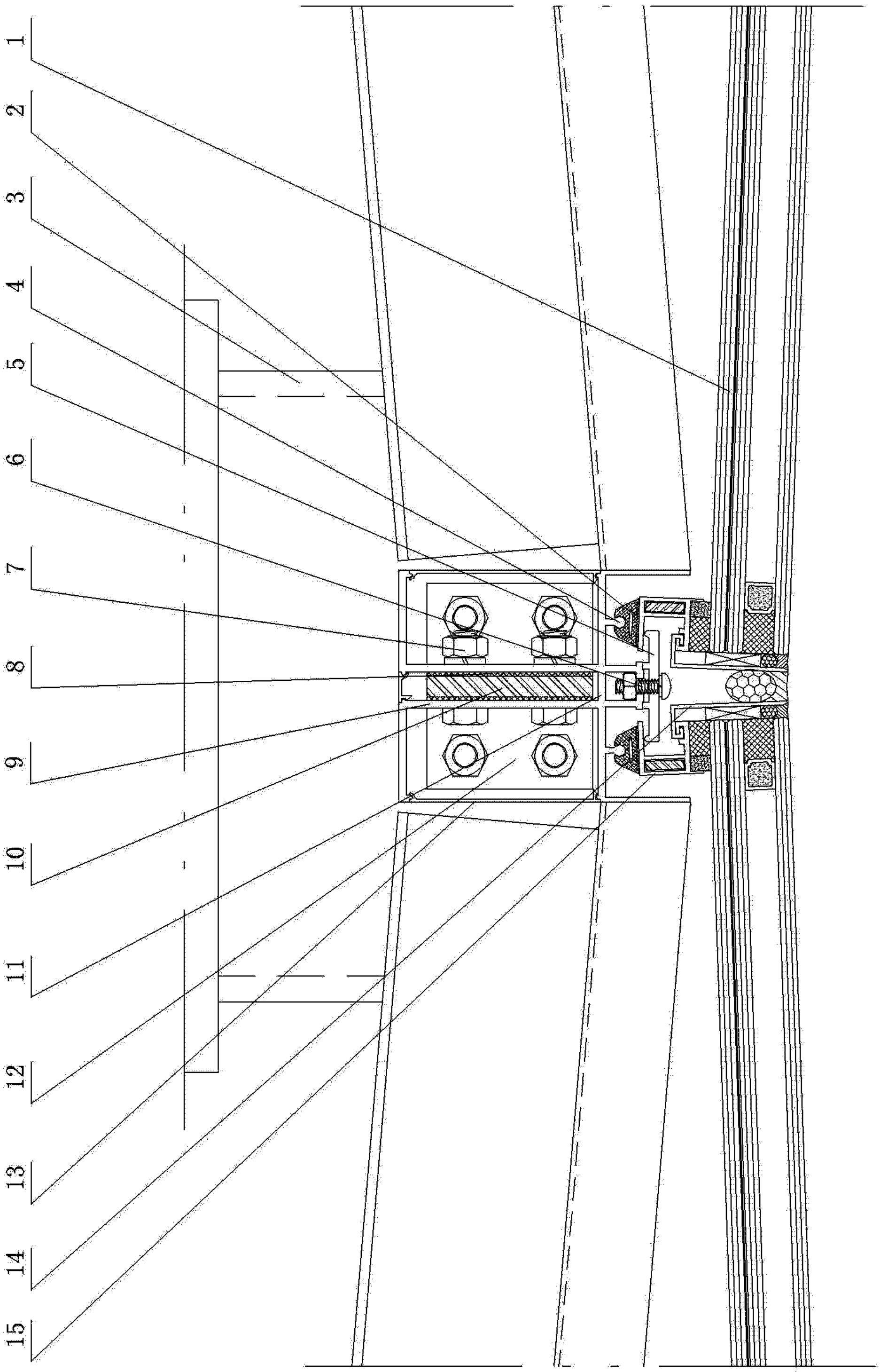

图 1

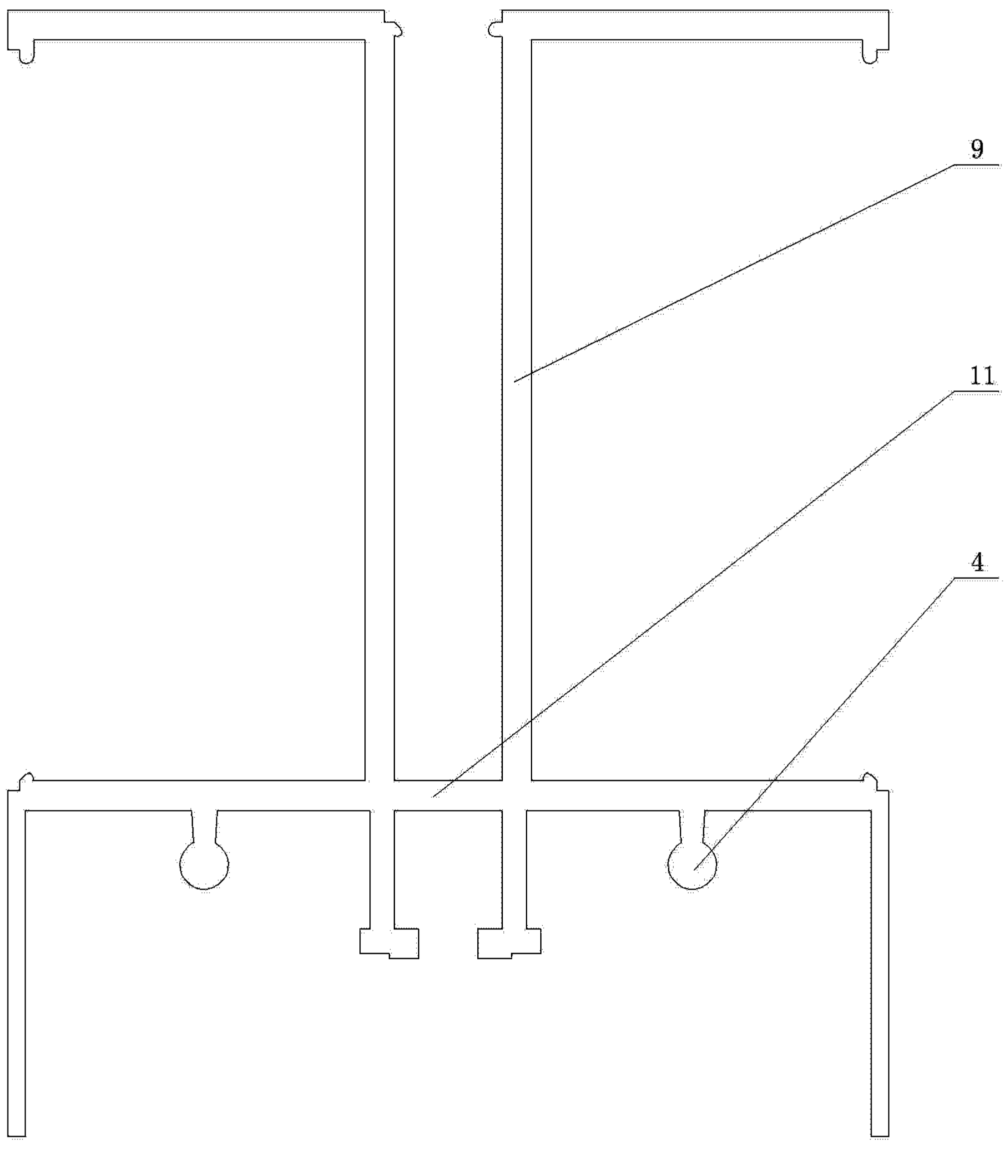

图 2

ANNEX 7

US008863454B2

(12) **United States Patent**
Davies et al.

(10) **Patent No.: US 8,863,454 B2**
(45) **Date of Patent: Oct. 21, 2014**

(54) **PULTRUDED PART FOR USE AS A FRAME MEMBER FOR AN EXTERIOR WALL CONSTRUCTION FOR A BUILDING**

(75) Inventors: **Laurence W. Davies**, Winnipeg (CA); **Matthew David de Witt**, Stony Mountain (CA)

(73) Assignee: **Omniglass SCT Inc.**, Winnipeg, MB (CA)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 949 days.

(21) Appl. No.: **12/271,294**

(22) Filed: **Nov. 14, 2008**

(65) **Prior Publication Data**

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(51) **Int. Cl.**

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E04H 3/00	(2006.01)
E04H 5/00	(2006.01)
E04H 6/00	(2006.01)
E04H 14/00	(2006.01)
E06B 3/54	(2006.01)
B32B 5/12	(2006.01)
E04B 2/88	(2006.01)

(52) **U.S. Cl.**

CPC ***B32B 5/12*** (2013.01); ***E06B 3/5427*** (2013.01); *E04B 2/885* (2013.01)

USPC **52/235**; 52/236.3; 52/309.1

(58) **Field of Classification Search**

CPC E04B 1/28; E04B 1/30; E04B 2/88; E04B 2/885; E04B 2/90; E04B 2/96; E04B 2/967; E06B 3/5427; E04C 2/20; B32B 5/12

USPC 52/281, 282.2, 282.5, 258.2, 309.1, 52/424, 426, 428, 483.1, 489.2, 272, 274, 52/234, 235, 236.3, 238.1

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,336,707	A *	8/1967	Horgan, Jr.	52/281
5,324,377	A	6/1994	Davies	
5,592,795	A *	1/1997	Rinehart et al.	52/235
5,687,524	A *	11/1997	Ting	52/461
6,746,747	B2	6/2004	Davies	
6,872,273	B2 *	3/2005	Davies et al.	156/148
2003/0026943	A1 *	2/2003	Davies et al.	428/113
2003/0115820	A1 *	6/2003	Assadi et al.	52/578
2003/0126812	A1 *	7/2003	Folsom et al.	52/204.62
2006/0201084	A1 *	9/2006	Arias	52/235
2007/0199261	A1 *	8/2007	Lang	52/204.5

FOREIGN PATENT DOCUMENTS

WO PCT/WO78529 A1 12/2000

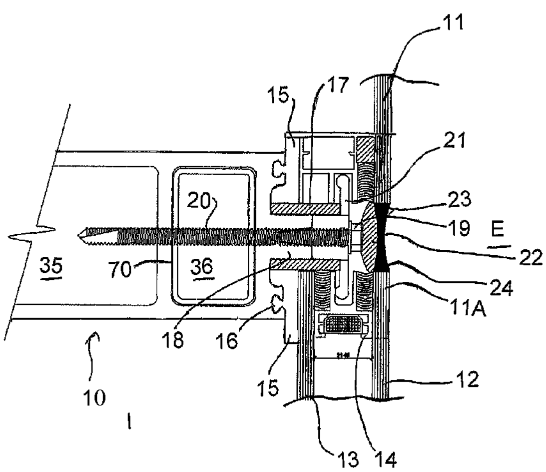
* cited by examiner

Primary Examiner — Joshua J Michener
Assistant Examiner — Theodore Adamos
(74) *Attorney, Agent, or Firm* — Adrian D. Battison; Ade & Company Inc.

(57) **ABSTRACT**

A building curtain wall is formed by vertical frame members carrying panels of glass bridging the space between the members so that edges of the panels are mounted on the members. Each frame member is a hollow pultruded member defined by a thermo-set resin reinforced by reinforcing fibers including longitudinal rovings and a mat located at an exposed surface of the inner wall and the side walls of the generally rectangular member. The exterior surface is defined by the resin which is pigmented but uncoated. In order to provide a required finish to the exterior surfaces the inner wall and the side walls have a thickness of at least 0.090 inch with a difference in thickness therebetween which is less than 20%.

19 Claims, 4 Drawing Sheets



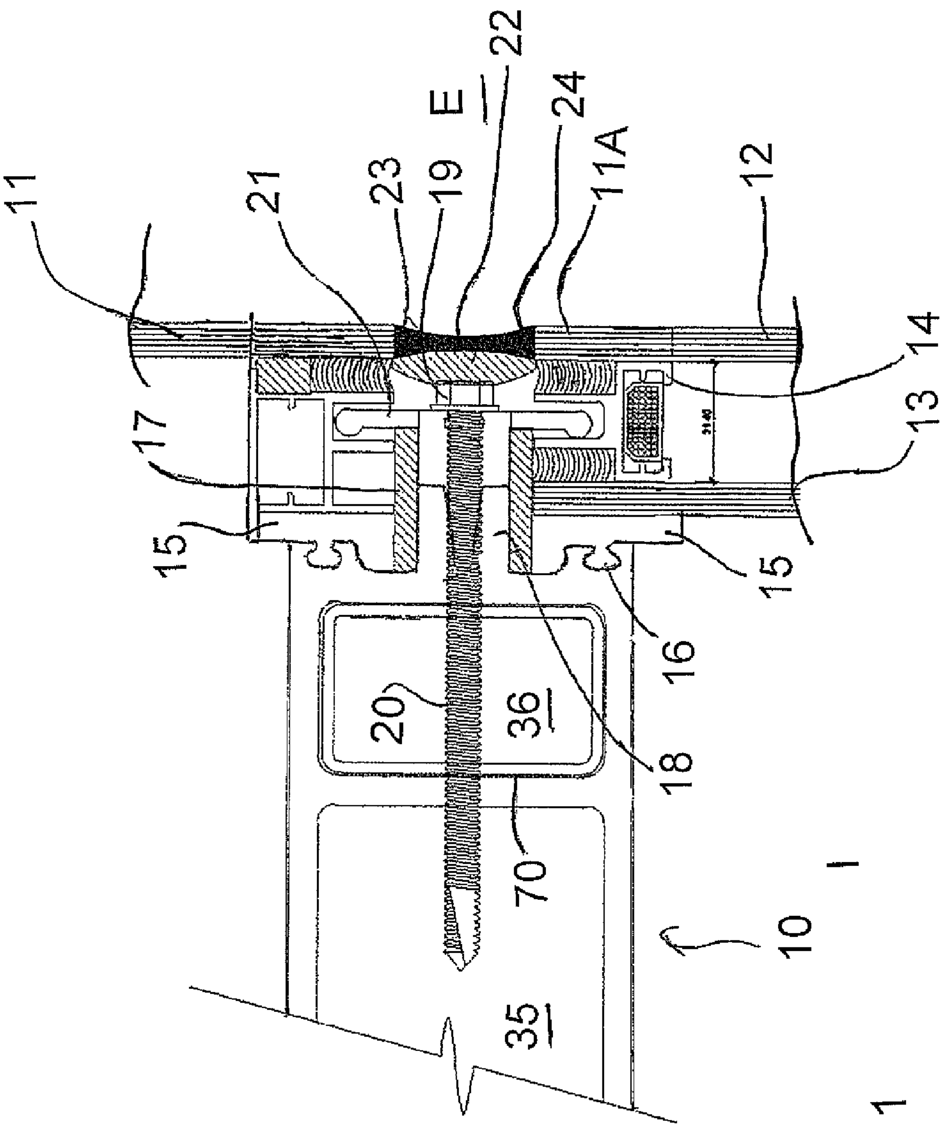


FIG. 1

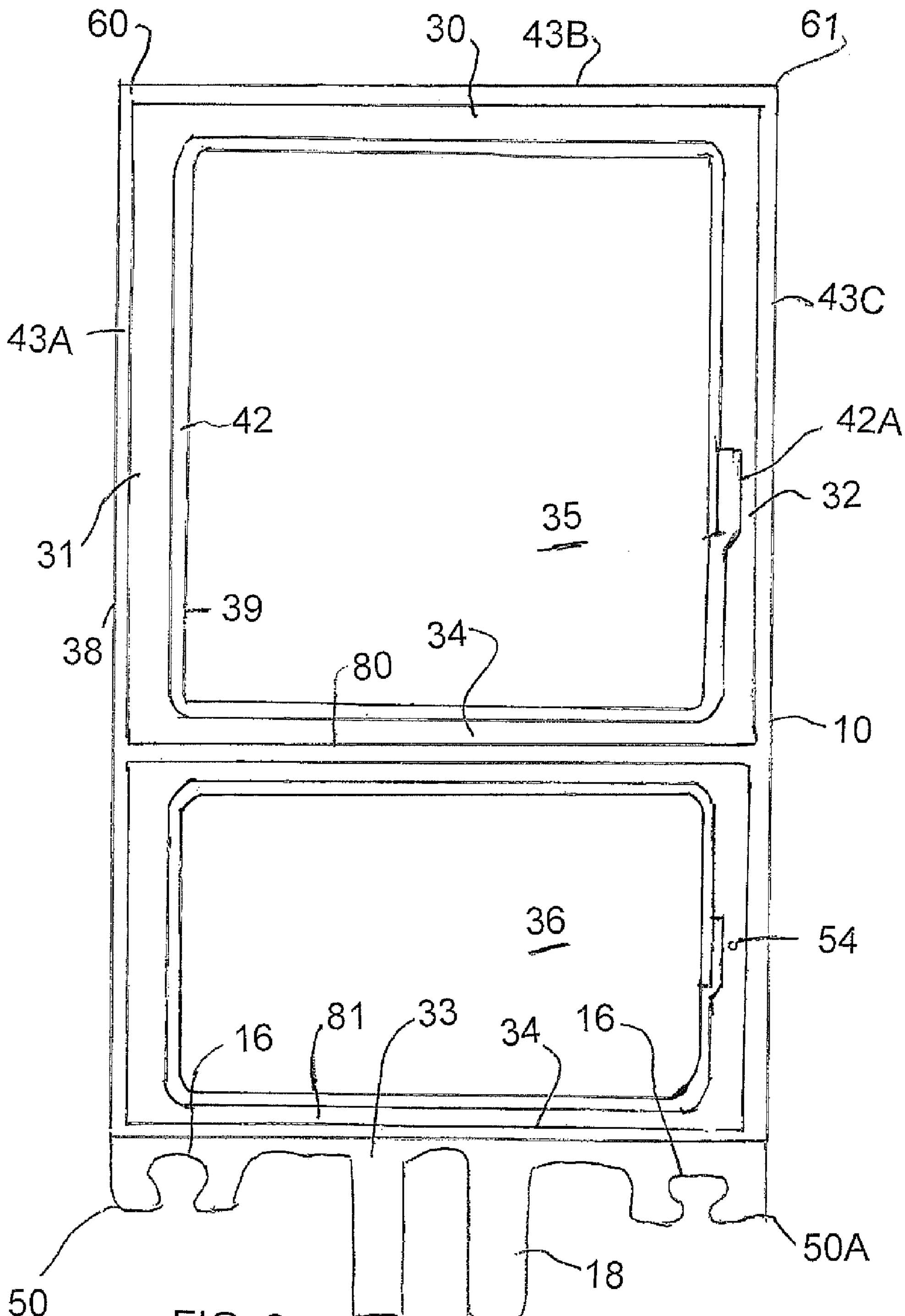

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FIG. 2

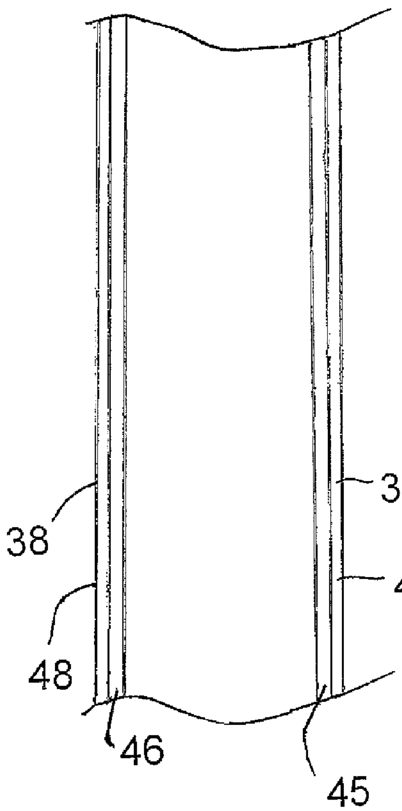

FIG. 4

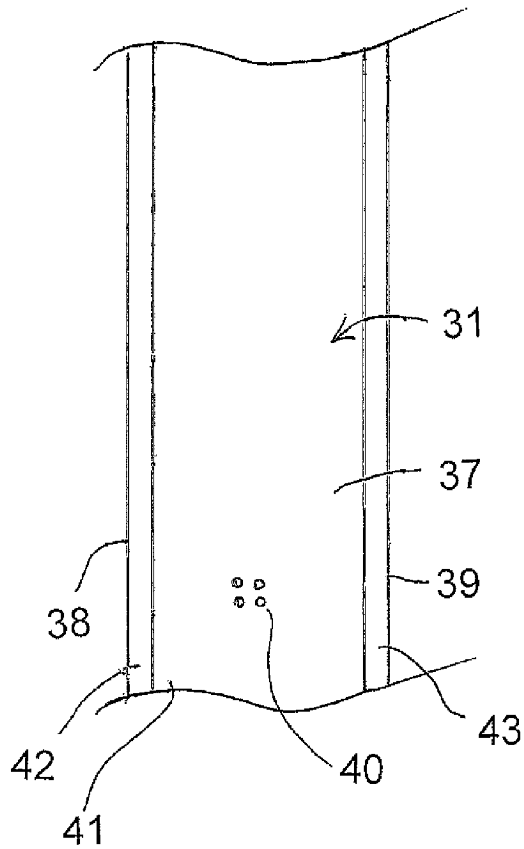

FIG. 3

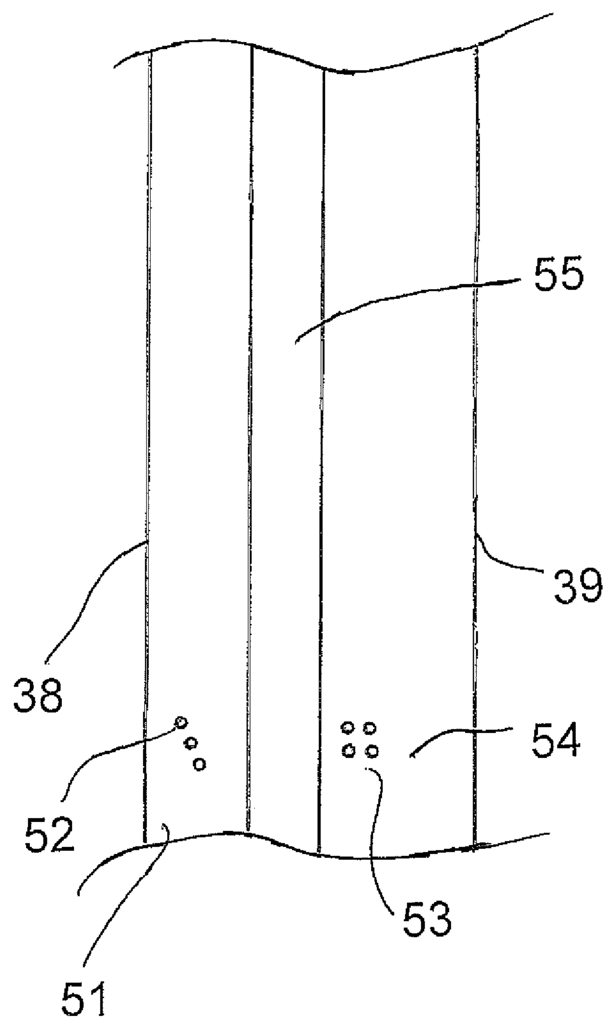

FIG. 5

PULTRUDED PART FOR USE AS A FRAME MEMBER FOR AN EXTERIOR WALL CONSTRUCTION FOR A BUILDING

This invention relates to a pultruded part arranged for use as a frame member for an exterior wall construction for a building where the construction includes a plurality of side by side parallel vertical frame members defining spaces therebetween and a plurality of panels each bridging the space between two of the frame members and each having side edges thereof connected to and mounted on a mounting structure of two adjacent ones of the frame members such that the panels cooperate to form an exterior sheet of the wall structure with the frame members mounted inwardly of the exterior sheet to support the exterior sheet. Such exterior wall construction can be of the type known as a curtain wall where the frame members bridge more than one storey of a multistorey building or of the type known as a storefront where the frame members span only a single storey and define a frame arrangement inserted into an opening in a wall of the building.

BACKGROUND OF THE INVENTION

Pultrusion is a technique in which longitudinally continuous fibrous structures are used to pull a resin through a die so that the resin sets and produces a rigid part downstream of the die to which the pulling force is applied.

Originally the longitudinal fibres consisted of simply longitudinal in the extending rovings and the parts were of a relatively simple cross section such as rods, T-bars and the like. However developments have been introduced to reduce the wall thickness of the parts so that complex cross sections including hollow cross sections could be manufactured. In order to achieve the necessary strength of the parts, it was necessary to introduce transverse fibers to provide strength in the transverse direction. Such transverse fibers are conventionally applied using a mat of a woven or non woven material. In many cases the fibers in the mat are generally random so that the number of fibers extending in the transverse direction is relatively small. One major problem with the mat is that it is relatively expensive and can be very expensive so that it is more than double per pound of the cost of the simple conventional rovings. One direction of development has been to provide improved mats which apply more of the fibers in the transverse direction thus allowing the mat to be of reduced thickness to provide the required strength or toughness in the finished part. An example of a mat tailored for pultrusion is shown in published International application PCT/WO78529A1 published 28 Dec. 2000 and assigned to Pella.

An alternative approach to the expense of the mat is to attempt to attach to the longitudinal rovings some transverse fibers which are simply chopped roving material. One example of an arrangement of this type is shown in U.S. Pat. No. 5,324,377 of the present inventor Davies. This method of pultrusion attempted to attach transverse fibers to the outside of a body of longitudinal rovings so as to be carried through the die with the rovings. This method has to date not achieved commercial success.

In order to minimize material costs, commercial pultrusion is normally carried out using polyester as the resin which is a simple thermo-set resin material so that it can be applied to the fibers from a bath and is thermo-set within the heated die. However other resins can be used.

Mats for reinforcing pultruded parts are provided to add structural strength and in order to provide the required or

expected amount of strength have a weight of fibers greater than 0.5 ounces per square foot and generally 0.75 to 1.0 ounces per square foot

Veils, which are used to provide surface characteristics and not to provide any structural strength are lighter, generally less than 0.5 ounces per square foot and typically of the order of 0.1 ounces per square foot. Conventional veils are used outside rovings or outside mats at the surface to increase the amount of resin located outside the mat and locate generally finer fibers at the surface to provide an improved surface appearance or to retain the stiffer glass fibers within the resin to prevent fiber "bloom" or projecting fibers which can act as slivers. This latter requirement to prevent slivers is particularly important in tool handles or similar products. The retention of fibers to prevent weathering or bloom is particularly important in fenestration or similar products. Veils are well known and well used, when required for the part concerned, by persons skilled in this art and are not intended to form part of and are not considered as part of the fiber reinforcement.

In U.S. Pat. No. 6,746,747 (Davies) of the present Applicants issued Jun. 8, 2004 is disclosed using a resin which can include non-linear resins such as urethane or polyester material and reinforcing fiber layers including at least one first layer of fibers having fibers extending only in the longitudinal pultrusion direction and one or more second layers, where the second layer consist of a pre-formed mat or veil having a total quantity of fibers in the layer which is of the order of or less than 0.5 ounces per square foot. The mat layer can be located in the pultruded wall so that it is on the inside surface of a hollow or in a central position between two layers of unidirectional rovings. The disclosure of the above Davies patent is incorporated herein by reference to provide details of pultrusion methods.

Curtain wall is a term used to describe a building façade which does not carry any dead load from the building other than its own dead load. These loads are transferred to the main building structure through connections at floors or columns of the building. A curtain wall is designed to resist air and water infiltration, wind forces acting on the building, seismic forces (usually only those imposed by the inertia of the curtain wall), and its own dead load forces.

Curtain walls differ from storefront systems in that they are designed to span multiple floors, and take into consideration design requirements such as: thermal expansion and contraction; building sway and movement; water diversion; and thermal efficiency for cost-effective heating, cooling, and lighting in the building.

The first curtain walls were made with steel mullions, and the plate glass was attached to the mullions with asbestos or fiberglass modified glazing compound. Later silicone sealants or glazing tape were substituted. Some designs included an outer cap to hold the glass in place and to protect the integrity of the seals. The 1970's began the widespread use of aluminum extrusions for mullions. Aluminum offers the unique advantage of being able to be easily extruded into nearly any shape required for design and aesthetic purposes.

Similarly, sealing methods and types have evolved over the years, and as a result, today's curtain walls are high performance systems which require little maintenance.

In addition to providing an aesthetic appearance for the sides of a modern multi-story building, some of the major performance objectives of a curtain wall system of supported panels are as follows:

to provide a barrier or at least resistance to excessive amounts of exterior air infiltrating around the edges of panels into one or more interior environments within the building;

to provide a barrier or at least resistance to excessive amounts of exterior rain or other exterior liquids/particles infiltrating around the panel edges into one or more interior spaces within the building, typically when the liquids or particles tend to infiltrate in conjunction with air infiltration;

to provide a coefficient of expansion which is close to that of glass so as to reduce or remove the necessity to provide the expansion joints which are necessary with aluminum bearing in mind that the frame members can span several floors of a building.

to provide resistance to structural loads, specifically including supporting the weight of the panels and resisting seismic loads, wind loads, and thermal expansion/contraction loads, if any; and

to provide a thermal barrier or at least resistance to excessive heat transfer between the exterior air and one or more interior environments.

Typically therefore current frame members for the curtains walls are manufactured of extruded aluminum. This can be coated with a paint or can be simply anodized to provide a suitable finish. The frame members are typically rectangular in cross section with an inner wall and side walls inside the outer sheathing of the building and the outer sheathing attached to an outer mounting portion of the frame member

However aluminum has many disadvantages in that it is susceptible to scratching and marring whether anodized or painted, it has high heat conductivity and its coefficient of thermal expansion is very different from that of glass.

SUMMARY OF THE INVENTION

It is one object of the present invention, therefore, to provide a frame member for an exterior wall construction for a building which is manufactured as a pultruded part.

According to a first aspect of the invention, therefore, there is provided an exterior wall construction for a building comprising:

a plurality of side by side parallel vertical frame members defining spaces therebetween;

each frame member being shaped to define a hollow structural member having an inner wall facing inwardly of the building, two side walls and an outer mounting structure facing outwardly of the building;

a plurality of panels each bridging the space between two of the frame members and each having side edges thereof connected to and mounted on the mounting structure of two adjacent ones of the frame members such that the panels cooperate to form an exterior sheet of the wall structure with the frame members mounted inwardly of the exterior sheet to support the exterior sheet;

each frame member comprising a pultruded member defined by a thermo-set resin reinforced by reinforcing fibers;

the reinforcing fibers including at least one first layer of fibers having fibers extending only in a direction longitudinal of the members;

the reinforcing fibers including at least one second layer of fibers having fibers with at least portions thereof extending transverse to the longitudinal direction and located in the member so as to be positioned at or adjacent an exposed surface of the inner wall and the side walls;

each frame member having an exterior surface defined by the resin so as to be free from coating material;

wherein the inner wall and the side walls each have a thickness of at least 0.090 inch;

and wherein the inner wall and the side walls have thicknesses selected such that a difference in thickness therebetween is less than 20%.

Typically the panels are arranged perpendicular to the frame members so as to span the frame members and form a front surface for the building. The panels are typically formed of a UV reflecting or absorbing glass. However other materials can be used and particularly panels of aluminum or other non-transparent material are used to cover part of the face of the building particularly at the space between the ceiling and floor.

Preferably the resin contains a pigment to provide a coloring thereto.

Preferably the inner wall and the side walls have thicknesses selected such that a difference in thickness therebetween is less than 15% and preferably of the order of or less than 10%. Thus the inner wall and the side walls are substantially of the same thickness with the variation being only that which is typical in normal tolerances obtainable in pultrusion where the thickness cannot be maintained highly accurately due to the floating movement of the mandrel used in forming the interior shape of a hollow. Typically 10% variation is the best that can be achieved and variations as much as 20% can be accepted in some constructions.

The use of thicker walls in the pultrusion process provides enhanced surface finish characteristics since the mat fibers which can mar the appearance by providing visible fiber lines

In one construction the exterior wall construction forms a curtain wall of a multi-storey building in which the frame members span more than one storey.

In another construction the same frame members can be used in an arrangement where the frame members span only a single storey and define a frame arrangement inserted into an opening in a wall of the building, such as in the construction known as "storefront". The frame members described herein can be used in either arrangement.

Preferably the thickness of the inner wall and the side walls lies in the range 0.090 inch to 0.50 inch. More preferably the thickness is in the range 0.17 to 0.25 inch and particularly a specific thickness of 0.20 inch has been found to be effective in certain embodiments

In one preferred arrangement, the second layer of fibers at or adjacent the exposed surface of the inner wall and the side walls consists of a single preformed mat.

In this arrangement, the mat typically has a weight in the range 0.125 to 3.0 oz/sq ft. More preferably the weight is in the range 0.75 to 1.5 oz/sq ft.

In another preferred arrangement, the second layer of fibers at or adjacent the exposed surface of the inner wall and the side walls consists of a preformed mat and a preformed veil located externally of the mat.

In this arrangement, the mat typically has a weight in the range above and the veil has a weight in the range 0.06 to 0.75 oz/sq ft.

Preferably each of the members is substantially rectangular in cross section so the sides are parallel and the inner wall is at right angles thereto.

There may be provided a cross wall at right angles to the side walls between the inner wall and the mounting structure.

Preferably for low cost the resin is polyester.

However other resins can be used for example the polyurethane described in the above Davies patent.

Typically the reinforcing fibers will include a third layer of mat fibers, that is those having fibers with at least portions thereof extending transverse to the longitudinal direction, which is located in the member so as to be positioned at or adjacent an inner surface of the inner wall and the side walls.

The advantage of the present invention is that it provides a low cost corrosion resistant part using the known process of pultrusion where the exterior surface is defined by the pigmented resin itself without any additional coating or paint layer. Such coatings can be scratched or marred leading to a poor appearance. The resin itself has been found to provide an effective exterior layer provided the wall thicknesses are of the minimum defined and are of substantially equal thickness as defined since uniform wall thickness gives a uniform mat print through or visibility of the fibers at the surface. Thus the mat or reinforcing fibers at the surface takes up an appearance at the outer resin surface which is attractive and consistent thus avoiding the necessity of the application of a coating, which requires additional cost and can be scratched.

Many standards are available for fenestration parts including standards provide by ASTM which are Government generated standards, and by AAMA which is the American Architectural Manufacturers Association. It has been found that the surface provide by the present invention can have better qualities than other available materials in tests such as:

The Pencil Hardness where the present invention provides values of at least 4H and up to 6H (ASTM D3363);

Adhesion of 5B (ASTM-03359-90)

Chemical resistance of 100 double rubs (ASTM D4752)

Taber Abrasion less than 100 mg loss in 1000 cycles (ASTM D4060).

Other more extensive tests of the AAMA can also be met by the arrangement of the present invention.

Typically the product according to the present invention has a cost approximately equal to that of aluminum.

Typically uncoated pultruded parts cannot be used for fenestration products and are specifically stated to be unacceptable for such uses according to Codes in view of the inability of pultruded parts to withstand UV degradation unless properly coated. It has been realized that the present arrangement is acceptable even though it forms a typical fenestration part since the part is in face wholly internal and does not present an externally exposed portion because that portion is covered by the cladding panels.

According to a second aspect of the invention there is provided an exterior wall construction for a building comprising:

a plurality of side by side parallel vertical frame members defining spaces therebetween;

each frame member being shaped to define a hollow structural member having an inner wall facing inwardly of the building, two side walls and an outer mounting structure facing outwardly of the building;

a plurality of panels each bridging the space between two of the frame members and each having side edges thereof connected to and mounted on the mounting structure of two adjacent ones of the frame members such that the panels cooperate to form an exterior sheet of the wall structure with the frame members mounted inwardly of the exterior sheet to support the exterior sheet;

each frame member comprising a pultruded member defined by a thermo-set resin reinforced by reinforcing fibers;

each frame member having an exterior surface defined by the resin so as to be free from coating material;

wherein the inner wall and the side walls each have a thickness of at least 0.090 inch.

In this arrangement, preferably the reinforcing fibers include at least one first layer of fibers located at an exposed surface of the side walls and the inner wall having fibers extending only in a direction longitudinal of the members.

Preferably the reinforcing fibers also include at least one second mat layer of fibers having fibers with at least portions thereof extending transverse to the longitudinal direction and located in the member so as to be positioned at a position spaced from the exposed surface of the inner wall and the side walls.

The second layer of mat fibers can be located at a position spaced from the exterior surface and from an inner surface of the inner wall and the side walls or the second mat layer can be located at a position at an inner surface of the inner wall and the side walls.

According to a third aspect of the invention there is provided a pultruded lineal for use in an exterior wall construction for a building comprising;

a pultruded member defined by a thermo-set resin reinforced by reinforcing fibers;

the pultruded member being a hollow structural member having an inner wall for facing inwardly of the building, two side walls and an outer mounting structure for facing outwardly of the building;

the reinforcing fibers including at least one first layer of fibers having fibers extending only in a direction longitudinal of the member;

the reinforcing fibers including at least one second layer of fibers having fibers with at least portions thereof extending transverse to the longitudinal direction and located in the member so as to be positioned at or adjacent an exposed surface of the inner wall and the side walls;

the frame member having an exterior surface defined by the resin so as to be free from coating material;

wherein the inner wall and the side walls each have a thickness of at least 0.090 inch;

and wherein the inner wall and the side walls have thicknesses selected such that a difference in thickness therebetween is less than 20%.

The transverse layer thus may be a scrim or mesh having openings for penetration of the resin between the fibers so as to allow effective cross-linking of the resin. It has also been found that surprisingly a veil of staple polyester fibers having a weight of as low as 0.1 oz/square foot can provide the required additional strength and/or toughness to the product.

The mat layer may be formed of any suitable fibers including but not limited to glass fibers, carbon fibers polymer fibers such as polyester or aramids, metal strands such as aluminum or steel or natural fibers such as cotton, jute, hemp or flax.

Natural fibers such as flax have the advantage that they are inexpensive and are to some extent porous thus allowing the resin to enter the interstices in the fibers and providing an increased bond between the fibers and the resin which can lead to reduced de-lamination and thus increased strength.

Metal strands have the advantage that they provide the required additional strength and/or toughness in the intermediate layer, but also they can provide other functions such as the required ferromagnetic effect for magnetic coupling as shown for example in U.S. Pat. No. 5,129,184 (Fish) issued Jul. 14, 1992 and/or an electrostatic charging effect for electrostatic deposition of a coating or paint material.

In one advantageous arrangement, the transverse fibers are formed of metal strands which provide both transverse strength and the characteristic of electrical conductivity and/or ferromagnetism for the part.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described in conjunction with the accompanying drawings, in which:

FIG. **1** is a cross sectional view of typical curtain wall construction including a pultruded part defining the frame member according to the present invention.

FIG. **2** is a cross sectional view on an enlarged scale of the frame member of FIG. **1**.

FIG. **3** is a cross sectional view on an enlarged scale of a first embodiment of one wall of the frame member of FIG. **1**.

FIG. **4** is a cross sectional view on an enlarged scale of a second embodiment of one wall of the frame member of FIG. **1**.

FIG. **5** is a cross sectional view on an enlarged scale of a second embodiment of one wall of the frame member of FIG. **1**.

DETAILED DESCRIPTION

In FIG. **1** is shown in cross section one part of a curtain wall system including one frame member **10** of a series of such frame members which are arranged in parallel spaced relationship along an open front face of a building. Attached across the space between each frame member **10** and the next adjacent frame member is a plurality of panels **11**. The panels **11** meet at the frame member **10** so that two such panels **11** and **11**A have edges which are closely adjacent and overlie the frame member **10**. The panels are arranged perpendicular to the frame members so as to span the frame members and form a front surface for the building. The panels are typically a UV reflecting or absorbing glass with panels of aluminum or other non-transparent material used to cover part of the face particularly at the space between the ceiling and floor.

Many different designs of the frame members and panels are available in the art and it will be appreciated that the present invention can utilize many such different arrangements.

The present invention is primarily concerned with the construction of the frame member **10** as described in more detail hereinafter.

In the embodiment shown, the panel **11**A includes an outer sheet **12** of glass and an inner sheet **13** of glass which are held in spaced position by a central spacer **14** to form a sealed window unit. The glass sheets are held against the spacer **14** by a suitable adhesive materials so that the glass sheets are held at the required spacing and are held together as a structural member by the spacer **14**.

A rubber spacer **15** is positioned between the inner sheet **13** of glass and an outside surface of the frame member **10**. The rubber spacer includes keying elements **16** which hold the spacer in engagement with the outer face of the frame member. A setting block **17** is located on a cylindrical protuberance **18** of the outer face of the frame member and defines a sleeve for receiving a fastener **19** including a screw thread section **20**. A mounting flange **21** engages against a portion of the panel **12** and holds that portion pressed against the setting block **17**. The mounting flange **21** is clamped in place by the threaded fastener **19** which extends through the protuberance **18** and into the structure of the frame member **10** as described in more detail hereinafter.

Thus it will be appreciated that the edges of the panels are clamped against the outer face of the frame member so that these edges are held in fixed position against the frame member against movement inwardly and outwardly of the building and against movement away from the frame members.

It will be appreciated that the exterior of the building is beyond the outer glass sheet **11**A as indicated at E and the interior of the building is inwardly of the exterior panels as indicated at **1**. Thus the panels form the exterior sheet and the frame members **10** are located inwardly of that exterior sheet within the building structure at the opening within the building.

In the arrangement shown in FIG. **1**, the mounting flange **21** applies pressure against only the inside sheet **13** of the glass and the outside sheet **12** is held in position by its attachment to the inside sheet. However similar arrangements can be provided which include a tape on the outside so that the pressure is applied against the outer sheet **12**. In the embodiment shown a bead **22** of a filler material is located in the space between the edges **23** and **24** of the outer sheets **12**.

Turning now to FIG. **2**, a cross section of the frame member is shown in more detail with the exterior sheathing panels omitted. The frame member **10** is generally rectangular so as to provide an inner wall **30** and two side walls **31** and **32**. The frame member further includes the outwardly facing mounting structure **33** which carries the external sheathing panels. As previously described, this includes keying elements **16** which cooperate with the spacer **15** together with the protuberance **18** along the center of the mounting portion **13**. Thus basically the mounting portion **13** includes a wall **34** parallel to the wall **30** and at right angles to the side walls **31** and **32**.

It will be appreciated that the shape of the frame members is not necessarily rectangular so that the side walls **31** and **32** may converge or diverge so that the width of the inner wall **30** may be different from the width of the outer wall **33**. An additional cross wall **34** parallel to the walls **30** and **33** is provided at a position therebetween so as to define two hollow chambers **35** and **36** within the frame member.

The frame member **10** is formed by cutting a required length from a pultruded lineal. As previously explained pultrusion is a known technique for manufacturing in effect continuously extending parts which are parts of a constant cross section which are then cut to length after the part is set.

When the system is used in a curtain wall construction, typically the frame members are cut to a length so that they span a distance greater than one story of the building on which the curtain wall is applied. Typically the frame members span two such stories and are connected end to end so that the frame member as connected extends from the bottom of the building through to the top of the building or at least through a height of the building on which the curtain wall is intended to be applied. Suitable fastening arrangements for connecting the end of one lineal piece to the next are well known and available to persons skilled in the art.

The frame members are fastened to the floor of each story again using bracket arrangements well known to a person skilled in the art

Turning now to FIG. **3**, a portion of one wall of the frame member **10** is shown as indicated at **31**. This wall is formed from a resin material **37** which extends through the whole body of the frame member and thus extends from an exterior surface **38** through the interior of each wall through an interior surface **39** of the frame member. Thus the outside surfaces **38** and **39** are formed from resin material. Inside the wall the resin material is reinforced by reinforcing fibers **40**. These reinforcing fibers **40** include a central layer **41** of longitudinally extending rovings together with an outer layer **42** at the surface **38** and an inner layer **43** at the surface **39**. The layers **42** and **43** are formed from a pre-formed mat of fibers which include fibers which deviate from the longitudinal direction. Mats of various types can be used including non-woven and woven mats but in most cases non woven mats are used where the fibers are in effect randomly oriented through the structure. This provides strength in two directions as is well known in the pultrusion technique.

In one example as shown in FIG. **2**, the mat **42** which is located on the inside surface of the hollow wraps around the whole inside surface with an overlap at the point **42**A to form a continuous inner mat. The mat **43** on the outer surface of the part is formed in separate pieces **43**A, **43**B and **43**C. This allows the corner **60** where the mat portions **43**A and **43**B meet and the corner **61** where the mat portions **43**B and **43**C meet to be sharper than is typical in pultrusion without forming folds of bends in the mat portions as they enter the pultrusion die.

Sharp corners that are corners of very small radius are preferred in this construction to reduce the gap where the edge of the horizontal frame members meets the corner of the vertical frame members. This radius and the gap formed thereby can also be accommodated by moving the horizontal frame members slightly outwardly by a distance approximately equal to the radius of curvature and taking up the extra distance caused by this movement at the outside edge in the compression of the rubber spacer **15**.

In FIG. **1** is shown a metal tube **70** which is inserted into the hollow **36** to act as a screw retention member for holding the screws **20** against pulling out of the pultruded frame member. The tube is inserted in the hollow **36** only at the screws. However it is still an additional component which must be inserted as an extra step and includes additional cost. In FIG. **2**, the tube is replaced by an extra layer of mat **81** in the cross member **34** and an extra layer **81** in the outer cross member **33**. In both cases the extra layer is inserted approximately mid way between the outer an inner surfaces and thus is spaced from the outer and inner mats.

The shape of the frame member with the inner wall **30** and the side walls **31** and **32** may be rectangular as shown or may be curved so that the side walls smoothly converge into the inner wall and form a part cylindrical shape in the inside facing the interior of the building. In this case, the horizontal frame members may be manufactured of a different pultruded profile having depth from the outer cross-wall to the inner wall which is only sufficient to reach the area where the side walls of the vertical frame members are parallel and before the curvature commences. Thus the horizontal frame members may be of reduced dimension in the direction at right angles to the exterior cladding panels since the strength requirement for the horizontal members is significantly less.

The formation of the part by pultrusion causes the fibers to be contained within the resin body so that the fibers are slightly spaced from the surfaces **38** and **39** thus presenting at the exterior surfaces a structure formed by the resin.

In FIG. **4** is shown an arrangement in which the reinforcing fibers include a mat **45**, **46** and an exterior veil layer **47**, **48**. The positioning of a veil outside the mat at the respective surface **38**,**39** tends to increase the amount of resin at the surface and to space the coarse fibers of the mat layer from the surface.

The frame member is formed so that the walls **30**, **31** and **32** are of substantially the same thickness. Thus the intention is that these walls have identical thickness. However in the pultrusion technique it is well known that the mandrel which forms the hollow can move during the pultrusion process thus changing the thicknesses of the walls. In some cases the walls may vary in thickness so that one of the walls is thicker than the other by up to 20%. It is preferred that the process is sufficiently controlled so that the variations and thickness are less than 15% and preferably less than 10%.

The thickness of the walls is at least 0.090 inch and more preferably in the range of 0.090 inch to 0.5 inch. This thickness of the pultruded wall is relatively thick. It has been found by the present inventors that the selection of the relatively thick wall together with the constant thickness through the walls **30**, **31** and **32** provides a situation where the external surface defined by the resin is of a constant appearance. Thus all of the exposed outer surfaces of the walls of the frame member from the edges **50** and **50**A at the outer mounting portion through the whole of the side wall **31**, the inner wall **30** and the side wall **32** have a constant processing characteristic leading to a constant appearance of the outside surface of the resin.

Yet further the selection of the above characteristics provides for the outside surface of the resin an attractive appearance in which the fibers of the mat are slightly visible but are constrained within the resin so their appearance is of an attractive nature rather than a nature which detracts from the appearance.

It has been found therefore that the above processing characteristics provides a structure in which the outside surface of the resin when carrying a pigment indicated at 54 provides an exterior which is resistant to scratching and yet provides an appearance which is sufficiently attractive to be presented to the public without the necessity for additional coatings.

The resin itself thus provides a hard resistant coating without the possibility of the coating being scratched away. The resin itself is resistant to chipping, scratching and abrasion so that it retains the attractive outside appearance.

Suitable mats which can be used in the present invention are available as follows;

Glass spun-bonded mat with course fiber reinforcement having a weight of 1 oz/sq ft.

This can be used with a veil also of glass having a weight of 0.75 oz/sq ft. The difference between the mat and the veil is that the veil is formed of finer fibers so as to reduce the amount of the appearance of the fiber at the surface and the location of the veil outside the mat means that it provides less strength reinforcement and more resin retention.

The thickness of the mounting portion wall **33** and the cross wall **34** can vary relative to the walls **30**, **31** and **32** since these have no outward visibility and thus the surface characteristics can change.

The pultruded member described above provides better scratch resistance and also better chemical resistance than conventional coatings or anodized aluminium.

The frame members are located inwardly of the exterior sheeting. Thus even though the exterior sheeting may be transparent, typically such transparent sheeting includes UV resistant layers or reflective layers so that the frame member is protected against UV degradation caused by the penetration of UV light. However typical UV stabilizers and pigments available for pultrusion and compatible with the resin being used can also be used.

In FIG. **5** is shown alternative arrangement in which the wall is formed again from resin between the surfaces **38** and **39**. Again the wall is reinforced by fiber layers but in this case the fiber layers include a layer **51** which is formed from longitudinally extending fibers **52**. A second layer of longitudinally extending fibers **53** is provided at layer **54**. An additional reinforcing mat layer **55** is provided to provide structural strength. However the roving layers **51** and **54** are located at the surfaces **38** and **39** thus providing a different appearance effect at the surfaces **38** and **39**. Such rovings can be provide a wood grain effect in appearance due to the longitudinal nature of the fibers at the surface where they can be seen just below the surface within the resin.

In all cases the thickness of the part is such that the fibers beneath the surface of the resin do not provide significant three dimensional pultrusion through the resin or vary the smoothness of the resin surface and the appearance of the fibers is primarily visual rather than having any relief effect.

Since various modifications can be made in my invention as herein above described, and many apparently widely different embodiments of same made within the spirit and scope of the claims without departing from such spirit and scope, it is intended that all matter contained in the accompanying specification shall be interpreted as illustrative only and not in a limiting sense.

We claim:

1. An exterior wall construction for a building comprising:

a plurality of side by side parallel vertical frame members defining spaces therebetween;

each frame member being shaped to define a hollow structural member having an inner wall facing inwardly of the building, two side walls and an outer mounting structure facing outwardly of the building;

a plurality of panels each bridging the space between two of the frame members and each having side edges thereof connected to and mounted on the mounting structure of two adjacent ones of the frame members such that the panels cooperate to form an exterior sheet of the wall structure with the frame members mounted inwardly of the exterior sheet to support the exterior sheet;

the inner wall, side walls and outer mounting structure of each frame member being formed by a pultruded member defined by a thermo-set resin reinforced by reinforcing fibers;

the reinforcing fibers including at least one first layer of fibers having fibers extending only in a direction longitudinal of the members;

the reinforcing fibers including at least one second layer of fibers having fibers with at least portions thereof extending transverse to the longitudinal direction and located in the member so as to be positioned at or adjacent an exposed surface of the inner wall and the side walls;

each frame member having an exterior surface defined by the resin so as to be free from coating material;

wherein the inner wall and the side walls each have a thickness of at least 0.090 inch;

and wherein the inner wall and the side walls have thicknesses selected such that a difference in thickness therebetween is less than 20%.

2. The exterior wall construction according to claim 1 wherein the inner wall and the side walls have thicknesses selected such that a difference in thickness therebetween is less than 15%.

3. The exterior wall construction according to claim 1 wherein the inner wall and the side walls have thicknesses selected such that a difference in thickness therebetween is less than 10%.

4. The exterior wall construction according to claim 1 wherein the exterior wall construction forms a curtain wall of a multi-storey building in which the frame members span more than one storey.

5. The exterior wall construction according to claim 1 wherein the frame members span only a single storey and define a frame arrangement inserted into an opening in a wall of the building.

6. The exterior wall construction according to claim 1 wherein the thickness of the inner wall and the side walls lies in a range of 0.090 inch to 0.5 inch.

7. The exterior wall construction according to claim 1 wherein the second layer of fibers at or adjacent the exposed surface of the inner wall and the side walls consists of a single preformed mat.

8. The exterior wall construction according to claim 7 wherein the mat has a weight in a range of 0.125 to 3.0 oz/sq ft.

9. The exterior wall construction according to claim 1 wherein the second layer of fibers at or adjacent the exposed surface of the inner wall and the side walls consists of a preformed mat and a preformed veil located externally of the mat.

10. The exterior wall construction according to claim 9 wherein the mat has a weight in a range of 0.125 to 3.0 oz/sq ft and the veil has a weight in a range of 0.06 to 0.75 oz/sq ft.

11. The exterior wall construction according to claim 1 wherein each of the members is substantially rectangular in cross section so the sides are parallel and the inner wall is at right angles thereto.

12. The exterior wall construction according to claim 1 wherein there is provided a cross wall at right angles to the side walls between the inner wall and the mounting structure.

13. The exterior wall construction according to claim 1 wherein the resin is polyester.

14. The exterior wall construction according to claim 1 wherein the reinforcing fibers including a third layer of fibers having fibers with at least portions thereof extending transverse to the longitudinal direction and located in the member so as to be positioned at or adjacent an inner surface of the inner wall and the side walls.

15. An exterior wall construction for a building comprising:

a plurality of side by side parallel vertical frame members defining spaces therebetween;

each frame member being shaped to define a hollow structural member having an inner wall facing inwardly of the building, two side walls and an outer mounting structure facing outwardly of the building;

a plurality of panels each bridging the space between two of the frame members and each having side edges thereof connected to and mounted on the mounting structure of two adjacent ones of the frame members such that the panels cooperate to form an exterior sheet of the wall structure with the frame members mounted inwardly of the exterior sheet to support the exterior sheet;

the inner wall, side walls and outer mounting structure of each frame member being formed by a pultruded member defined by a thermo-set resin reinforced by reinforcing fibers at least some of which are rovings which extend longitudinally along the member;

each frame member having an exterior surface defined by the resin so as to be free from coating material;

wherein the inner wall and the side walls each have a thickness of at least 0.090 inch.

16. The exterior wall construction according to claim 15 wherein the exterior wall construction forms a curtain wall of a multi-storey building in which the frame members span more than one storey.

17. The exterior wall construction according to claim 15 wherein the frame members span only a single storey and define a frame arrangement inserted into an opening in a wall of the building.

18. The exterior wall construction according to claim 15 wherein the thickness of the inner wall and the side walls lies in a range of 0.090 inch to 0.5 inch.

19. The exterior wall construction according to claim 15 wherein each of the members is substantially rectangular in cross section so the sides are parallel and the inner wall is at right angles thereto.

* * * * *

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(54) **SEMI-CURTAIN FACADE**

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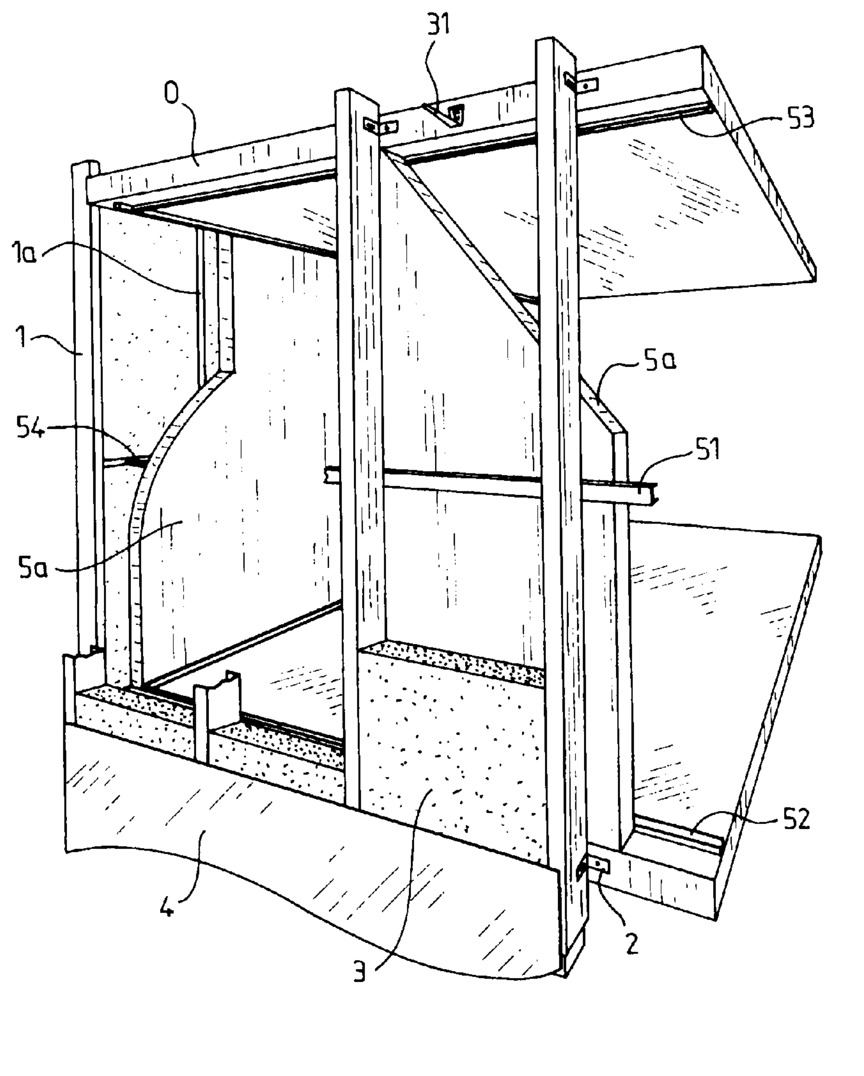
(57) **ABSTRACT**

A building facade including an exterior envelope including facade elements, a rain barrier, profiled holding and supporting elements fixed vertically to floor edges, a thermal insulation system including a first insulating element in front of floor edges and a second insulating element on the inside, between floors, a vapor barrier, and an interior lining. The first insulating element is basically continuous across the surface of the facade, or is essentially free of air pockets, two adjacent breadths of the first insulating element being separated by a flat surface of the profiled elements projecting forwards of the floor edges.



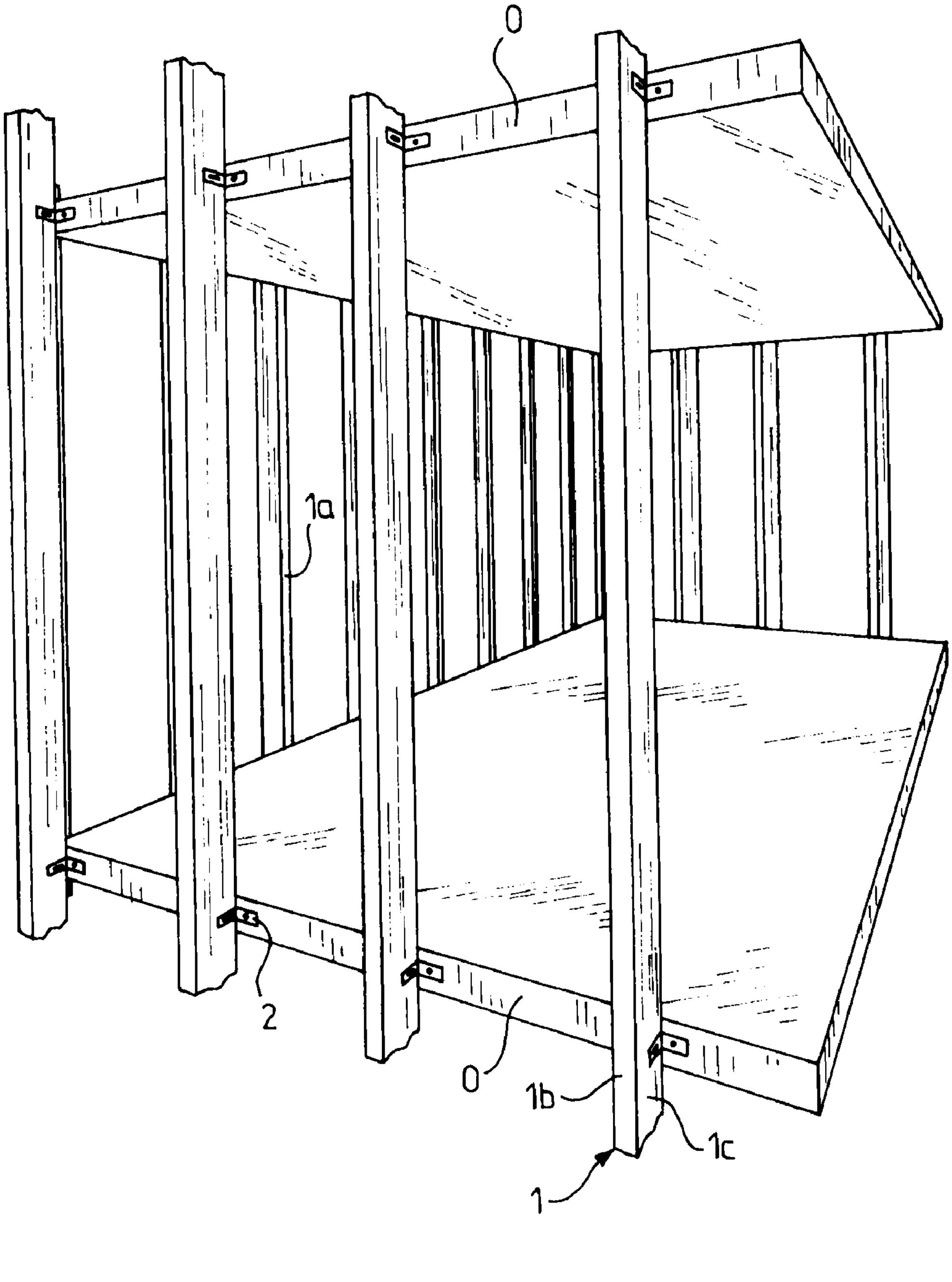


FIG.1

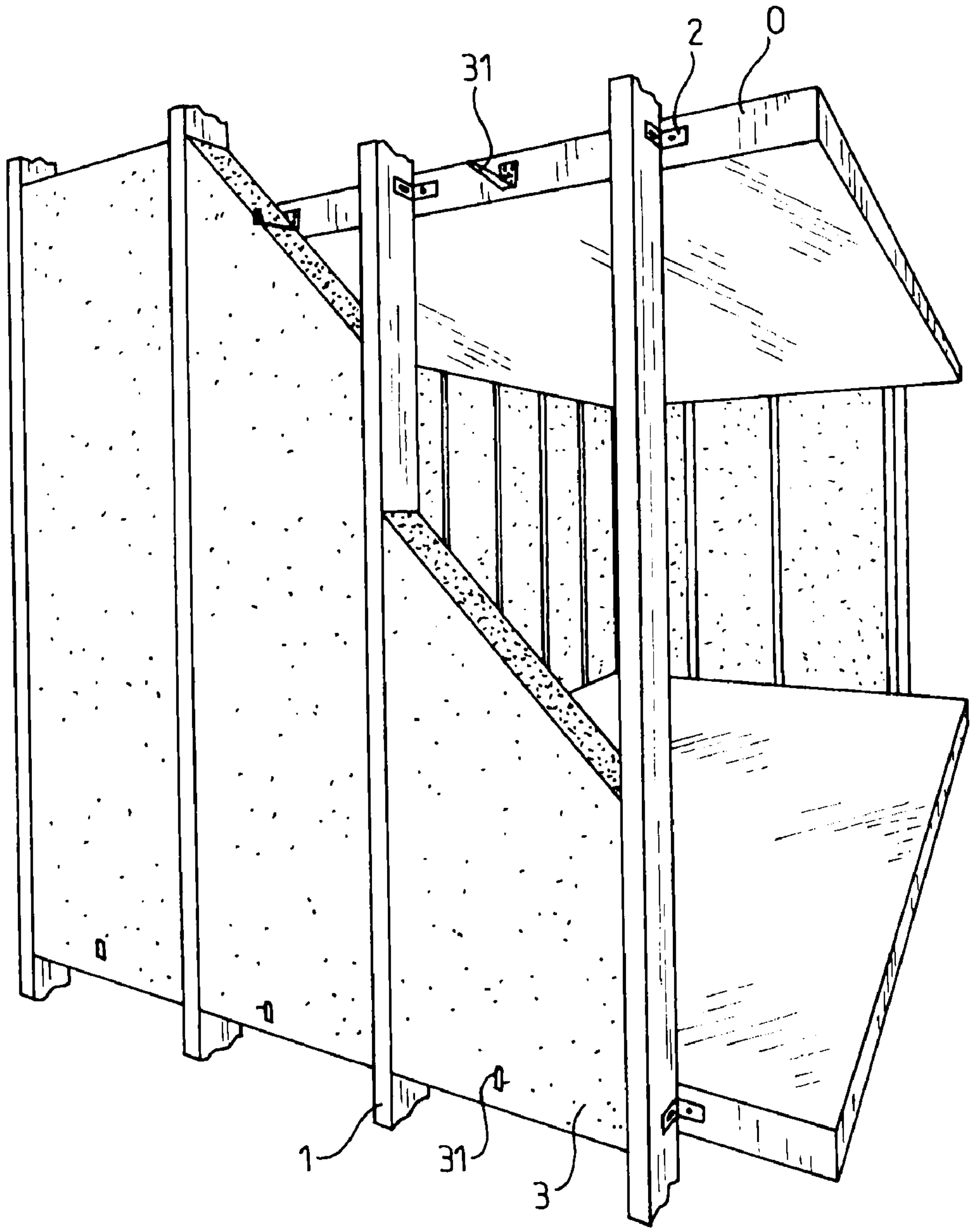


FIG.2

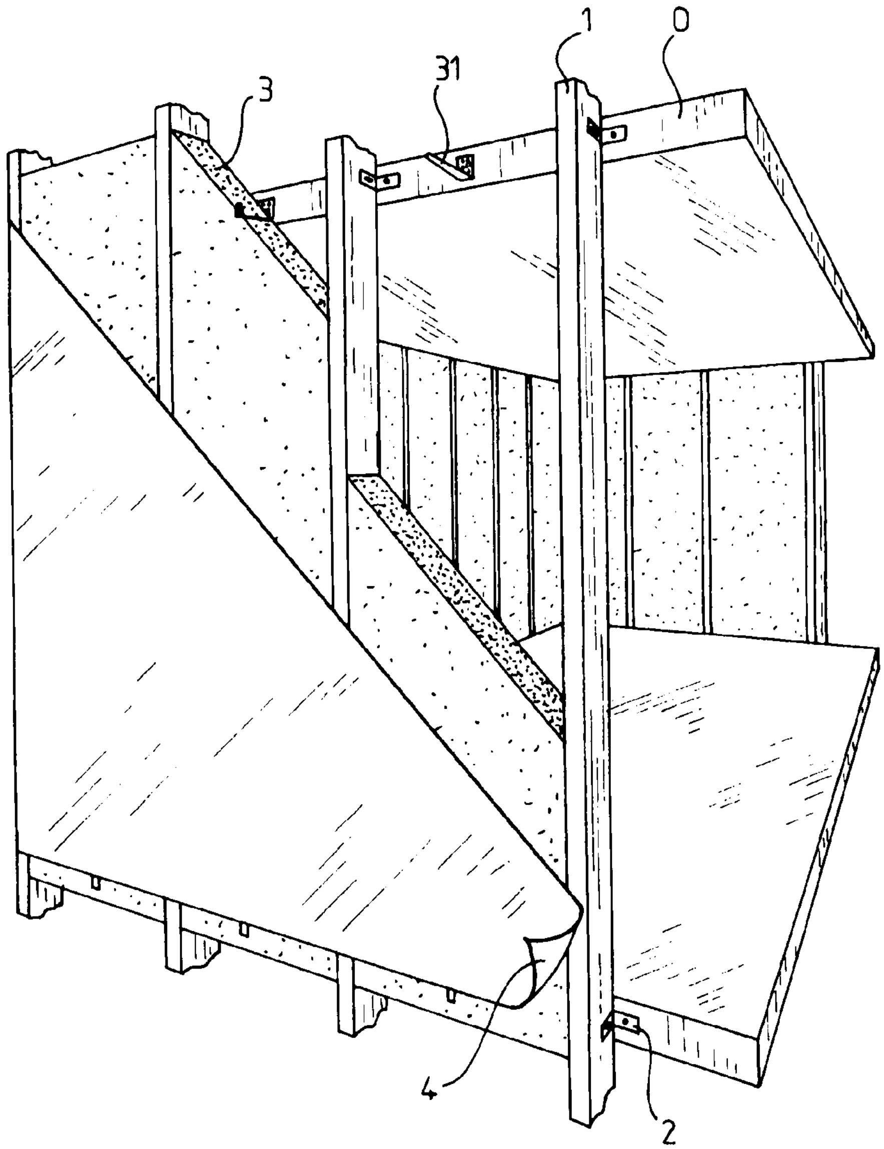


FIG.3

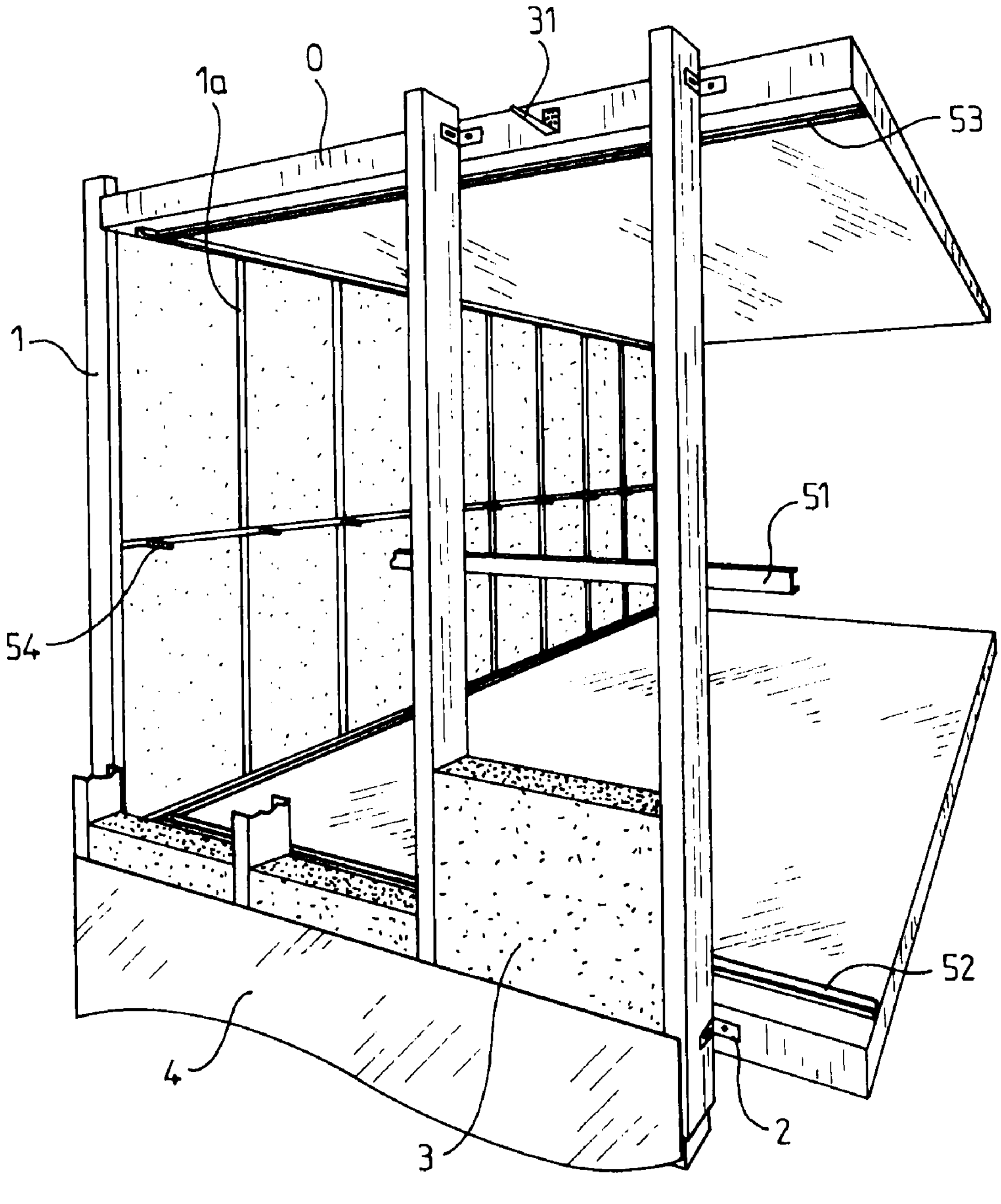


FIG.4

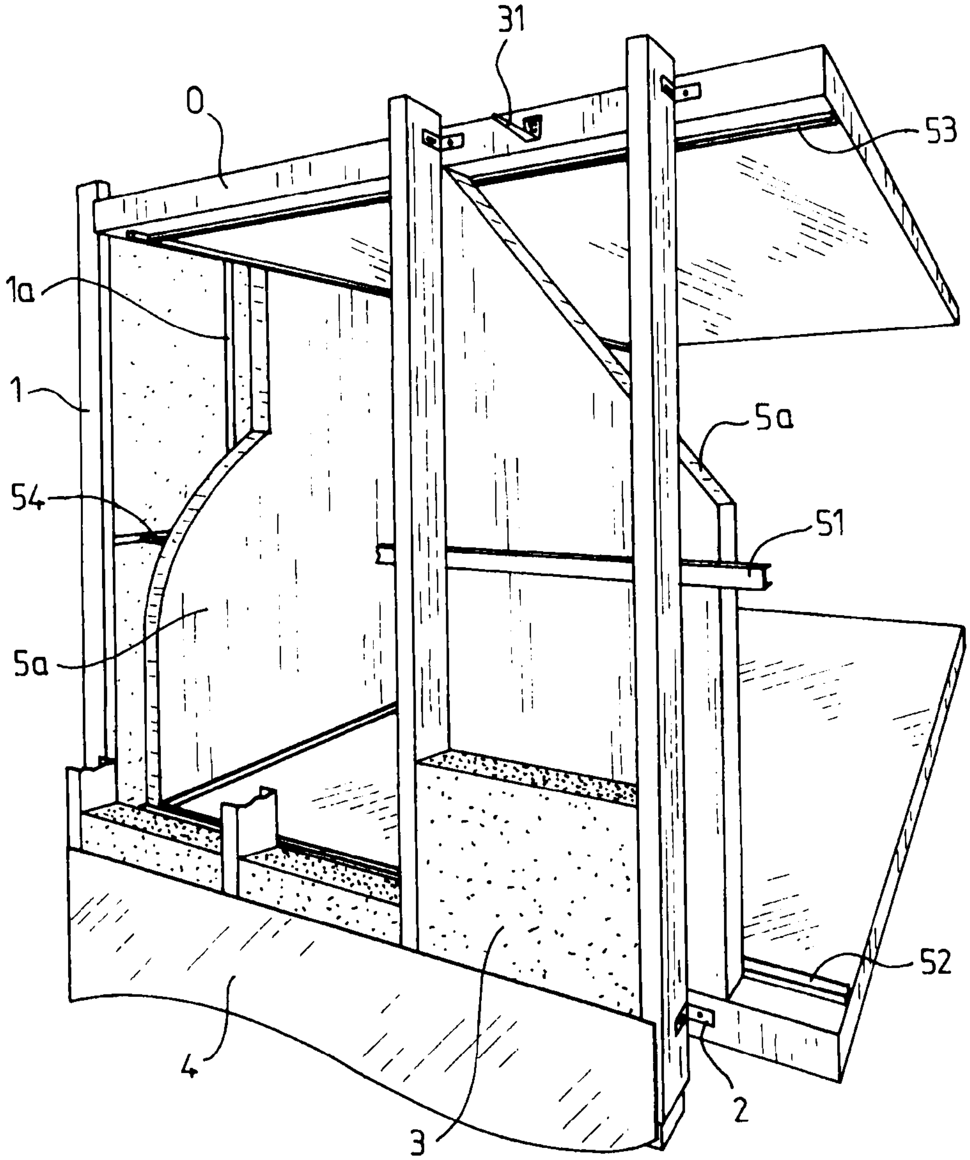


FIG.5

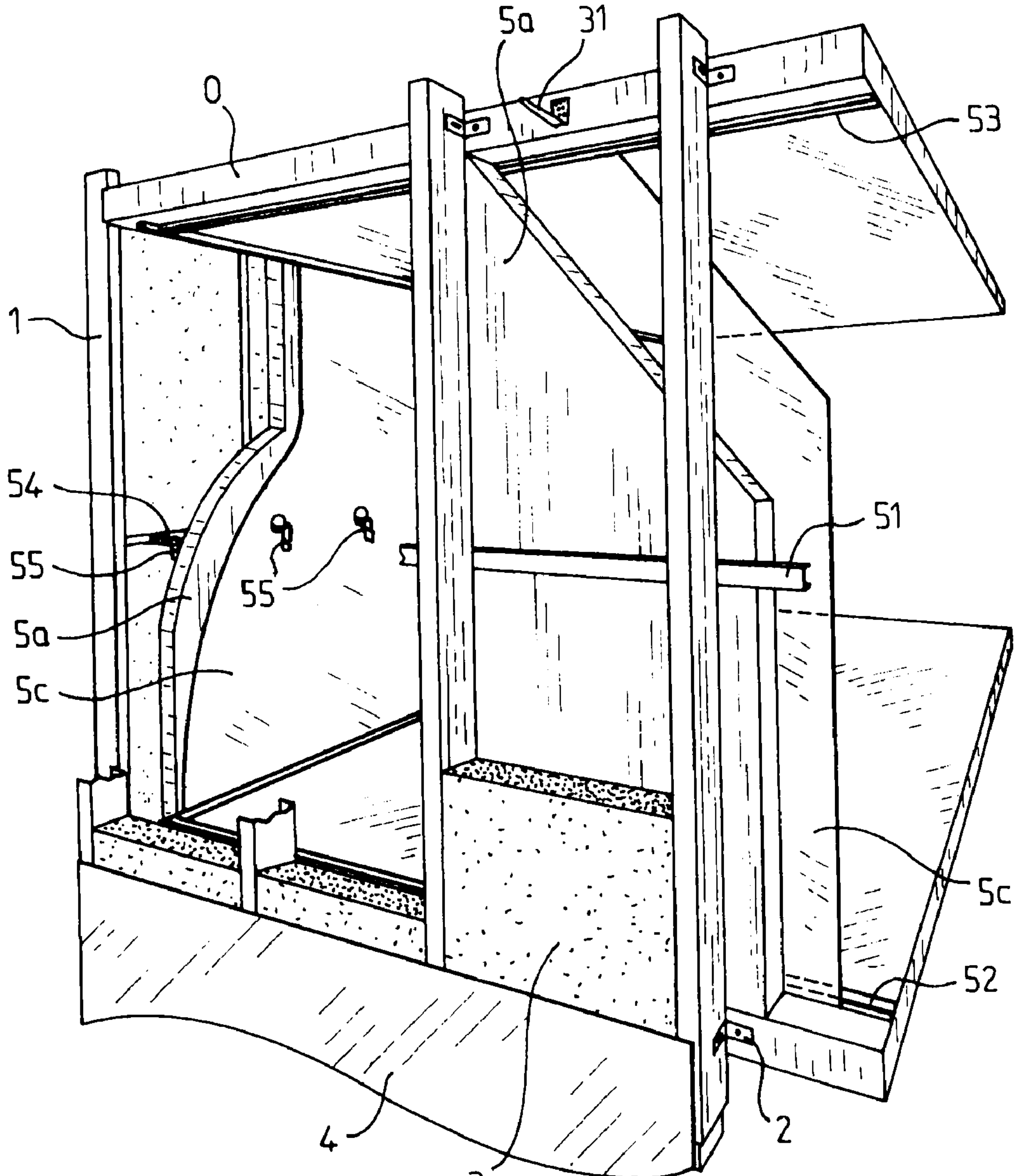


FIG.6

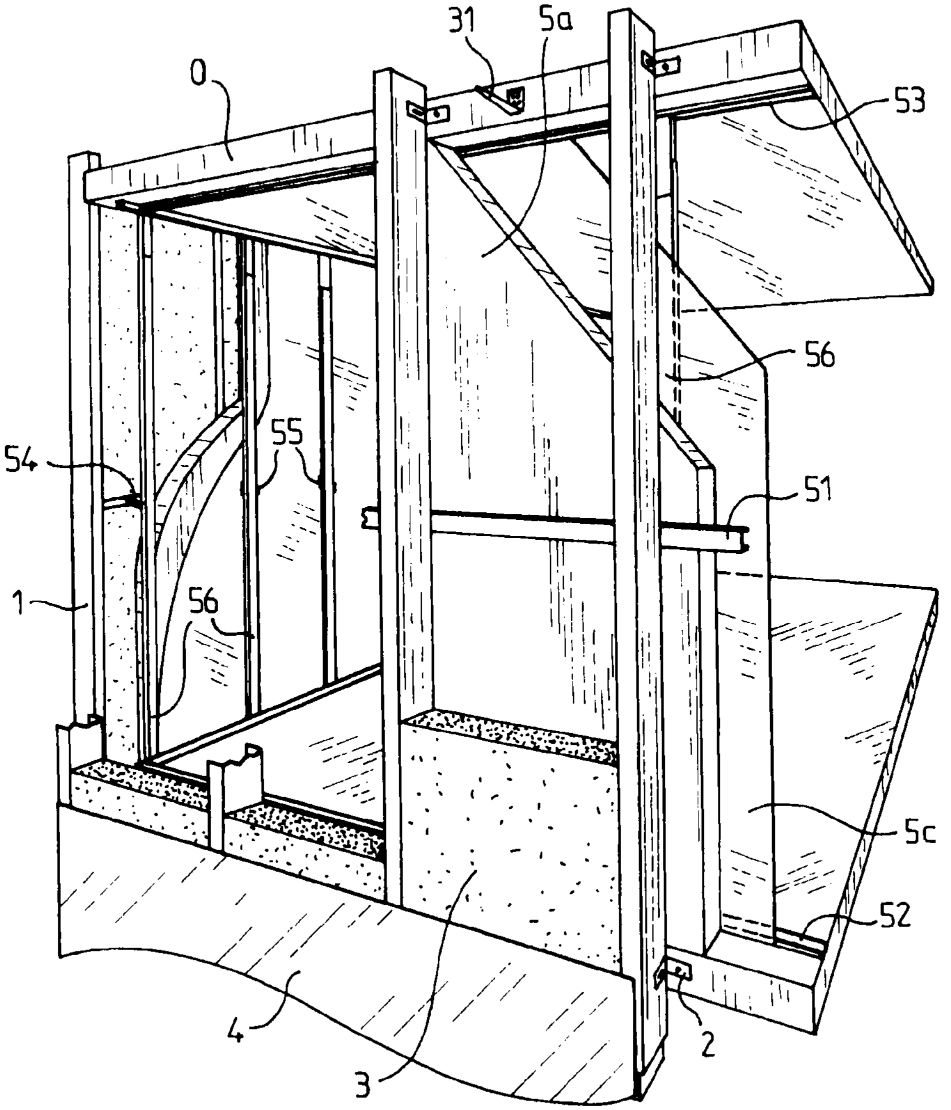


FIG.7

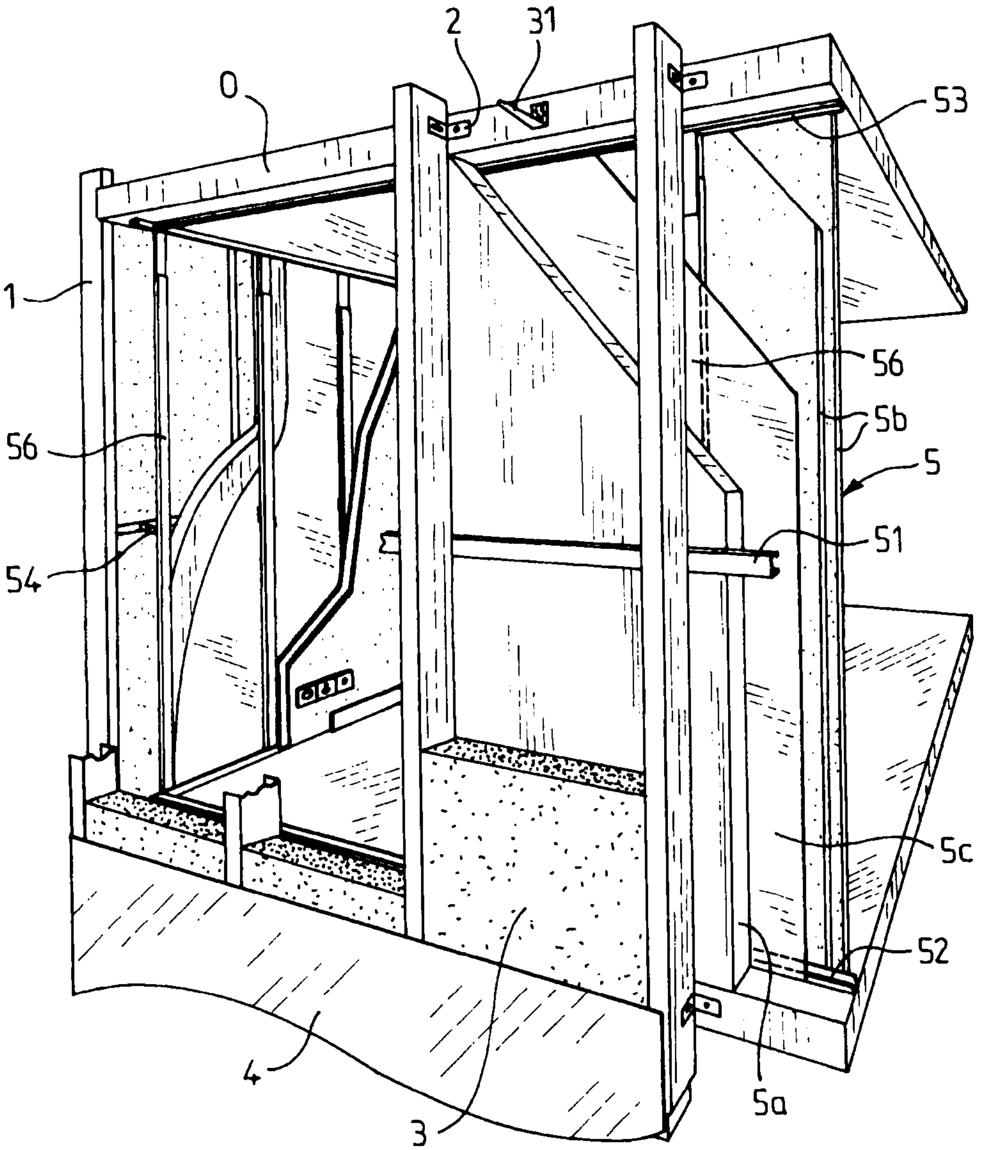


FIG.8

SEMI-CURTAIN FACADE

[0001] The present invention relates to facades for buildings.

[0002] Many facades are currently made in masonry using small elements, and/or concrete casing formwork.

[0003] These facades are relatively heavy and in some cases difficult to produce.

[0004] They do not provide satisfactory treatment of the thermal bridges at the interfaces with the structure and at particular points (balconies, loggias, changes in the direction of the wall and so forth), either in terms of interior or exterior thermal insulation.

[0005] When the building comes to the end of its life, these facades have necessarily to be demolished since there is no way of dismantling them.

[0006] Attempts to develop lightweight facades such as semi-curtain walling have so far failed to satisfy all of the following requirements:

- **[0007]** thermal bridges must be limited to a reasonable level,
- **[0008]** both opaque and glazed parts must be integrated,
- **[0009]** they must be adequately watertight and airtight,
- **[0010]** they must be adaptable to different types of construction, and
- **[0011]** construction costs must be contained.

[0012] These problems have been solved by the invention which, in particular:

- **[0013]** enables the whole of the facade of the building to be treated, including opaque parts and glazed parts,
- **[0014]** produces a facade which can be totally (and hence still more partially) dismantled, and
- **[0015]** is particularly advantageous in terms of cost, both in construction and use.

[0016] Excellent levels of thermal and acoustic insulation can be achieved.

[0017] To this end, the invention relates to a building facade comprising essentially, and in the following order:

- **[0018]** an exterior envelope made of facade elements,
- **[0019]** a rain barrier,
- **[0020]** profiled holding and supporting elements fixed vertically to the floor edges,
- **[0021]** a thermal insulation system comprising a first insulating element in front of the floor edges and a second insulating element on the inside, between floors,
- **[0022]** a vapor barrier, and
- **[0023]** an interior lining,

[0024] said facade being characterized in that the first insulating element is basically continuous across the surface of the facade, being in particular essentially free of air pockets, two adjacent breadths of this first insulating element being separated by a flat surface of said profiled elements projecting forwards of the floor edges.

[0025] The type of facade elements used for the exterior envelope is not limited. They may for example be metal wall cladding (sheet metal, optionally corrugated, etc.) or a timber facing. These facade elements or in other words this exterior facing are advantageously fixed to vertical profiled elements (which may for example be Z sections) which are themselves fixed to said profiled elements, above the rain barrier, or to a horizontal framework fixed to these vertical profiled elements or vertical Z sections. An air gap occupies the full depth of the Z sections, for example 2 cm.

[0026] An air gap advantageously at least 2 cm thick is thus created between the rain barrier and the outer facing (allowing for vertical air circulation), in the volume corresponding to the depth of the vertical profiled elements to which the exterior facing is fixed.

[0027] The rain barrier, which is a flexible plastic sheet, is fixed to the exterior face of said profiled elements. Alternatively a sheet of timber or OSB (Oriented Strand Board), or equivalent, may be inserted between profiled elements and rain barrier, to improve the acoustic performance of the facade.

[0028] The latter are fixed to the floor edges by any suitable method, a particularly practical method being from the outside, several forms of which will be detailed later.

[0029] Said first insulating element preferably occupies virtually the entire volume corresponding to the depth of said profiled elements. There is no need for the thickness of insulating element to be exactly the same as the depth of said profiled elements, but it is essential that the surface of the facade be covered by as continuous as possible a layer of insulating material. The layer of this first insulating material is thus interrupted, between two adjacent breadths, only by the thickness of a thin wall, perpendicular to the facade, of said profiled elements.

[0030] The possibilities of arranging the second between floors interior insulating element, the vapor barrier and said lining, creating an interior insulation system, are multiple, and several examples will be detailed below.

[0031] The building facade of the invention offers very good mechanical properties, at the level currently required in terms of impact resistance, or relative to cleaning cradles for example, or to the effects of earthquakes in the case of residential buildings situated in medium-risk zones and where the height does not exceed 28 meters, in particular.

[0032] Opaque and glazed parts are both easily catered for, and it is very easy to apply the invention to the most varied types and styles of construction.

[0033] Airtightness, produced by applying an independent vapor barrier film, is good, while excellent thermal and acoustic insulation can be achieved.

[0034] The facade of the invention is easy to dismantle and its cost of manufacture is moderate.

[0035] Said profiled elements preferably have

- **[0036]** a flat rear surface for contact with at least one floor edge and for contact with and/or attachment of an interior insulation system,
- **[0037]** a flat front surface for the support and attachment of the rain barrier and of the facade elements, and
- **[0038]** a flat middle surface which joins the flat rear and front surfaces.

[0039] In a simple and practical embodiment, the flat rear and front surfaces are in planes parallel to the main plane of the facade, and the flat middle surface is in a vertical plane perpendicular to said main plane. This means that breadths of insulating elements of generally parallelepiped shapes can be installed on either side of said flat middle surface to maximize the space occupied by the insulating element.

[0040] In a first variant of this particular embodiment, the flat rear surface is on only one side of the plane of the flat middle surface. Said flat middle surface can thus easily be fixed, by screws, for example, to a bracket on the opposite face of said flat middle surface from that with the flat rear surface. This fixing is easily done from the outside of the building, the bracket having previously been fixed to the floor edge in the same way.

[0041] Three particularly practical embodiments may be mentioned.

[0042] In the first embodiment, said flat front surface is positioned on the same face of the flat middle surface as the flat rear surface: the profiled element is basically U or C shaped (the edges of the profiled element are bent into flanges).

[0043] In the second embodiment, said flat front surface is positioned only on the opposite face of the flat middle surface from that with the flat rear surface: the profiled element may be approximately a Z (two adjacent arms of the Z being perpendicular).

[0044] In the third embodiment, the flat front surface is positioned on both faces of the flat middle surface.

[0045] In a second variant, which can be combined with the first variant, said profiled elements are essentially inscribed within H profiled elements—that is, they are H profiled elements, or differ from an H only by the absence of one end part. This brings us back in particular to the shapes of the three embodiments of the first variant.

[0046] The H profiled elements can easily be fixed to the floor edges from the outside. All that is required is to first fix to the floor edge a fixing bracket having a first part to be fixed to the flat middle surface of a first H profiled element (upper) and a second part to be fixed to the flat middle surface of the second H profiled element (lower). Said flat front surface of each profiled element covers one of the two lateral edges of a panel or breadth of said first insulating element, or two such lateral edges of adjacent panels or breadths.

[0047] Said profiled elements are made from any material offering the high mechanical properties required at reasonable thicknesses and weights: a metal, especially aluminum, and preferably a reinforced plastic may be mentioned. Reinforced plastic has excellent mechanical properties in profiled elements within wall cross sections, good insulating performance, solving the problem of thermal bridges at the floor edges, and good fire properties. These advantages will be detailed later.

[0048] The profiled elements are advantageously made of pultruded resin and glass fiber composite, which may in particular be continuous and/or in the form of mats. The resin employed may be an acrylic, polyester, vinylester or epoxy resin.

[0049] These materials offer the required mechanical properties.

[0050] They are excellent thermal insulators—with a thermal conductivity of around 0.2 W/mK, they are a good solution to the thermal bridge problems. They are also excellent electrical insulators.

[0051] They have very good fire resistance, are self-extinguishing, and do not emit toxic fumes in the event of fire, in the case of many of them.

[0052] To give an indication, the thickness of the walls of the profiled elements is around 4 to 10 mm, which in particular gives satisfactory continuity of the insulating layer created by the juxtaposition of breadths of insulating elements on either side of said middle wall.

[0053] Said first and second insulating elements are preferably selected from inorganic fiber-based insulating materials such as glass wool, rock wool, plant fibers such as hemp, flax and cotton wool, or fibers of animal origin such as sheep's wool.

[0054] Said interior lining is preferably based on a plasterboard sheet (of type BA 25 or thicker) or multiple superposed such sheets (at least two BA 13, etc.).

[0055] The invention also relates to an assembly of components as described above for making such a facade.

[0056] A clearer understanding of the invention will be gained from the following description of the accompanying drawings, in which FIGS. **1-8** show diagrammatically in perspective the successive stages in constructing a facade according to the invention.

[0057] FIG. **1** shows two adjacent floor edges **0**. It should be noted however, that the facade of the invention is perfectly suitable for a structure with a larger number of floors.

[0058] Profiled elements **1** are fixed vertically at regular intervals of 600 mm to the floor edges **0**.

[0059] The profiled elements **1** are U-shaped: each has a concavity which is not visible and which is situated, in the case of the profiled elements nearest the viewer, on the left-hand side.

[0060] Each profiled element **1** has a flat rear surface **1***a* and a flat front surface **1***b* parallel to the latter. These are joined together by a perpendicular flat middle surface **1***c*. The latter is about 120 mm wide and is 6 mm thick.

[0061] The profiled elements **1** may be made of polyester resin reinforced with continuous glass fibers, and glass fiber mats.

[0062] The profiled elements **1** are fixed to the floor edges **0** by brackets **2**. The floor edges **0** do not have to be exactly plumb with each other, so this mode of fixing the profiled elements **1** is compatible with no contact between these elements **1** and a floor edge **0**, i.e. with a non-zero—but small—distance between a profiled element **1** and a floor edge **0**.

[0063] The brackets **2** are made of metal or reinforced plastic. They are screwed both into a floor edge **0** and into a flat middle surface **1***c* of a profiled element **1**.

[0064] FIG. **2** shows the application of insulating material **3** occupying the full space defined by the depth of the profiled elements **1**.

[0065] The insulating material **3** consists of 120 mm thick panels of glass wool sold by Saint-Gobain Isover under the name Panolène Facade. This glass wool has a thermal conductivity of 0.032 W/mK.

[0066] The glass wool is inserted into the concavity of the U-profiled elements **1**. When presented to the floor edges **0**, it is first stuck on spikes **31** fixed to the floor edges **0**. The spikes **31** are bent up on the outside of the glass wool **3** when the glass wool **3** is in place.

[0067] A rain barrier **4** is then applied to said flat front surfaces **1***b* of the profiled elements **1**, on top of the insulating material **3**—see FIG. **3**. The rain barrier is, as in the prior art, a flexible plastic sheet, sold for example by Doerken Delta Fassade.

[0068] The exterior covering the facade, although part of the system of the invention, has no special features and is not described in any greater detail here.

[0069] The construction of an internal insulation for a facade according to the invention will now be described.

[0070] Referring to FIG. **4**, horizontal rails **51** are fixed to said flat rear surfaces **1***a* of the profiled elements **1**. A quick gun-riveting process can be used.

[0071] The rails **51** are metal U profiled elements with perpendicular flanges. On this subject, and in the rest of the description of the interior insulation, application WO 2006/061538 is also referred to.

[0072] Also fixed to the floor edges **0** are bottom tracks **52** and top tracks **53**. The distance between these and said flat rear surfaces **1***a* is chosen so that the lining sheets of the interior insulation rest against the bottom tracks **52** and top tracks **53**.

[0073] Contact and spacer elements **54** are then fixed into the horizontal rails **51**, each time for example by a certain elastic deformation of the rails.

[0074] As seen in FIG. **5**, an insulating element **5***a* is stuck onto the contact and spacer elements **54**. The insulating element **5***a* is then positioned in contact with the flat rear surfaces **1***a* of the profiled elements **1** and with the horizontal rails **51**, behind the bottom tracks **52** and top tracks **53**.

[0075] The insulating element **5***a* is a glass wool whose thickness may be chosen anywhere between 80 and 120 mm, and with a thermal conductivity of 0.032 W/mK from Saint-Gobain Isover under the name Isoconfort **32**.

[0076] Rail holding elements **55** are then attached to the contact and spacer elements **54**—FIG. **6**.

[0077] Then, as shown in FIG. **7** vertical rails **56** are fixed to the holding elements **55**. The rails **56** are positioned behind the bottom tracks **52** and top tracks **53**.

[0078] The vertical rails **56**, like the horizontal rails **51**, are metal U profiled elements with perpendicular flanges. The holding elements **55** engage with the contact and spacer elements **54** in such a way as to allow easy adjustment of their position so that they are perpendicular to the facade and can then be locked. They also engage with the vertical rails **56**, fixing them in the desired position perpendicular to the facade.

[0079] A vapor barrier **5***c* is applied to the flat back of the rails **56**.

[0080] The vapor barrier is advantageously a moisture regulating membrane marketed under the name Vario by Saint-Gobain Isover. A standard vapor barrier may consist of a 100 to 200 μm thick polyethylene sheet, for example.

[0081] As shown in FIG. **8**, two sheets of 13 mm thick plasterboard or one sheet of 25 mm thick plasterboard **5***b* is fixed to the vertical flat surface formed by the vertical rails **56** and the bottom **52** and top **53** tracks.

[0082] Numerous variants are possible for installing the second insulating element **5***a*, the vapor barrier **5***c* and the interior lining **5***b*.

[0083] In particular, the combination made up of the horizontal rails **51**, the contact and spacer elements **54**, the holding elements **55** and the vertical rails **56** can easily be replaced.

[0084] Thus, it is possible to fix spikes **31** as described above to that face of the profiled elements **1** which is toward the building interior, to allow the second insulating element **5***a* to be skewered to it and retained on it. Alternatively, the function of such spikes **31** may be performed by vertical profiled elements (such as U elements) fixed to that face of the profiled elements **1** which is toward the building interior, between two floors.

[0085] The vapor barrier **5***c* can be applied on top of the spikes **31** or on top of the vertical U profiled elements.

[0086] In front of the vapor barrier **5***c*, uprights M **36** to French standard NF DTU 25.41 can be fixed in runners R **36** to the same standard, from the floor and ceiling, back to back (in pairs) in a vertical position. These uprights M **36** are U profiled elements. The volume corresponding to the depth of these uprights is left empty (air gap).

[0087] Two sheets of BA 13 type plasterboard **5***d* (or a single sheet of BA 25) are fixed to the uprights M **36**.

[0088] In this embodiment the fixings of the plasterboard sheets **5***b* are independent and not connected to the profiled elements **1**.

[0089] The resulting facade meets the standards for mechanical strength and is easy to dismantle. It provides excellent thermal and acoustic insulation. No masonry or equivalent wall is required between the first or exterior insulating material and the second or interior insulating material between floors.

1-**8**. (canceled)

9. A building facade comprising essentially, and in the following order:

an exterior envelope comprising facade elements;

a rain barrier;

profiled holding and supporting elements fixed vertically to floor edges;

a thermal insulation system comprising a first insulating element in front of the floor edges and a second insulating element on an inside, between floors;

a vapor barrier; and

an interior lining,

wherein the first insulating element is basically continuous across the surface of the facade, or is essentially free of air pockets, two adjacent breadths of the first insulating element being separated by a flat surface of the profiled elements projecting forwards of the floor edges.

10. The building facade as claimed in claim **9**, wherein the profiled elements include:

a flat rear surface for contact with at least one floor edge and for contact with and/or attachment of an interior insulation system;

a flat front surface for the support and attachment of the rain barrier and of the facade elements; and

a flat middle surface that joins the flat rear and front surfaces.

11. The building facade as claimed in claim **9**, wherein the profiled elements are essentially inscribed within H, C, U, or Z profiled elements.

12. The building facade as claimed in claim **9**, wherein the profiled elements are made of reinforced plastic.

13. The building facade as claimed in claim **9**, wherein the profiled elements are made of pultruded resin and glass fiber composite, which may be continuous and/or in a form of mats.

14. The building facade as claimed in claim **9**, wherein the first and second insulating elements are selected from inorganic fiber-based insulating materials, glass wool, rock wool, plant fibers, hemp, flax, cotton wool, or fibers of animal origin, or sheep's wool.

15. The building facade as claimed in claim **9**, wherein the interior lining is based on a plasterboard sheet or multiple superposed plasterboard sheets.

16. An assembly for making a building facade, comprising:

facade elements;

a rain barrier;

profiled holding and supporting elements and means for fixing the profiled elements vertically to floor edges;

a thermal insulation system comprising a first insulating element suitable for placing in front of the floor edges and a second insulating element suitable for placing on the inside, between floors;

a vapor barrier; and

an interior lining,

the profiled elements being suitable for receiving the first insulating element in a layer that is basically continuous across the surface of the facade, or is essentially free of air pockets, the elements having a flat surface configured to project forwards of the floor edges and separate two adjacent breadths of the first insulating element.

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