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<https://doi.org/10.3390/met15101082>

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Corrosion Resistance Properties of As-Sintered 17-4 PH Samples Additive-Manufactured Through Binder Jetting

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Abstract

The corrosion resistance and microstructural characteristics of 17-4 PH stainless steel fabricated through Metal Binder Jetting (MBJ) were investigated through Cyclic Potentiodynamic Polarization (CPP), Open Circuit Potential (OCP) monitoring, SEM-EDX, optical microscopy, XRD, and chemical etching. Electrochemical tests revealed that as-sintered samples exhibited isotropic corrosion performance across different build-up orientations and directions. The CPP tests indicated the formation of a passive film with limited stability, while the monitoring of the OCP showed initial instability, followed by stabilization over time. Microstructural analysis indicated the presence of microporosities and a structure consisting of martensitic and ferritic grains in the as-sintered 17-4 PH, alongside copper and niobium segregations at grain boundaries, which may deeply influence localized corrosion susceptibility. These findings suggest that the as-sintered 17-4 PH fabricated through MJB exhibits comparable corrosion behavior to 17-4 PH additive-manufactured through other techniques in which the sintering process is involved. The study highlights the influence of microstructure on electrochemical performance and underscores the need for post processing treatments to enhance corrosion resistance.

Keywords: additive manufacturing; binder jetting; as-sintered; stainless steel; segregations; cyclic potentiodynamic polarization; open circuit potential; corrosion resistance; passive film instability; isotropy



Academic Editor: Jürgen Eckert

Received: 31 March 2025

Revised: 17 September 2025

Accepted: 19 September 2025

Published: 27 September 2025

Citation: Forcellese, P.; Khan, W.A.; Mancia, T.; Simoncini, M.; Reiser, M.; Kouřil, M.; Bellezze, T. Corrosion Resistance Properties of As-Sintered 17-4 PH Samples Additive-Manufactured Through Binder Jetting. *Metals* **2025**, *15*, 1082. <https://doi.org/10.3390/met15101082>

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1. Introduction

The most common metal Additive Manufacturing (AM) technologies on the market are laser-based or electron-based systems, including Powder Bed Fusion (PBF) and Direct Energy Deposition (DED), which together accounted for 70% of the metal AM market in 2020 [1]. Contrary to these common AM systems in which powders are melted using a beam to directly build parts while printing, Metal Binder Jetting (MBJ) metals and alloys are fabricated in different steps. The MJB printing process consists of the deposition of a liquid polymeric binder over a layer of metal powders. A printhead typically sprays a

binder, then a recoater, or roller, deposits a new layer of powder onto the build platform, followed by the application of the binder. This process continues until the green part, a composite structure of metal powders bound by the polymer, is entirely fabricated. After printing, the resulting green parts undergo further steps to reach the required mechanical properties of metals and alloys. This process includes curing the polymer, depowdering the loosened powders, debinding the polymer, and finally sintering at a temperature close to the melting point of the specific material [2,3].

MBJ has recently gained attention as an efficient and cost-effective alternative AM technology for producing metals and alloys without needing high-energy beams [4–7]. Another aspect worth considering is the recyclability of metal powders in MBJ, which is paramount for sustainable manufacturing. Studies on powder reuse show that while recycled powders exhibit slight variations in particle size distribution and flowability, their impact on mechanical properties remains limited [8,9].

However, despite these advantageous characteristics, MBJ is less widely adopted than PBF and DED systems, mostly due to the lower mechanical properties of the sintered parts. This limitation is primarily caused by the porosity left after the sintering process, which remains a technological challenge to overcome for broader industrial adoption [10–13]. As the printing process of MBJ does not involve powder melting, the materials fabricated using this technology are characterized by porosities and complex microstructures. Specifically, the interaction between powder and binder is crucial in determining the mechanical properties and integrity of the parts [14,15]. Debinding and sintering are particularly critical as they influence shrinkage, densification, and microstructure [2,16]. Although MBJ can produce near-net-shape parts with isotropic properties, they require optimization through post-processing treatments to improve strength and surface finish. The binder content and saturation also significantly influence the green part strength and dimensional stability [15,17–20].

In contrast to MBJ, laser-based and electro-based AM systems produce stainless steel parts with anisotropic microstructural properties that depend on the build direction, directly affecting both mechanical and corrosion performance [21,22]. The heat source of these technologies induces significant thermal gradients due to repeated heating and cooling cycles. This leads to a heterogeneous stainless steel microstructure, characterized by grains elongated preferentially along the build direction, residual stress, and segregations [23]. Although additive-manufactured stainless steel can outperform the corrosion resistance properties of parts fabricated using subtractive metallurgy processes, the build direction significantly influences the corrosion behavior of stainless steel, with parts fabricated parallel to the build plate generally exhibiting superior corrosion performance [24,25].

Corrosion resistance is critical in determining the effective applicability of additive-manufactured components. Previous studies [26–28] investigated the localized corrosion resistance of 17-4 PH stainless steel fabricated using Material Extrusion (ME). They reported lower properties of the passive film than wrought material and significant variations based on build orientation and heat treatments. Strategies that have proven to improve corrosion resistance properties of sintered stainless steel include post-processing heat treatments such as solution-annealing and aging [27,28]. Similar concerns can be translated to MBJ since the microstructure resulting from the sintering process is similar to that of ME [29,30]. Austenitic stainless steel produced through MBJ displayed inconsistent corrosion resistance behavior in a neutral pH sodium chloride environment. While the as-built (unground, unpolished) 316L samples exhibited transpassive behavior, the same samples showed increased susceptibility to pitting corrosion compared to wrought counterparts after the grinding procedure [31,32]. In contrast, in a highly acidic environment, both as-built and

polished 316L samples exhibited higher corrosion resistance properties than those of a wrought [33].

In light of the above, while MBJ remains a promising AM technique, its widespread adoption remains hindered by the need to optimize binder formulations, sintering conditions, and post-processing treatments, especially concerning the role of the microstructure. The present study aims to address these challenges, focusing on the localized corrosion resistance properties of MBJ-produced 17-4 PH stainless steel in neutral pH sodium chloride solutions, as it is widely adopted as a structural material in aerospace, oil and gas, and biomedical industries. The main goal of this study is to evaluate the influence of different build-up orientations and directions by characterizing the microstructural properties and electrochemical behavior of the passive film in 17-4 PH stainless steel fabricated through MBJ, thereby addressing the current knowledge gap and advancing the understanding of its industrial applicability.

2. Materials and Methods

In this study, 17-4 PH stainless steel as-sintered samples were fabricated through Binder Jetting AM technology, with various build-up orientations and directions, as illustrated in Figure 1. The printing process was performed using the Shop System (Desktop Metal, Burlington, MA, USA), with a layer thickness set at 75 μm . The printhead roller operated with a transverse speed of 75 $\text{mm}\cdot\text{s}^{-1}$ and a rotational speed of 330 rpm. Regarding binder saturation, the components were divided into different regions, with the saturation values defined in the proprietary software that controls the binder deposition pattern. The actual binder saturation values (expressed as deposited volume percentage) were 61% in the top and shell, 38% in the inner region, and 31% in the bottom. After printing, the green parts were depowdered and handled using the Powder Station from Desktop Metal. Before sintering, the samples underwent a curing step in the Drying Oven, also available on the same platform. The samples underwent a single thermal cycle combining debinding and sintering, carried out in the Shop System furnace (Desktop Metal) under an inert gas atmosphere of 97% argon and 3% hydrogen, ensuring slightly reductive conditions. The sintering step reached a peak temperature of 1300 $^{\circ}\text{C}$ at a pressure of 17 torr. The thermal profile could not be displayed or adjusted, as it was predefined by the Shop System, which runs an algorithm to optimize binder removal and promote densification for achieving the desired mechanical properties.

Figure 1 shows the seven squared plates investigated in this study, with a side length of 25 mm and a thickness of 10 mm. The samples were fabricated by combining three build-up orientations (0° , 45° , and 90°), concerning the build plate (XZ plane) and labeled as A, and three build-up directions (0° , 45° , and 90°), concerning the printhead direction (XY plane) and labeled as B.

The squared side (25×25 mm) of these samples was ground to 1200 grit using emery paper and then cleaned in a sonicator with water for 5 min, followed by 15 min with normal-hexane. Before performing the electrochemical tests, the samples were left to rest for 24 h. Then, a polyimide tape was applied to the ground side of the samples, leaving an exposed area of 2 cm^2 for the electrochemical tests. At least three repetitions were performed for each build-up orientation and direction investigated through the electrochemical methods considered in this study.

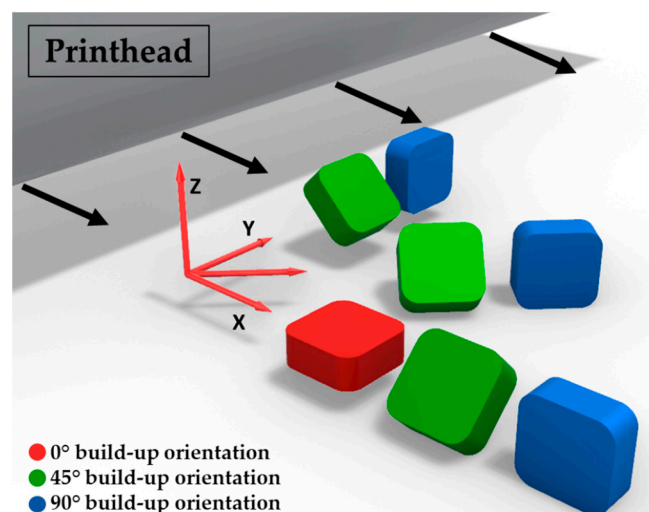


Figure 1. Schematic representation of the different build-up orientations and directions of the 17-4 PH samples fabricated through MBJ. The samples were fabricated with three different build-up orientations (XZ plane) concerning the build plate: 0° (red sample), 45° (green samples), and 90° (blue samples); and three different build-up directions (XY plane) concerning the printhead direction (black arrows): 0°, 45°, and 90°. Build-up orientations were labeled as A, whereas the directions as B.

The Cyclic Potentiodynamic Polarization (CPP) was carried out at room temperature using a Gamry Reference 600 and Interface 1010 potentiostat (Gamry Instruments, Warminster, PA, USA) in a neutral pH 0.35 wt.% sodium chloride electrolyte using a three-electrode cell configuration. The working electrode was the tested as-sintered sample, a Saturated Calomel Electrode (SCE, $E = 0.241$ V vs. SHE) was used as the reference electrode, and a titanium-activated wire was used as the counter electrode. The CPP curves were performed, with a forward and reverse scan rate of $83 \mu\text{V s}^{-1}$, starting at 175 mV negative to the free corrosion potential and going towards positive potentials until the current density reached $0.1 \text{ mA}\cdot\text{cm}^{-2}$; then, the scan was reversed until current densities were close to those of passivation conditions, recorded during the forward scan. The working electrode potential was recorded for 30 min before the test. Furthermore, the electrochemical impedance spectroscopy was carried out before recording the CPP curves, over a frequency range of 100 kHz to 1 Hz with 10 points per decade and an applied signal amplitude of 10 mV for determining the electrolyte resistance to correct the curves from the ohmic drop. After the tests, the corrosion current density (i_{corr}) was estimated using the Tafel model using Gamry Echem Analyst 2 software. Optical microscopy was conducted after the CPP measurements to observe whether pitting or crevice forms of localized corrosion occurred on the surface of the tested sample.

Open circuit potential (OCP) monitoring was conducted on the as-sintered samples at a controlled temperature of 30 ± 0.1 °C in a neutral pH 3.5 wt.% sodium chloride electrolyte for 96 h. The potential readings were recorded every 2.5 min using an SCE as a reference electrode and an Agilent Data Switching Unit—Model 34970A equipped with a multiplexer module—Model 34901A (Agilent, Santa Clara, CA, USA). Also, a 17-4 PH wrought sample (Wr) was investigated in the OCP monitoring to compare the electrochemical stability of the passive film with that of the as-sintered samples fabricated through MBJ. The OCP analysis was performed between 24 and 96 h using a numerical procedure to assess the passive film instability, following the same methodology described in a previous study [27]. Baseline points corresponding to steady-state conditions were identified, and a nonlinear regression curve was used to interpolate these values. Activation events exceeding a threshold of

−10 mV relative to the baseline were integrated using the trapezoidal rule to quantify the instability of the passive film, or the area of these events expressed in [mV·h].

The microstructural characterization was performed on as-sintered 17-4 PH using a procedure similar to that of a previous study [27]. However, only the A0B0 sample is shown in this study, as it was considered representative of the build-up orientations and directions. Scanning Electron Microscopy (SEM) (Carl Zeiss Microscopy GmbH, Jena, Germany) with Energy-Dispersive X-ray Spectroscopy (EDX) (Bruker Nano GmbH, Berlin, Germany) was conducted on the samples, polished to 1 µm using spray monocrystal diamond powders, to assess grain structure, inclusions, segregations, and porosity. SEM-EDX analyses were performed using the Backscattered electron detector, at a voltage of 15 kV, with a working distance of 9 mm and an aperture size of 60 µm. X-ray Diffraction (XRD) was conducted on A0B0 as-sintered samples ground to 1200 grit, to evaluate the phase composition, distinguishing between ferritic and austenitic structures. The XRD measurements were carried out using a Bruker D8 Advance diffractometer (Bruker, Billerica, MA, USA) with monochromatic Cu-K α radiation ($\lambda = 1.54 \text{ \AA}$), scanning over a 2θ range from 30° to 80° . Kalling's reagent (1.5 g of copper chloride in 33.3 mL of water, 33.3 mL of ethanol, and 33.3 mL of hydrochloric acid) and Vilella's reagent (1 g of picric acid in 100 mL of ethanol and 5 mL of hydrochloric acid) were used to etch the surface of the A0B0 as-sintered samples polished to 1 µm with spray monocrystal diamond powders, to reveal microstructural features that were observed using optical microscopy.

The chemical composition of the as-sintered A0B0 sample, ground to 1200 grit using emery paper and then cleaned by sonication in deionized water for 5 min, was analyzed at six points using a Spark Analyzer (Spectrolab, Sylmar, CA, USA).

3. Results and Discussion

The chemical composition of the as-sintered A0B0 sample fabricated through MBJ is reported in Table 1. The values are consistent with those of a typical wrought 17-4 PH stainless steel.

Table 1. Average chemical composition (wt.%) of the as-sintered sample.

Cr	Ni	Cu	Si	C	Mn	Mo	Fe
16.54	4.77	3.35	0.54	0.02	0.46	0.21	Bal.

The XRD diffractogram shown in Figure 2 of the as-sintered A0B0 sample reveals the presence of only BCC phase peaks commonly attributed to martensite and ferrite in stainless steel. In contrast, a typical wrought sample displays both Face-Centered Cubic (FCC) and Body-Centered Cubic (BCC) peaks, although retained austenite (BCC) represents just a small fraction in volume, as observed in a previous study [27]. This suggests the sintering process leads to different microstructures rather than those typically observed for wrought samples.

Moreover, the absence of residual austenite in sintered stainless steel has been attributed to different factors in the existing literature: the presence of H₂ gas in the sintering chamber together with pores and heterogeneities characterizing grain boundaries, which both foster the ferrite formation in place of the austenite [34]; the transformation of austenite to martensite at room temperature, or below 912°C , due to slow cooling rates after sintering [35,36]; the sintering temperature above $1200\text{--}1300^\circ\text{C}$ [36,37]; and the low carbon content of the stainless steel [38]. On the other hand, the formation of a secondary phase of ferrite is common in sintered stainless steel, and it has mainly been caused by the segregation of ferrite-stabilizing elements such as Cr due to the slow cooling rates after sintering [36,39–43].

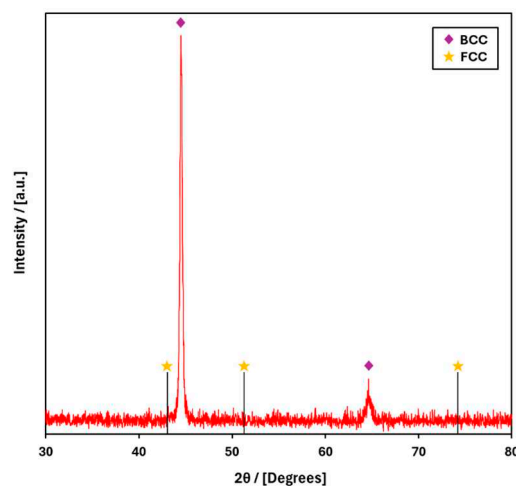


Figure 2. XRD diffractograms of the as-sintered A0B0 sample showing the peaks associated with the BCC phase.

The microstructure of A0B0, revealed using Kalling's and Vilella's reagents, as shown in Figure 3, highlights the typical features of sintered stainless steel. The darker grains revealed using Kalling's (Figure 3a) etchant are characteristic of martensitic grains, in agreement with observations made in other studies on samples fabricated through ME, MBJ, and material injection molding [27,34,35,38,44]. Despite the absence of a typical wrought martensitic microstructure, the similarity to a previous study conducted on an ME technique (i.e., Bound Metal Deposition) suggests a mixed martensitic and ferritic microstructure [27]. When Vilella's etchant is used (Figure 3b), oxides, carbides, segregations, and inclusions appear on the surface, particularly at grain boundaries. However, their precise identification using the optical microscopy technique remains uncertain. These features are consistent with those observed in a previous study [27] on as-sintered 17-4 PH stainless steel fabricated through ME, although the surface seems to be less affected by inclusions and porosities.

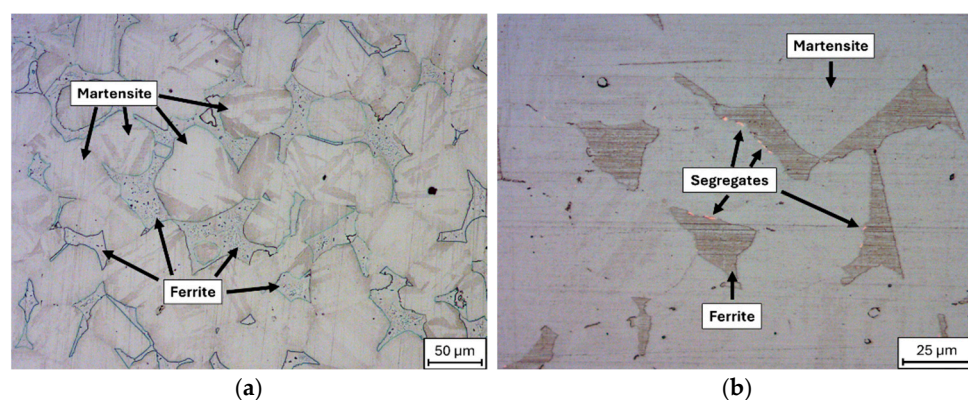


Figure 3. Microstructural characterization through optical microscopy of the A0B0 as-sintered sample etched using Kalling's (a) and Vilella's (b) reagents.

The SEM-EDX investigations using the backscattered electron detector conducted on the A0B0 sample shown in Figure 4a confirm the presence of two distinct grains: ferrite and martensite. Furthermore, the average chemical composition analyzed through EDX, obtained using the points labeled in Figure 4a (1, 2, and 3 for the martensitic grains; 4, 5, and 6, for the ferritic grains), and shown in Table 2, suggests the presence of ferritic grains that are enriched in chromium (~22 wt.%) and depleted in nickel (~2 wt.%) and copper (~1 wt.%). In contrast, the martensitic grains exhibit the typical chemical composition of 17-4 PH (Cr = 15–16 wt.%; Ni = 4 wt.%; Cu = 4 wt.%). These results are consistent with

those observed for as-sintered 17-4 PH fabricated through ME in a previous study [27]. Small porosities, a few micrometers in diameter, are also visible as shown in Figure 4a. The elements present on the surface (Cr, Cu, and Nb) were mapped on a magnified image (Figure 4b) of the SEM investigation, and shown in Figure 4c. The elemental map highlights copper and niobium segregations, with copper found predominantly within ferritic grains and along porosities and niobium segregated at grain boundaries.

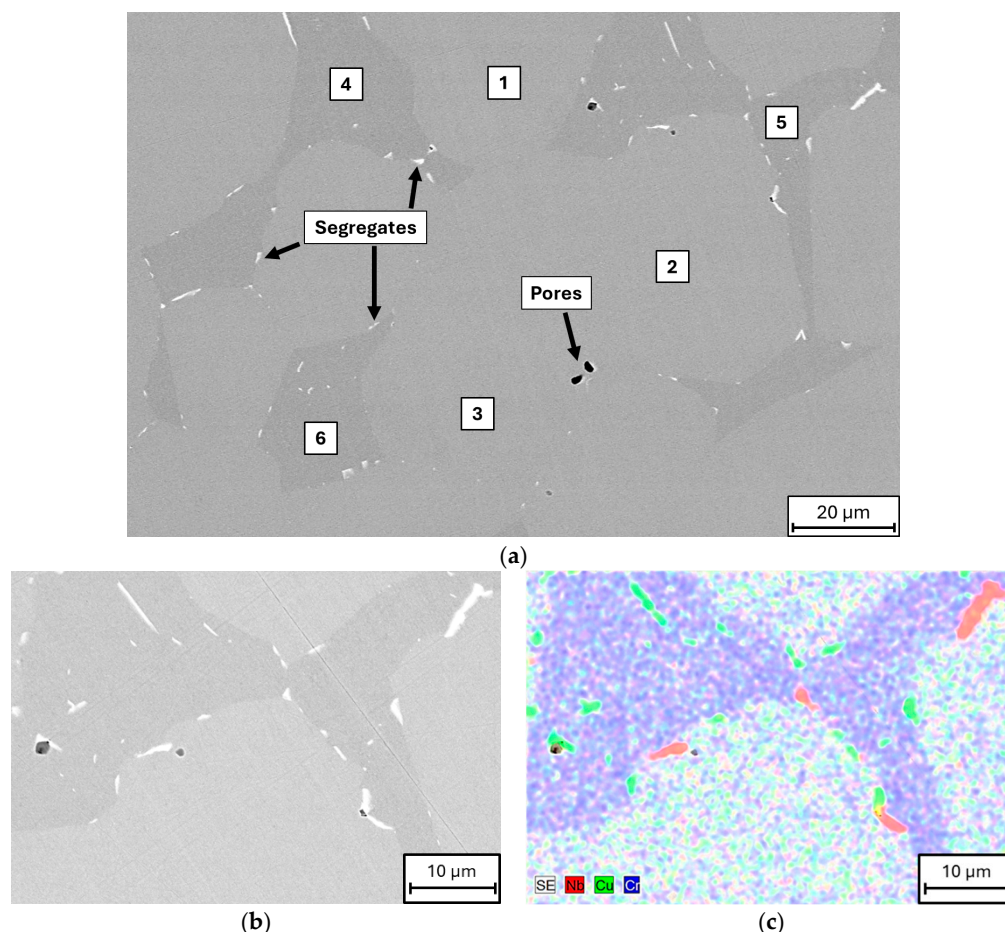


Figure 4. Microstructural characterization through SEM-EDX of the A0B0 as-sintered sample: backscattered detector (a,b) and elemental map (c) showing chromium (blue), copper (green), and niobium (red).

Table 2. The average chemical composition (wt.%) of the grains shown in Figure 4a analyzed through EDX.

		Cr	Ni	Cu	Nb	Si	Fe
Bright grains (martensite)	Average	15.6	4.4	4.0	0.3	0.7	75.0
	Std. Dev.	0.2	0.1	0.1	0.1	0.1	0.1
Dark grains (ferrite)	Average	22.2	1.9	0.9	0.3	1.0	73.7
	Std. Dev.	0.1	0.1	0.1	0.0	0.0	0.0

The CPP curves shown in Figure 5 indicate a corrosion behavior similar to that of as-sintered 17-4 PH samples fabricated using the ME technique, as reported in a previous investigation [26]. The corrosion potential of the samples fabricated through MBJ varied from -115 mV to -150 mV, which is the same interval as the as-sintered 17-4 PH printed using ME technology [26]. None of the CPP curves displayed a distinct anodic passive region,

typical of stainless steel in neutral sodium chloride solutions, except for a limited passive region near -0.1 V to 0 V, thus, it was not possible to determine a localized breakdown potential. Unlike the results obtained on 17-4 PH printed by ME, the repassivation potential is always above the corrosion potential, suggesting a better corrosion resistance than that of as-sintered ME samples. Moreover, no significant differences in passive behavior were observed among the tested samples, suggesting an isotropic corrosion performance in different build-up orientations and directions.

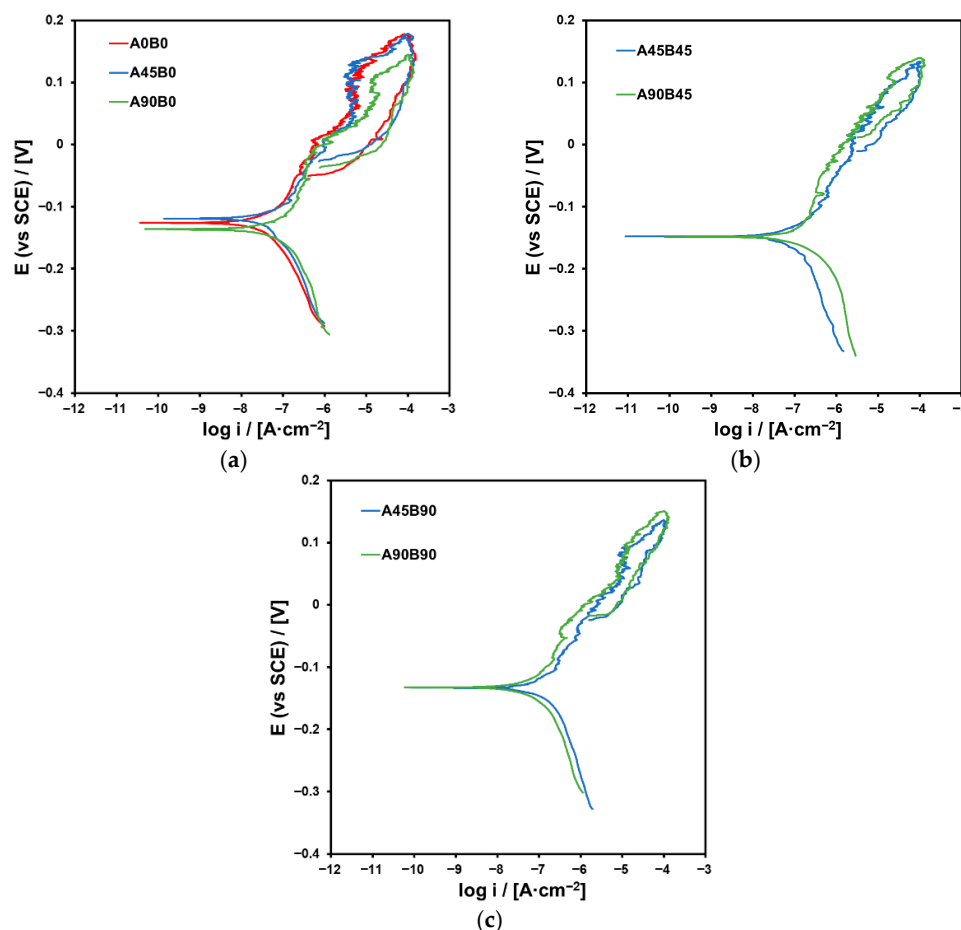


Figure 5. CPP curves of as-sintered samples with different build-up orientations and directions: A0B0, A45B0, and A90B0 (a); A45B45 and A90B45 (b); A45B90 and A90B90 (c).

Although significant differences can be observed in the average values of i_{corr} shown in Figure 6, these values range between 0.1 and $0.9 \mu A \cdot cm^{-2}$, comparable to those of wrought and as-sintered stainless steel passive films in neutral pH sodium chloride solutions, as reported in another study on as-sintered 17-4 PH fabricated through ME technology [26], in which they ranged between 0.04 and $0.15 \mu A \cdot cm^{-2}$. This indicates that a protective passive film may still form on the material surface despite the absence of a clear anodic passive trait of the CPP curves.

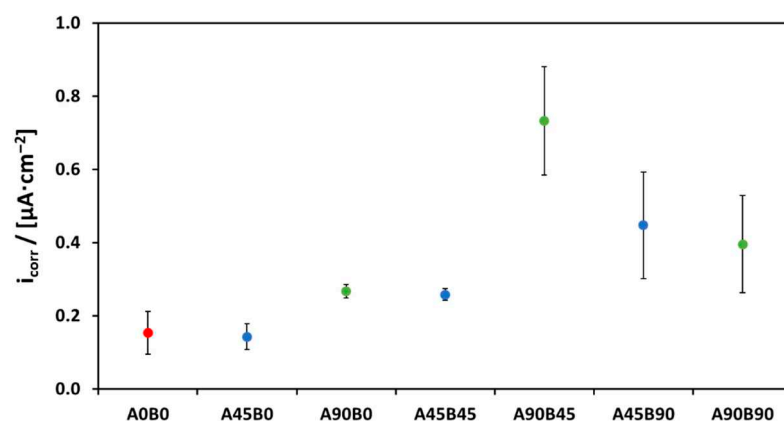


Figure 6. Corrosion current density average values and standard deviations of as-sintered 17-4 PH samples.

The optical microscopy observations conducted after the CPP tests and shown in Figure 7 indicate the presence of localized forms of corrosion. Crevice corrosion is evident along the edges of the polyimide tape (Figure 7a), and similar forms of corrosion were observed across all samples. Localized corrosion attacks are visible in Figure 7b–d. It is uncertain whether pitting or crevice corrosion affected the surface, due to the lack of a distinct anodic passive trait and pitting potential in CPP curves. Porosities and segregations, such as copper and niobium, may initiate these localized corrosion attacks [26,27,45,46], but it is unclear which is mainly responsible. Figure 7e reveals a printing pattern consisting of porosities, though its impact on corrosion resistance is not well-defined since no significant electrochemical differences were observed among the samples.

The OCP monitoring of the most representative wrought and as-sintered 17-4 PH samples (Figure 8) reveals initial instability in as-sintered plates compared to the wrought, particularly in the first 6–12 h, where negative activation peaks were frequent (Figure 8a–c). The passive film instability can be caused by the copper and niobium segregations, which may also explain the active-like behavior observed in CPP tests (Figure 5) and the differences in the average values of i_{corr} shown in Figure 6. Evidences in the existing literature suggest that the segregations, such as copper and niobium, play a dominant role from atomic to micro scales in the initiation of localized corrosion in stainless steel, particularly when they are combined with other microstructural features such as porosities [47,48].

However, after 24 h (Figure 8d–f), activation events in as-sintered samples significantly decreased, and their OCP trends became more stable, approaching that of wrought 17-4 PH. This further confirms the formation of a passive film, which correlates with the low i_{corr} values observed in Figure 6. The OCP stabilization trend is deeply related to the passive properties of as-sintered stainless steel. This hypothesis is supported by a previous study [28], which proved that a clear anodic passive trait is observed in as-sintered 17-4 PH fabricated through ME following a long-term OCP monitoring, though an active-like behavior after 30 min of immersion in neutral pH sodium chloride electrolyte [26]. Notably, sample A45B45 (Figure 8e) exhibits a significantly nobler corrosion potential with higher activation events, compared to wrought and as-sintered samples, suggesting higher instability of the passive film over time. A similar trend toward nobler potential was observed in a previous study [26], where numerous activation events occurred during the OCP, suggesting that this behavior may be related to a higher instability of the passive film.

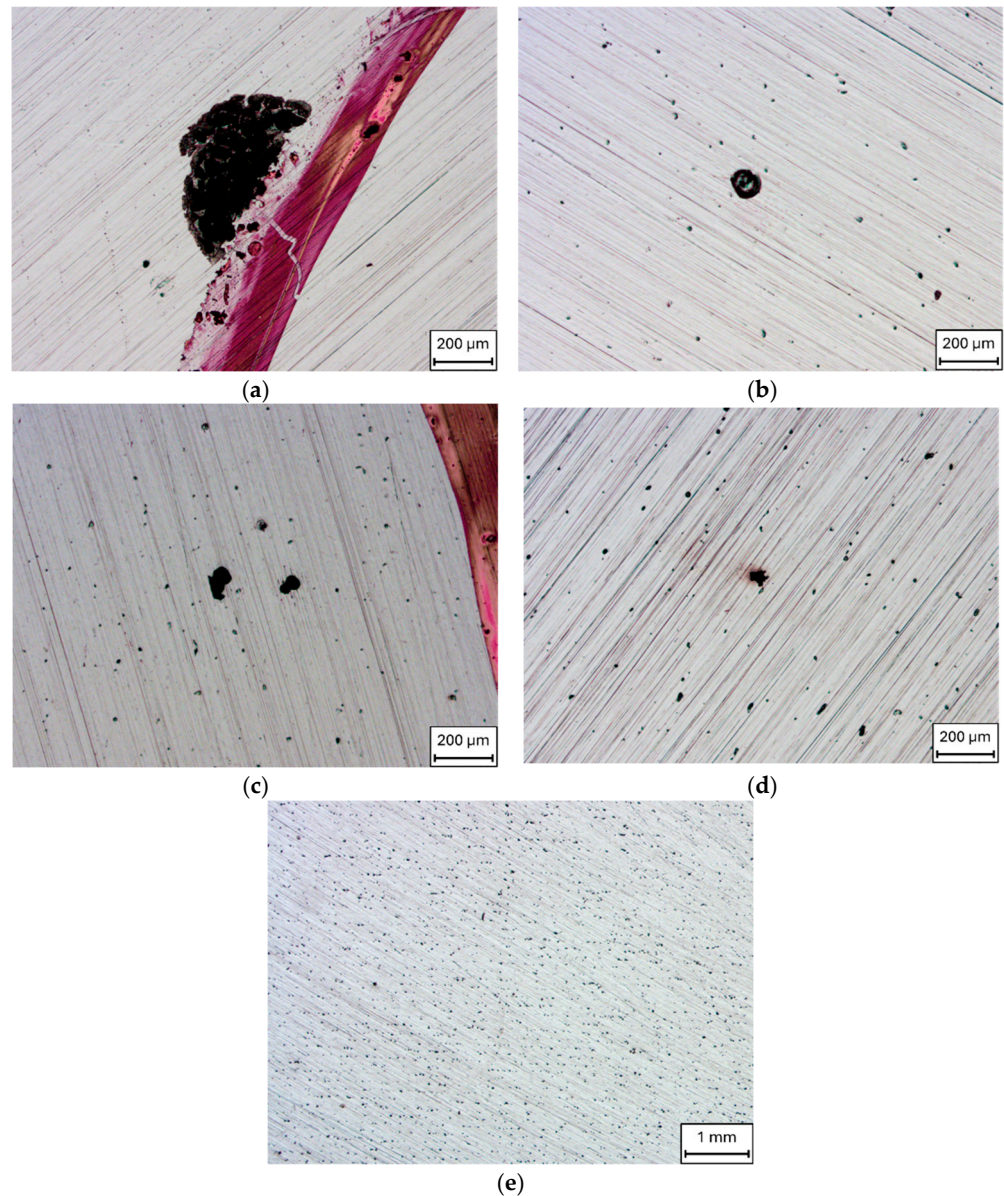


Figure 7. Optical microscopy images of as-sintered samples after the CPP tests: crevice on A0B0 (a); localized attacks on A45B0 (b), A90B0 (c), and A90B45 (d); printing patterns on A45B90 (e). The red marks, visible in (a,c), were drawn after the electrochemical tests to highlight the edge of the polyimide tape.

The quantitative analysis of the OCP in Figure 9 confirms no significant differences among the wrought and as-sintered samples. The average values of the areas are representative of the instability of the passive film or the area of the activation events expressed in $[mV \cdot h]$. The average values of the area of the as-sintered samples closely match those of wrought 17-4 PH, indicating that, after 24 h, the instability of the passive film becomes comparable to that of wrought stainless steel. While A45B45 shows a higher instability, no surface corrosion was observed through optical microscopy, suggesting that these variations may not be practically significant. The standard deviation of A45B45 further suggests occasional but non-systematic instability.

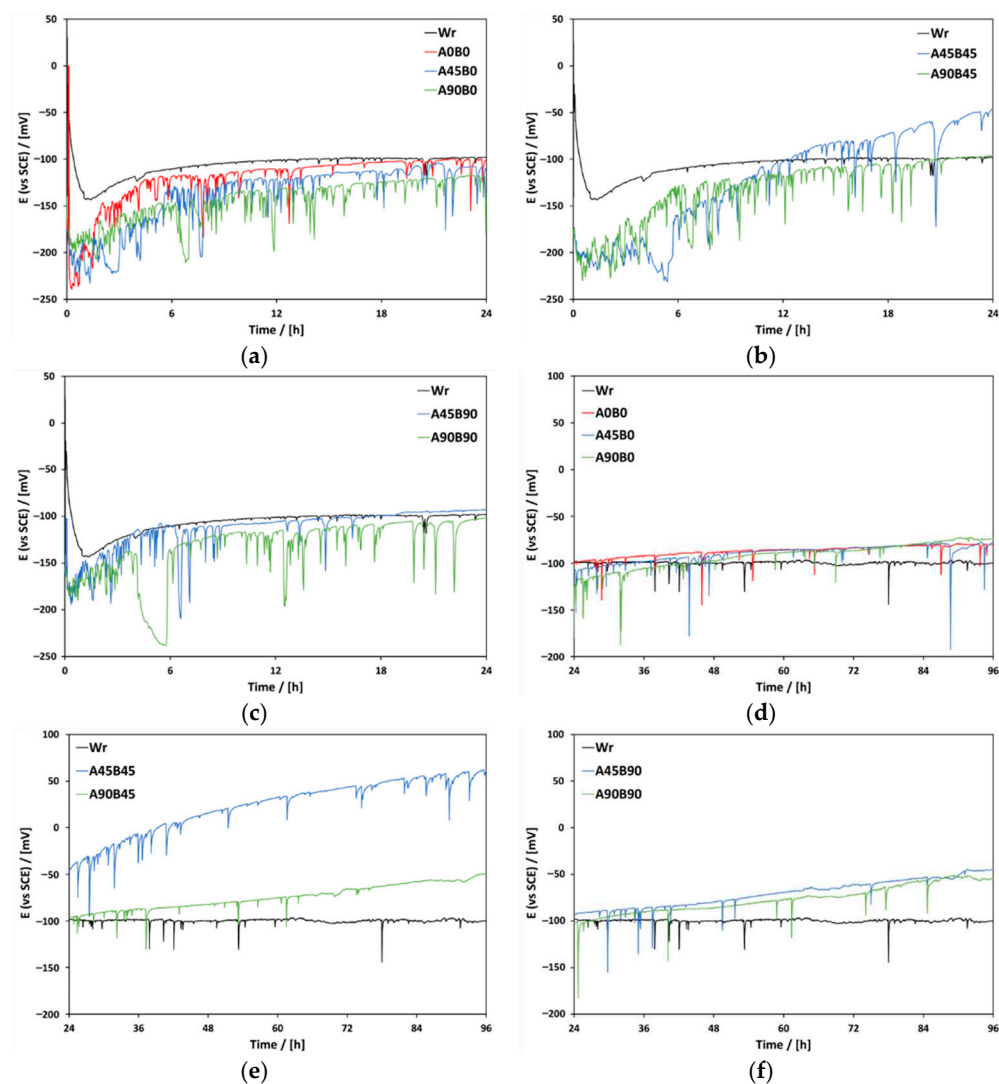


Figure 8. Most representative OCP monitoring curves of the wrought and as-sintered samples: 0–24 h (a–c) and 24–96 h (d–f) of exposure to the neutral sodium chloride electrolyte at 30 °C.

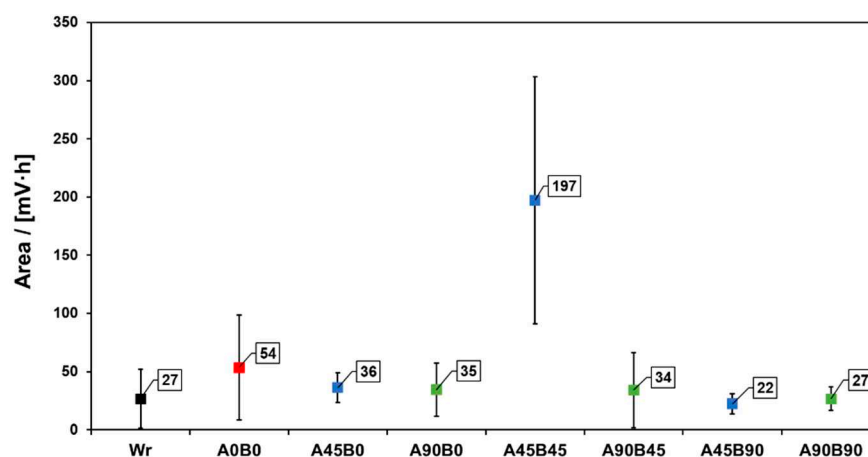


Figure 9. Results of the analysis of the instability of the OCP monitoring between 24 and 96 h of exposure to the neutral sodium chloride environment.

Overall, the combined electrochemical tests indicate that the as-sintered 17-4 PH stainless steel exhibits isotropic corrosion resistance properties, with behavior comparable to that of a wrought 17-4 PH. The microstructure, consisting of ferrite and martensite grains

along with niobium and copper segregations, influences the electrochemical behavior of the as-sintered samples examined in this study. While porosities are present, their effect on corrosion resistance remains unclear. A previous study [26] suggested that porosities negatively affect the corrosion resistance of as-sintered material, although they were found to be more abundant and their size was higher than those observed in this work. However, in this study, the limited electrochemical differences suggest that other microstructural factors, such as phase distribution and segregation, may play a more dominant role, according to another study [27].

The corrosion mechanisms remain uncertain, but the presence of copper and niobium segregations along grain boundaries and within ferritic grains may serve as potential initiation sites for localized attack, particularly when these segregations are found near porosities. Further studies, such as localized electrochemical techniques or microstructural investigations, along with post-processing heat treatments, may help clarify the role of these segregations in corrosion initiation and improve the corrosion resistance properties of the material.

4. Conclusions

The corrosion resistance properties of as-sintered 17-4 PH stainless steel additive-manufactured by the Metal Binder Jetting (MBJ) technique with different build-up orientations and directions were evaluated through Cyclic Potentiodynamic Polarization (CPP) and Open Circuit Potential (OCP) monitoring in neutral sodium chloride environments. The microstructural properties were evaluated as well through X-ray Diffraction, Scanning Electron Microscopy (SEM) with Energy-Dispersive X-ray Spectroscopy (EDX), and chemical etching, to establish the connection of these features with the corrosion resistance properties.

The results suggest that the as-sintered stainless steel exhibits isotropic corrosion behavior, as no significant differences were observed in the localized corrosion resistance properties among the samples fabricated with different build-up orientations and directions. The electrochemical behavior of the as-sintered samples, while atypical compared to conventional stainless steel, indicates the presence of a passive film.

The OCP analysis highlighted an initial period of instability in the as-sintered samples, particularly in the first 6–12 h of immersion. However, after 24 h, the potential stabilized, approaching the behavior of wrought 17-4 PH stainless steel. This suggests that the passive film undergoes modifications over time, improving its protective properties. Despite the early instability, no clear evidence of significant localized corrosion susceptibility was found across the different build-up orientations and directions, further supporting the isotropic nature of the material in terms of electrochemical response.

The microstructural analysis confirmed the presence of both martensitic and ferritic grains, along with elemental segregations and inclusions, particularly of niobium and copper. While both the mixed structure and the presence of segregations contribute to electrochemical behavior, evidence from previous studies suggests that inclusions and segregations play a key role in corrosion susceptibility and may contribute to the instability of the passive film and potentially influence localized corrosion initiation, particularly near grain boundaries and porosities. However, their specific role in the corrosion process remains unclear and requires further investigation.

A more detailed analysis of the OCP response during the first 24 h could provide additional insights into the instability of the passive film. Electrochemical impedance spectroscopy could help characterize the protective properties of the passive film, while a deeper microstructural analysis would assist in understanding the role of inclusions and segregations in corrosion initiation. Additionally, comparing these findings with results

obtained from different additive manufacturing technologies and heat-treated samples would offer valuable information on how different technological factors affect corrosion behavior, guiding the optimization of processing conditions in engineering applications.

Author Contributions: Conceptualization, P.F. and T.B.; methodology, P.F., M.K. and T.B.; software, P.F. and T.B.; validation, P.F.; formal analysis, P.F., M.S., M.K. and T.B.; investigation, P.F., W.A.K. and M.R.; resources, P.F., T.M., M.S. and T.B.; data curation, P.F. and W.A.K.; writing—original draft preparation, P.F.; writing—review and editing, P.F., W.A.K., T.M., M.S., M.R., M.K. and T.B.; visualization, P.F. and T.M.; supervision, M.S., M.K. and T.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data required to reproduce these findings cannot be shared, as they are part of ongoing investigations.

Acknowledgments: The authors thank Tommaso Verdini, Marco Favario, and Antonio Vulcano for their support during this research activity.

Conflicts of Interest: The authors declare no conflicts of interest.

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