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Structural Adhesive Joints: State of the Art, Challenges, and Future Perspectives

F. Marchione*

Dipartimento di Ingegneria Civile, Edile e Architettura (DICEA), Università Politecnica delle Marche, via B. Bianche, Ancona, Italy

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A B S T R A C T

The design of adhesive joints is crucial in industries like aerospace, automotive, and railways, where they offer a lightweight alternative to traditional methods such as welding and bolting. Adhesive joints distribute stress uniformly and enable the assembly of complex geometries. This review focuses on cutting-edge technologies, highlighting the role of nanomaterials in enhancing fatigue strength and chemical-thermal stability. It also explores the potential of additive manufacturing to create customized joint geometries and enable real-time monitoring through embedded sensors. The paper examines widely used adhesives, including epoxies and polyurethanes, as well as innovative joint designs, such as sinusoidal profiles and multi-material configurations, which improve stress distribution and structural integrity. Surface preparation techniques and advanced numerical tools, like cohesive zone modeling and artificial intelligence, are also discussed for their role in optimizing joint performance. The study identifies key challenges, including standardization of processes and integration of novel materials, and outlines strategies to enhance the performance of bonded joints in advanced industrial applications.

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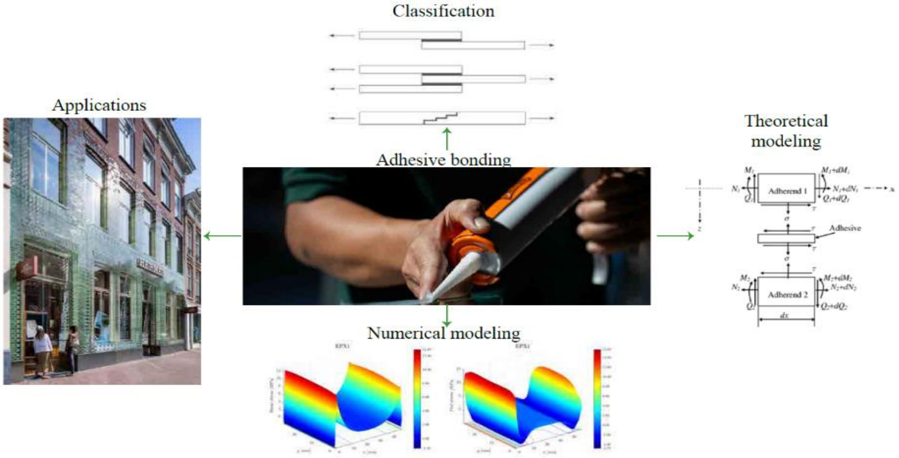
Graphical Abstract



1. INTRODUCTION

Adhesive joints are emerging as a key technological solution to address the challenges of structural efficiency and sustainability in advanced applications, as evidenced by the abundant scientific literature (1-3). Compared to traditional methods such as bolting and welding, adhesive joints offer significant advantages such as uniform stress distribution, the ability to connect dissimilar materials and greater design freedom, as reported by Adams et al. (1). These aspects make them essential in the aerospace sectors (4), automotive and rail

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[*] Corresponding Author Institutional Email: f.marchione@pm.univpm.it (F. Marchione)

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(5, 6), where overall weight reduction and mechanical strength are top priorities.

Despite the advantages, the large-scale adoption of adhesive joints is hampered by technical challenges related to adhesive selection (7), surface preparation (8) and the design of geometries to optimize stress distribution, as reported in literature (9-11). In addition, exposure to extreme environmental conditions, such as high humidity or fluctuating temperatures, is critical to the durability and reliability of joints, as evidenced by several experimental works (12-15).

Recent advances, such as the introduction of nanomaterials and the use of advanced numerical models (16), have significantly improved performance and design efficiency.

In recent years, adhesive engineering has been revolutionized by technologies like nanomaterials and additive manufacturing. Nanomaterials enhance adhesive joint strength, making them more durable and resistant to extreme stress. Additive manufacturing allows for custom-designed adhesives tailored to specific needs. These innovations are opening new possibilities in sectors like aerospace, automotive, and construction, where lightness and strength are crucial, enabling the creation of more efficient, durable, and sustainable structures.

The most recent research focuses on optimising geometric configurations and understanding crisis phenomena, both through experimental approaches and numerical simulations. The adhesive plasticity theory, introduced in the most recent works (17, 18), broadened the understanding of joint behaviour under complex loads, highlighting how the mechanical properties of the interface can affect overall performance.

Emerging technologies such as additive manufacturing (19) and artificial intelligence (20) are revolutionising design, offering new opportunities to develop customized, high-performance joints. Additive manufacturing enables the production of complex geometries, while artificial intelligence allows design parameters to be optimized by analyzing large amounts of experimental and simulation data. Both of these technologies are proving to be fundamental in addressing the increasingly sophisticated needs of modern industry.

Figure 1 (a-b) shows two real cases of structural adhesive applications in civil engineering. In particular, the Dow Corning warehouse in Feluy, Belgium (Figure 1a) and the Hermès flagship store in Amsterdam (Figure 1b) are shown. In the first case, the stainless steel connectors of the curtain wall are fixed to the glass panels using silicone; in the second building, on the other hand, a thin transparent adhesive was used, which joins the glass blocks by replicating the appearance of traditional masonry.

The objective of this review is to provide a review of the state of the art in adhesive joint design, exploring materials, geometric configurations, surface preparation techniques and analytical and numerical methodologies. Future perspectives and emerging research areas will also be discussed, with a focus on the integration of advanced technologies and collaboration between academic research and industry.

(a)

(b)

Figure 1. Real cases of application of structural adhesives for building facades

2. STRUCTURAL ADHESIVES

Adhesive materials are at the heart of structural adhesive joint design, as they largely determine the mechanical performance and durability of the system. They can be classified into several main categories based on their chemical composition, as stated by Adams (1) and Da Silva (21):

- Epoxy adhesives: They offer excellent mechanical and thermal properties, but show brittleness at low temperatures, limiting their use in extreme conditions. Their high adhesion makes them ideal for aerospace applications, but they require precise surface preparation to ensure effective bonding.
- Polyurethane adhesives: With greater elasticity and impact resistance, they are ideal for applications requiring vibration absorption, but are less suitable

for high temperatures. Their ability to tolerate high deformation makes them particularly useful in automotive applications. Due to their ductility, they are able to absorb larger displacements and are therefore more suitable for curtain wall applications and situations with high thermal expansion.

- Acrylic adhesives: Characterized by rapid cure and good ductility, they are ideal for high-speed assemblies, although sensitive to moisture. They are widely used in the electronics industry due to their compatibility with various materials.
- Cyanoacrylate adhesives: With fast adhesion, they are suitable for emergency applications, but have lower mechanical strength than other categories. Despite their limitations, they find use in medical applications due to their biocompatibility.

Recent innovations include the use of nanomaterials, such as silica nanoparticles and carbon nanotubes, to improve fatigue resistance and chemical-thermal stability. Addition of these materials allows traditional limitations to be overcome, expanding the range of applicability of adhesives even in extreme environments. For example, the incorporation of graphene into epoxy adhesives has shown a significant improvement in thermal conductivity, making them suitable for applications requiring heat dissipation.

Graphene improves adhesive strength, resistance, and durability, also boosting thermal and electrical conductivity. For instance, a microwave-activated graphene-based adhesive increases stiffness by 20% without compromising load capacity, enabling clean separation in 70 seconds with just 1% graphene. This reduces nanoparticle usage and energy consumption, offering recycling in automotive applications (22).

The combination of adhesives with advanced materials is leading to hybrid solutions that combine flexibility, strength and durability. Examples from recent research experience include glass-to-metal bonds, which combine the high strength of glass with the ductility offered by metal. This includes the work of Overend et al. (7), Scoccia et al. (23), Chiappini et al. (24), Marchione et al. (25), Pascual and Overend (26) Machalicka et al. (27-29).

Figure 2 shows two types of experimental prototypes, tested and discussed extensively by Scoccia et al. (23) and Marchione et al. (30, 31), respectively.

These developments are the result of a growing collaboration between academic research and industry, aimed at meeting the needs of increasingly complex applications.

(a)

(b)

Figure 2. Prototypes for applications in civil engineering: (a) Tensegrity Floor; (b) Invisible Window

2. CLASSIFICATION OF ADHESIVE JOINTS

The geometric configuration of an adhesive joint is one of the most critical aspects of the design, as it directly influences the stress distribution, overall strength and durability of the system. Various configurations have been developed to meet specific structural requirements, including simple overlap, double-lap, stepped-lap, scarf and sinusoidal joints. Each configuration has advantages and limitations, making the choice dependent on the application context, as highlighted by Adams et al. (1, 32).

- Single-lap joints (SLJ): these are among the most widely used due to their simplicity of design and low cost. However, the concentration of stresses at the edges is a significant criticality, which can lead to premature failure, especially under cyclic or dynamic loads.
- Double overlap joints (DLJ): they offer a more uniform stress distribution than SLJ joints, as the load is distributed over two adhesive surfaces. This makes them more suitable for applications requiring higher tensile strength and better stability under high loads.
- Step-lap joints: they represent an evolution of SLJ joints, with a stepped configuration that reduces stress concentrations and improves fatigue strength.

They are often used in aerospace structures, where durability is a critical requirement.

- - Scarf joints: With a progressive angle along the joint line, they offer an exceptionally uniform stress distribution. This makes them ideal for applications requiring high longitudinal tensile strength.
- Stepped-lap and scarf joints: they distribute stresses more evenly, reducing stress concentrations and improving overall strength. Step-lap joints are often used in aerospace structures, while scarf joints offer high strength for loads in the longitudinal direction.
- Sinusoidal profile joints: increases adhesion area and reduces discontinuities in stress distribution. Sinusoidal joints are particularly effective in applications subject to cyclic loads, such as wind turbine blades. Sinusoidal joints in wind turbine blades improve load distribution, reduce stress concentrations, and enhance durability. Combined with advanced adhesives like epoxy and polyurethane, they optimize resistance to external factors, boosting turbine reliability and longevity in harsh conditions.

Figure 3 summarizes the illustrated joint types.

Optimizing geometric configurations is a crucial process for improving the structural performance of adhesive joints, supported by advanced tools such as Finite Element Analysis (FEA). Using three-dimensional simulations, it is possible to accurately assess the stress distribution and identify any critical areas requiring design intervention. The adoption of multi-layer materials and hybrid configurations is an effective strategy to adapt the joint to the specific needs of the application, as highlighted in recent studies, including the one reported by Marchione (33).

Advances in additive manufacturing have revolutionized the design of adhesive joints, offering new possibilities to realise complex, customised geometries.

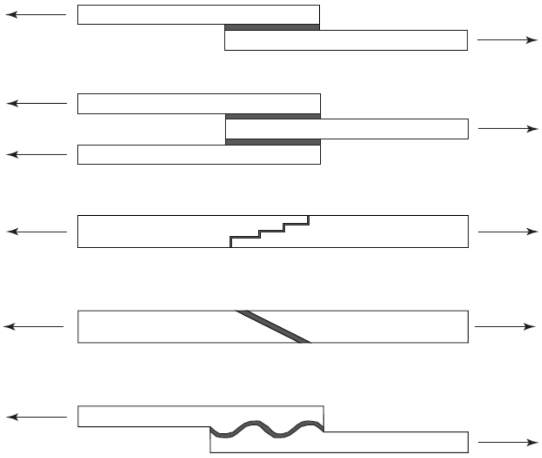


Figure 3. Types of adhesive joints

This innovative technology also allows local reinforcements to be integrated directly into structures, increasing strength without compromising overall weight. These developments have expanded the options available to meet the challenges imposed by advanced applications and critical operating conditions.

Among the most common solutions, simple overlap joints (SLJs) stand out for their simplicity of construction and low cost. However, the concentration of stresses at the edges is a significant limitation, negatively affecting fatigue strength and the ability to withstand high loads. Figure 4 shows the single-lap adhesive joints assembled for the study reported by Marchione (34).

The use of optimised configurations, combined with advanced technologies, can help overcome these limitations. Geometric optimization of joints uses finite element analysis (FEA) to simulate load behavior and identify stress points, while parametric design explores different configurations to balance strength, flexibility, and manufacturability, improving joint performance.

In summary, the integration of advanced simulation methods and innovative technologies such as additive manufacturing allows the performance of adhesive joints to be optimized while ensuring reliability and safety. Accurate design of geometries is a crucial element in successfully tackling the most complex engineering challenges.

3. SURFACES PREPARATION

Surface preparation is crucial to ensure the strength and durability of adhesive joints, as it directly influences the quality of adhesion between the adhesive and the substrate. In metals, treatments such as anodizing and sandblasting improve anchorage: anodising, in particular, creates a porous oxidized layer that favours chemical adhesion. In composite materials, the layered nature requires specific techniques such as peel ply, which leaves a uniform surface, or plasma treatment, which increases surface energy by removing contaminants. Low-pressure sandblasting also proves effective in cleaning surfaces without damaging the fibres.

Figure 4. Single-lap adhesive joints specimens assembled between timber adherends

The use of specific primers is a further step in stabilizing surfaces, improving chemical adhesion and protecting against environmental factors. Recently, the use of functionalised nanostructures has introduced new opportunities, increasing the adhesive-substrate contact area and the overall strength of the joint. Functionalized nanostructures improve adhesive strength by increasing the contact surface between the adhesive and the substrate. Functionalized chemical groups on the surface of the nanostructures form chemical bonds with the adhesive and the material, strengthening the bond. This increases the distribution of adhesive forces and reduces the risk of peeling, improving the strength of the joint.

Standardization and monitoring of surface preparation are crucial for joint integrity, with quality control methods like roughness analysis and adhesion tests ensuring reliable results. Real-time monitoring systems further improve process reliability. Advances in additive manufacturing have transformed adhesive joint design, enabling complex, customized geometries and local reinforcements that enhance strength without increasing weight. These innovations provide more options to address the challenges of advanced applications and demanding operating conditions.

In this sense, some experimental cases of additive manufacturing are those conducted by Naat et al. (35) and Cavalcanti et al. (36).

In the first case, the study shows that stainless steel produced by additive manufacturing (SLM) can achieve a significant increase in shear strength in adhesive joints due to bio-inspired textures, such as frog skin imitation (+70%), which improve mechanical bonding and physical adsorption. In contrast, abrasion with sandpaper reduces surface roughness and worsens adhesive performance. In the second case, PLA adhesive joints reinforced with curauá fibres showed a strength improvement of more than 1.5 times compared to non-reinforced PLA joints, due to good adhesion with epoxy resin. In contrast, ABS joints showed lower performance due to the weaker mechanical properties of the material.

To enhance the discussion, it would be beneficial to include a cost-benefit analysis of various surface treatment methods, considering both economic and performance aspects. Methods such as abrasive blasting, chemical etching, and plasma treatment each carry distinct costs. Abrasive blasting, for instance, can be cost-effective in terms of equipment and maintenance but incurs higher expenses related to material consumption and labor. Chemical etching, while offering precise surface modification, involves recurring costs for chemicals, waste disposal, and safety measures, which may not be ideal for high-volume applications. Plasma treatment, although requiring a higher initial investment for equipment, can provide long-term savings by reducing material consumption and energy use, while also improving joint strength. A comprehensive cost-benefit analysis of these methods, factoring in efficiency, durability, operational costs, and environmental impact, would enable industries to make more informed decisions regarding the most suitable surface treatment for their specific applications.

4. NUMERICAL MODELING AND STRESS ANALYSIS

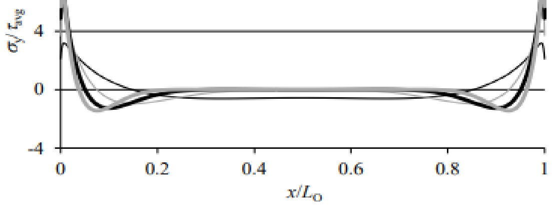
The design and verification of adhesive joints require advanced tools to simulate behaviour under complex loads, which include static, dynamic and cyclic stresses. One of the most widely used methods is the cohesive zone model (CZM), which allows the study of fracture propagation within the joint and the prediction of failure points. This approach integrates the microstructure of the adhesive into the model, providing detailed predictions of critical conditions. CZM and FEA have been used in industrial applications to optimize adhesive joints. For example, in the automotive industry, FEA has been used to analyse and improve the strength of joints in doors and side panels, while CZM has been used to study fracture propagation. In aerospace, these tools have also been instrumental in optimizing joints in aircraft wings, improving strength without increasing weight.

In parallel, finite element analysis (FEA) is another key tool for adhesive joint optimisation. Using two- and three-dimensional computational models, the distribution of stresses and strains along the joint can be analyzed, identifying areas subject to stress concentrations.

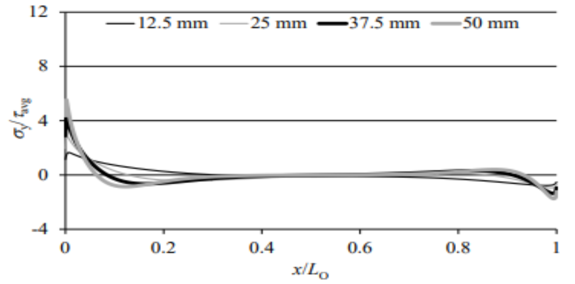
Figure 5 shows the stress distribution in single and double-lap adhesive joints. It is observed how the geometry and asymmetry of the joint influence the stress distribution in the overlap length (37).

This type of analysis is particularly useful for complex geometric configurations, such as sinusoidal profile joints or stepped-lap joints. Recent developments in the use of advanced software allow more accurate simulations, integrating phenomena such as creep and adhesive plasticization.

Figure 6 shows the 3D stress distribution discussed by Marchione (10). The stress distribution is obtained by FE analysis.

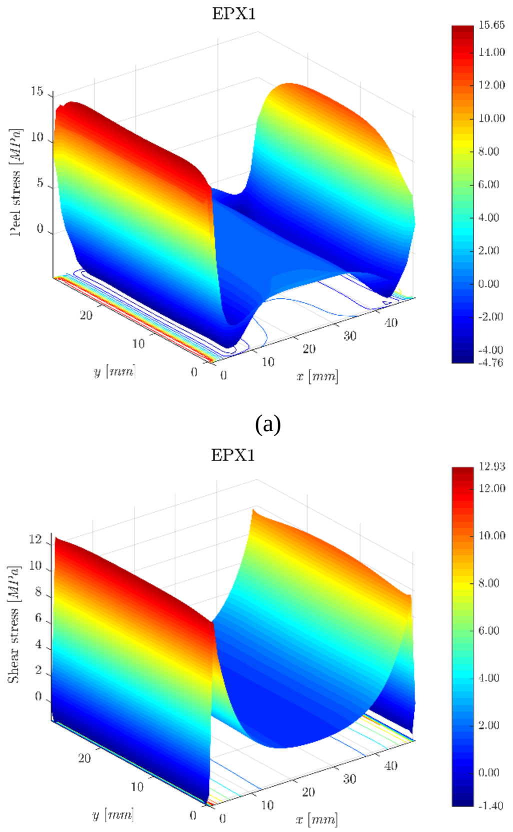


(a)



(b)

Figure 5. Adimensional Stress distribution in single-lap adhesive joints (a), and in double-lap adhesive joints (b) for different overlap lengths



(a)

(b)

Figure 6. 3D distribution of peel and shear stress distribution for single-lap joints

Multiscale models link the microstructural behavior of adhesives to the macroscopic performance of joints, allowing for better prediction of long-term durability and the interaction between adhesive and substrate. Incorporating experimental data enhances model reliability. Additionally, AI and machine learning are transforming numerical modeling by analyzing large datasets to identify optimal material, geometry, and process combinations, such as joint configurations that maximize strength while minimizing weight.

The study conducted by Fernandes et al. (38) compares data-driven (DDM), physical (PBM) and hybrid (HM) models to predict the fatigue life of adhesive joints. DDMs are more accurate but more sensitive to dataset size, with LGBM performing best. Hybrid models improve accuracy and reduce data sensitivity, with HM-I optimizing predictions, especially with small datasets.

Furthermore, the adoption of topological optimisation techniques is emerging as a promising solution to design joints with customized adhesive distributions. These methods reduce material consumption while maintaining high mechanical performance.

To ensure the reliability of the numerical simulations using methods such as finite element analysis (FEA), it is crucial to carefully evaluate the assumptions and simplifications made during model construction. These assumptions, such as idealizing material properties, boundary conditions, or neglecting certain geometric features, should be clearly justified based on the specific application and the level of accuracy required. Sensitivity analysis can be used to assess the impact of these assumptions on the simulation results, ensuring that they do not significantly affect the overall predictions. Additionally, validating the numerical model through comparison with experimental data or established benchmark cases can further confirm the reliability of the simulation results. By applying these practices, it is possible to mitigate the risks of over-simplification and ensure that the model accurately represents the real-world behavior of adhesive joints under different conditions.

In conclusion, numerical analysis and advanced modelling offer indispensable tools for designing high-performance adhesive joints. The adoption of innovative techniques, such as CZM, FEA and AI, combined with multi-scale modelling and optimization approaches, opens up significant prospects for improving the safety, reliability and efficiency of adhesive joints in critical applications.

5. CONCLUSIONS

The design of adhesive joints is a complex yet exciting challenge, with recent advancements in materials such as nanomaterials, along with emerging technologies like additive manufacturing and artificial intelligence, significantly enhancing their performance. However, several key challenges remain. Standardization of surface preparation and manufacturing methods is essential to ensure reliable, repeatable performance. Future research should prioritize defining standardized protocols for these processes, particularly in terms of sustainability, to reduce waste and energy consumption in production.

To address standardization challenges in bonding technology, clear implementation steps are needed, such as creating uniform guidelines for surface preparation, material selection, and testing. Initial small-scale projects can test these standards, with broader adoption following successful results. Expected benefits like improved reliability, reduced variability, and enhanced sustainability should be defined and backed by case studies. These steps will provide a practical framework for standardization, benefiting both industry and research.

Moreover, further investigation into the adaptability of adhesive joints under varying environmental conditions, including exposure to moisture and extreme temperatures, is necessary. Enhanced numerical modeling tools like CZM and FEA should continue to be applied to predict and optimize joint behavior in these complex real-world scenarios. A crucial area for both research and industrial implementation is the integration of real-time monitoring techniques, such as embedded sensors, which can enhance safety, enable predictive maintenance, and help reduce the environmental impact of repairs. The role of adhesive joints in promoting more sustainable construction practices should be further explored, particularly in terms of their ability to reduce material waste, lower energy consumption, and improve the longevity of structures, thereby contributing to a circular economy. Collaboration between academia and industry is vital to accelerate the adoption of these technologies, reduce development time, and lower costs, while simultaneously advancing the sustainability of structural systems. In summary, adhesive joints have significant potential to play a central role in the future of construction, and overcoming current challenges through focused research, standardization, and innovation will ensure they contribute to more efficient, durable, and sustainable structures.

7. REFERENCES

1. Adams RD, Comyn J, Wake WC. Structural adhesive joints in engineering: Springer Science & Business Media; 1997.
2. Da Silva LF, Öchsner A, Adams RD. Handbook of adhesion technology: Springer Science & Business Media; 2011.
3. Munafò P, Marchione F. Caratterizzazione meccanica di giunti adesivi-Costruzione di componenti edilizi più semplici, leggeri e con alte prestazioni. 2023.
4. Banea M, da Silva LF. The effect of temperature on the mechanical properties of adhesives for the automotive industry. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications. 2010;224(2):51-62. https://doi.org/10.1243/14644207JMDA283
5. Ciupack Y, Pasternak H, Mette C, Stammen E, Dilger K. Adhesive bonding in steel construction-Challenge and innovation. Procedia Engineering. 2017;172:186-93. https://doi.org/10.1016/j.proeng.2017.02.048
6. Machado J, Marques E, da Silva LF. Influence of low and high temperature on mixed adhesive joints under quasi-static and impact conditions. Composite Structures. 2018;194:68-79. https://doi.org/10.1016/j.compstruct.2018.03.093
7. Overend M, Jin Q, Watson J. The selection and performance of adhesives for a steel–glass connection. International Journal of Adhesion and Adhesives. 2011;31(7):587-97. https://doi.org/10.1016/j.ijadhadh.2011.06.001
8. Žigon J, Kovač J, Zaplotnik R, Saražin J, Šernek M, Petrič M, et al. Enhancement of strength of adhesive bond between wood and metal using atmospheric plasma treatment. Cellulose. 2020;27(11):6411-24. https://doi.org/10.1007/s10570-020-03212-8
9. Marchione F. Investigation of vibration modes of double-lap adhesive joints: Effect of slot. International Journal of Engineering, Transactions A: Basics. 2020;33(10):1917-23. https://doi.org/10.5829/ije.2020.33.10a.10
10. Marchione F. FE analysis of single-lap adhesive joints with tapered adherends. International Journal of Engineering, Transactions A: Basics. 2021;34(10):2213-8. https://doi.org/10.5829/ije.2021.34.10a.03
11. Marchione F. Analytical stress analysis in single-lap adhesive joints under buckling. International Journal of Engineering, Transactions B: Applications,. 2021;34(2):313-8. https://doi.org/10.5829/ije.2021.34.02b.02
12. Marchione F, Chiappini G, Munafò P. Effect of temperature and relative humidity on the shear performance of double-lap adhesive joints between steel and glass adherends. Journal of Building Engineering. 2022;45:103546. https://doi.org/10.1016/j.jobe.2021.103546
13. Marchione F, Munafo P. Experimental investigation on timber-glass double-lap adhesive joints reinforced with nylon fabric. Construction and Building Materials. 2021;275:122152. https://doi.org/10.1016/j.conbuildmat.2020.122152
14. Ozturk B. Seismic behavior of two monumental buildings in historical Cappadocia region of Turkey. Bulletin of Earthquake Engineering. 2017;15:3103-23. https://doi.org/10.1007/s10518-016-0082-6
15. Güney D, Aydin E, Öztürk B, editors. The evaluation of damage mechanism of unreinforced masonry buildings after Van (2011) and Elazig (2010) Earthquakes. Journal of Physics: Conference Series; 2015: IOP Publishing.
16. Suhir E. Predictive analytical thermal stress modeling in electronics and photonics. 2009. https://doi.org/10.1115/1.3077136
17. de Castro J, Keller T. Ductile double-lap joints from brittle GFRP laminates and ductile adhesives, Part II: numerical investigation and joint strength prediction. Composites Part B: Engineering. 2008;39(2):282-91. https://doi.org/https://doi.org/10.1016/j.compositesb.2007.02.016
18. Foraboschi P. Behavior and failure strength of laminated glass beams. Journal of Engineering Mechanics. 2007;133(12):1290-301. ttps://doi.org/10.1061/(asce)0733-9399(2007)133:12(1290)
19. Ntintakis I, Stavroulakis GE, Plakia N. Topology optimization by the use of 3D printing technology in the product design process. HighTech and Innovation Journal. 2020;1(4):161-71. https://doi.org/10.28991/HIJ-2020-01-04-03
20. Sommer D, Haufe A, Middendorf P. A machine learning material model for structural adhesives in finite element analysis. International Journal of Adhesion and Adhesives. 2022;117:103160. https://doi.org/10.1016/j.ijadhadh.2022.103160

21. Da Silva L. Improving bonding at high and low temperatures. Advances in structural adhesive bonding: Elsevier; 2010. p. 516-46.
22. Ciardiello R, Belingardi G, Martorana B, Brunella V, Hodge S, Galhena D, et al. Reversible graphene-based adhesives for automotive applications. International Journal of Adhesion and Adhesives. 2025;138:103935. https://doi.org/10.1016/j.ijadhadh.2025.103935
23. Scoccia C, Carbonari L, Palmieri G, Callegari M, Rossi M, Munafó P, et al. Design of a tensegrity servo-actuated structure for civil applications. Journal of Mechanical Design. 2022;144(4):043302. https://doi.org/10.1115/1.4053283
24. Chiappini G, Coccia M, Rossi M, Marchione F, Munafò P, Scoccia C, et al., editors. Assessment of the deformation behavior of a tensegrity floor through photogrammetry. IOP Conference Series: Materials Science and Engineering; 2022: IOP Publishing.
25. Marchione F, Munafò P. Experimental strength evaluation of glass/aluminum double-lap adhesive joints. Journal of Building Engineering. 2020;30:101284. https://doi.org/10.1016/j.jobe.2020.101284
26. Pascual C, Overend M. Buckling of sandwich struts with a particular application in composite multi-layer glazing. Engineering Structures. 2021;230:111545. https://doi.org/10.1016/j.engstruct.2020.111545
27. Machalická K, Eliášová M. Adhesive joints in glass structures: effects of various materials in the connection, thickness of the adhesive layer, and ageing. International Journal of Adhesion and Adhesives. 2017;72:10-22. https://doi.org/10.1016/j.ijadhadh.2016.09.007
28. Machalická K, Vokáč M, Eliášová M. Influence of artificial aging on structural adhesive connections for façade applications. International Journal of Adhesion and Adhesives. 2018;83:168-77. https://doi.org/10.1016/j.ijadhadh.2018.02.022
29. Machalická K, Horčičková I, Eliášová M, editors. Shear adhesive connections for glass structures. IOP Conference Series: Materials Science and Engineering; 2015: IOP Publishing.
30. Marchione F, Chiappini G, Rossi M, Scoccia C, Munafò P. Experimental assessment of the static mechanical behaviour of the steel-glass adhesive joint on a 1: 2 scale tensegrity floor prototype. Journal of Building Engineering. 2022;53:104572. https://doi.org/10.1016/j.jobe.2022.104572
31. Marchione F, Munafò P. Applicazione della tecnologia adesiva a componenti edilizi innovativi: dalla verifica tecnico-costruttiva alla realizzazione. Design and construction–Progetto e Costruzione: EdicomEdizioni; 2021. p. 1359-73.
32. Adams R, Peppiatt N. Stress analysis of adhesive-bonded lap joints. Journal of strain analysis. 1974;9(3):185-96. https://doi.org/10.1243/03093247V093185
33. Marchione F. Stress distribution in double-lap adhesive joints: Effect of adherend reinforcement layer. International Journal of Adhesion and Adhesives. 2021;105:102780. https://doi.org/10.1016/j.ijadhadh.2020.102780
34. Marchione F, Munafo P. Effect of thermal aging on the mechanical performance of timber-timber single-lap adhesive joints. International Journal of Adhesion and Adhesives. 2021;108:102883. https://doi.org/10.1016/j.ijadhadh.2021.102883
35. Naat N, Boutar Y, Naïmi S, Mezlini S, da Silva LF, Bashiri AH. Influence of bio-inspired surface texture of additively manufactured 17-4 PH stainless steel adherends on the strength of adhesively bonded joints. International Journal of Adhesion and Adhesives. 2023;126:103478. https://doi.org/10.1016/j.ijadhadh.2023.103478
36. Cavalcanti D, de Queiroz H, Banea M. Performance enhancement of adhesive joints of additive manufactured parts by using different types of fibre reinforcements. International Journal of Adhesion and Adhesives. 2023;124:103371. https://doi.org/10.1016/j.ijadhadh.2023.103371
37. Nunes S, Campilho R, Da Silva F, De Sousa C, Fernandes T, Banea M, et al. Comparative failure assessment of single and double lap joints with varying adhesive systems. The Journal of Adhesion. 2016;92(7-9):610-34. https://doi.org/10.1080/00218464.2015.1103227
38. Fernandes PHE, Silva GC, Pitz DB, Schnelle M, Koschek K, Nagel C, et al. Data-driven, physics-based, or both: Fatigue prediction of structural adhesive joints by artificial intelligence. Applied Mechanics. 2023;4(1):334-55. https://doi.org/10.3390/applmech4010019

Persian Abstract

چکیده

طراحی اتصالات چسب در صنایعی مانند هوافضا، خودروسازی و راه آهن بسیار مهم است، جایی که آنها جایگزین سبک وزنی برای روش های سنتی مانند جوشکاری و پیچ و مهره هستند. اتصالات چسب تنش را به طور یکنواخت توزیع می کنند و امکان جمع آوری هندسه های پیچیده را فراهم می کنند. این بررسی بر روی فناوری‌های پیشرفته تمرکز دارد و نقش نانومواد را در افزایش استحکام خستگی و پایداری شیمیایی–حرارتی برجسته می‌کند. همچنین پتانسیل ساخت افزودنی را برای ایجاد هندسه مشترک سفارشی و امکان نظارت در زمان واقعی از طریق حسگرهای تعبیه شده بررسی می کند. این مقاله به بررسی چسب‌های پرکاربرد، از جمله اپوکسی‌ها و پلی‌اورتان‌ها، و همچنین طرح‌های اتصالات نوآورانه، مانند پروفیل‌های سینوسی و پیکربندی‌های چند ماده‌ای می‌پردازد که توزیع تنش و یکپارچگی ساختاری را بهبود می‌بخشد. تکنیک‌های آماده‌سازی سطح و ابزارهای عددی پیشرفته، مانند مدل‌سازی منطقه منسجم و هوش مصنوعی، نیز برای نقش آنها در بهینه‌سازی عملکرد مفصل مورد بحث قرار گرفته‌اند. این مطالعه چالش‌های کلیدی، از جمله استانداردسازی فرآیندها و ادغام مواد جدید را شناسایی می‌کند، و استراتژی‌هایی را برای افزایش عملکرد اتصالات پیوندی در کاربردهای صنعتی پیشرفته تشریح می‌کند.