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EFFECT OF Cu ON MULTILAYER PTA DEPOSITION OF AISI 316 STAINLESS STEEL

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Abstract. *The coronavirus pandemic (COVID-19) in 2020, has leveraged and intensified the search for measures to prevent the dissemination of the virus. Surfaces of objects touched or handled by a large number of people are potential focus of virus propagation. On metallic surfaces such as stainless steel, coronavirus such as Covid-19 remains active for as long as 72 hours contributing to the dissemination of the virus. There are several approaches to mitigate this silent contamination scenario, among these the use of materials with antiviral properties for the fabrication of common use objects, such as door handles and elevator buttons. The antiviral action of copper is well known and researches have shown that the addition of copper to stainless steel can grant antiviral behavior to the steel. However, the metallurgical characteristics altered by the addition of Cu required a better understanding particularly to assess the impact on the fabricability of the Cu modified steel. This study addressed the response of Cu modified stainless steel deposited by plasma transferred arc. Multilayers were processed both with stainless steel and with Cu modified stainless steel. Results showed processing parameters need to be optimized for each composition as Cu alters wettability, hence the geometry of deposits. Differences in the microstructure and hardness can also be related to the presence of Cu in the composition of steel.*

Keywords: *plasma transferred arc, additive manufacturing, copper, stainless steel.*

1. INTRODUCTION

In the past year, the coronavirus (COVID-19) pandemic has intensified the search for measures to prevent the dissemination of the virus, masks, social distance and hand hygiene are the most recommended practices. However, as each person touches countless surfaces during everyday activities, such as grocery shopping and public transportation making these surfaces a focus for virus propagation. In this scenario, door handles, handrails, elevator buttons and other surfaces touched thousand times a day, are suitable environments for the spread of contagious diseases. Depending on the material objects are fabricated viruses are able to survive on the surface for several days (Kampf et al. 2020). The coronavirus has a similar behavior, on the surface of materials, in particular Van Doremalen et al. (2020) showed that coronavirus can survive up to 72h in stainless steel in contrast with a lifetime of 4h on the surface of copper.

Copper is known for its antimicrobial activity, with the ability to eliminate bacteria, viruses and fungi when in contact (Wu et al. 2020; da Silva et al. 2019; Gunell et al. 2017). Therefore, copper and its alloys have been used on surfaces of common touch in hospitals and long-term care facilities, to prevent the spread of contagious diseases (Colin et al. 2020; Kampf et al. 2020; Palza et al. 2018). Also, the addition of copper in other materials ensures antimicrobial activity to the base material. As an example, stainless steel, which in itself does not have an antimicrobial action when modified with copper, the antimicrobial action can be identified (Xi et al. 2017).

In this scenario, additive manufacturing (AM) presents itself as a manufacturing technique capable of producing parts with complex geometries, with chemical composition freedom and a certain control over the microstructure of deposited metal alloys (Thompson et al. 2016). However, to produce reliable, defect-free, structurally sound solid parts by additive manufacturing an understanding of materials, processes, structures and properties is required (Debroy et al., 2017). The metallic AM process results in solidification conditions out of equilibrium, followed by a sequence of multiple thermal cycles, consequently a variety of microstructures can form. In turn, these variations promote differences in the mechanical properties (Banait et al., 2019). The microstructure obtained during the solidification of the metal in the MA is a result of the melting conditions, the chemical composition of the alloy and the thermodynamic properties. Therefore, understanding these phenomena helps to control the material properties (Mohammadpour et al., 2019; Loh et al., 2018). Directed energy deposition (DED) is among the additive manufacturing processes, in which the Plasma Transferred Arc (PTA) fits.

In spite of the knowledge that Cu can increase antiviral behavior of stainless steel to take advantage of new technologies such as additive manufacturing it is important to assess the impact of Cu in the processability and metallurgy of stainless steels. This study is part of an ongoing project that aims to contribute to fill this gap of knowledge using Plasma Transferred Arc to process multilayers of stainless steel with and without copper to evaluate its effects on the processability of the steel. At this stage of the investigation the impact of Cu was assessed by geometry and the hardness of the deposited multilayers.

2. MATERIALS AND METHODS

Two materials were investigated in this study, a gas atomized AISI 316 stainless steel, with chemical composition presented in Tab 1. The other material (SS+Cu) is a mixture of AISI 316 stainless steel with 5%wt pure Cu (99,9%) . The stainless steel gas atomized alloy had a particle size ranging from 104 to 203µm. The copper powder had a particle size ranging from 55 to 155µm. The powders were mixed in a Y mixer for 1 hour before deposition.

Table 1. Chemical composition of AISI 316 stainless steel (ASM, 1997)

Fe	C	Mn	P	S	Si	Cr	Ni	Mo
Balance	0,08%	2,00%	0,045%	0,030%	1,00%	16,00-18,00%	10,00-14,00%	2,00-3,00%

The powdered materials were deposited by PTA in a Stellite StarWeld system. Multilayers consisting of 5 layers of 80mm length were deposited on AISI 316 stainless steel plates (100 x 50 x 12mm). An unidirectional deposition strategy was adopted with a cooling time between layers of 5 minutes. Processing parameters used are shown in Tab. 2.

Table 2. Processing parameters

Composition	316SS + 5%wt Cu	316SS	316SS + 5%wt Cu	316SS	316SS + 5%wt Cu
Deposition current	60A	80A		100A	
Deposition speed	100 mm/min				

The analysis of the samples was carried out on a OLS4000 confocal microscope and a HMV-2T microhardness tester. The samples were prepared (sectioning, mounting, grinding and polishing) and attacked to reveal the solidification structure with Villela mixed-acid etch (HNO_3 + HCl + H_2O_2 + glycerin) applied for 2 minutes. Vickers hardness was measured on the transverse cross-section using a 300g load and 15s of testing time.

3. RESULTS AND DISCUSSION

Adding Cu to the stainless steel impacts on the response of the material to processing, as assessed by the geometry of multilayers deposition by Plasma Transferred Arc. The measured increase in height of multilayers processed with 100A varying from 7,32mm and 8,19mm for stainless steel without and with Cu, respectively, Fig. 1-a and Fig. 1-b. Differences in geometry can be accounted for by the increase in thermal conductivity, hence cooling rate, when Cu was added to the AISI 316 steel (SS+Cu). Higher thermal conductivity accounts for the reduced wettability of the first deposited layers. As more layers are deposited, wettability increases as processing is carried out on layers that are above 300ºC. A similar effect is observed with the deposition current used, processing SS+Cu with 80A showing a first layer with reduced width and an increase in the total height of the multilayers of 0,32mm, Fig. 1-c. For the same chemical composition, the height of the multilayers decreases with increasing deposition current a consequence of the increase in the wettability with temperature.

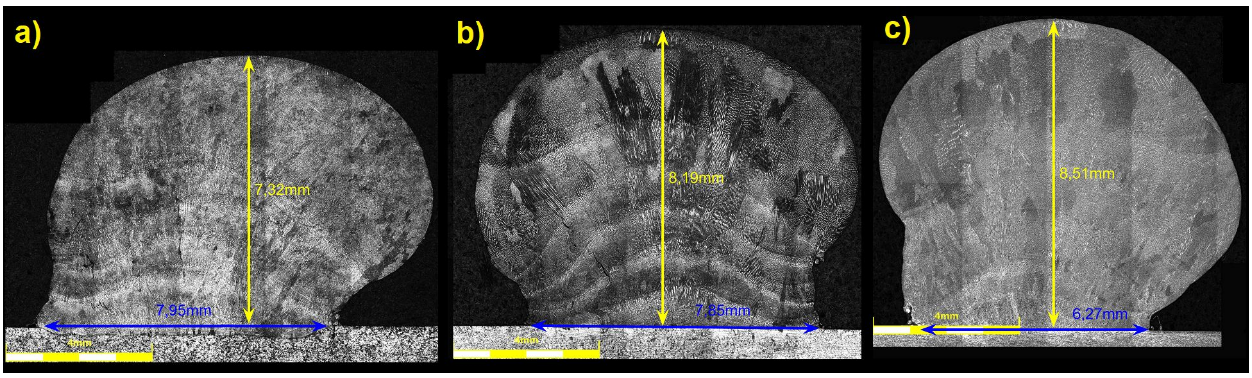

Figure 1. Transverse cross section macrographs: (a) 316SS – 100A, (b) 316SS + 5%wt Cu – 100A and (c) 316SS + 5%wt Cu – 80A

The impact of the composition of the processed material is also perceived at the interface with the substrate, variation of the penetration area with deposition current is strongly influenced by the presence of Cu in the powder mixture, Fig. 2. Regardless of the deposition current, penetration area of multilayers processed with the modified stainless steel is smaller compared to that of the AISI 316 multilayers. This trend reaches its limit when processing with 60A, the Cu modified stainless steel detached from the substrate, which was caused by a lack of fusion between the first layer and the stainless steel substrate as not enough energy is available to melt both the deposited material and the substrate.

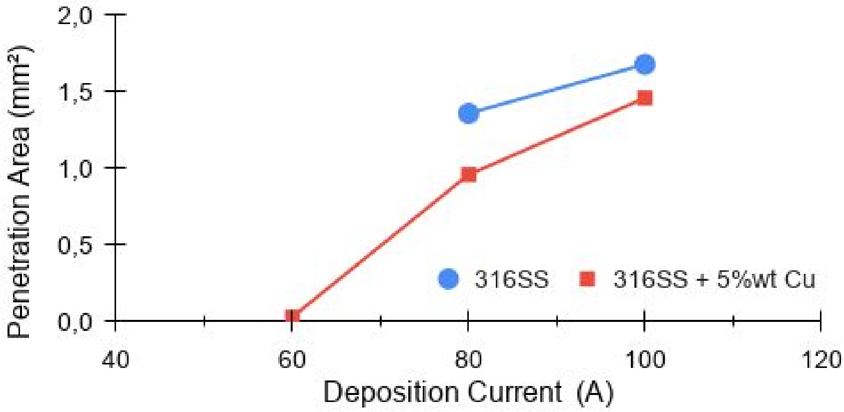

Figure 2. Penetration area of multilayer depositions with different deposition currents and the two compositions

At the interface with the substrate the deposited material formed a solidification structure of multilayers with similar features although a defined fusion line with the substrate is identified when processing the Cu modified stainless steel in contrast with a blurry fusion line for the AISI 316 multilayers. The influence of adding Cu to the stainless steel can also be observed from the modifications imposed in the heat affected zone (HAZ) in the substrate plate. Analysis of the substrate grain structure reveals that processing with the Cu modified stainless steel causes a significant abnormal grain growth, Fig. 3. The heat affected zone in the substrate reaches temperatures that are not high enough to melt the material, but can change the microstructure of the stainless steel plate grain structure. Differences in the thermal conductivity of the deposited material and substrate plate allow to raise the hypothesis that a faster heating of the HAZ is to be expected when processing the stainless steel modified with copper, due to a higher thermal conductivity imposed by the copper thus accounting for the grain growth (Kou, 2003).

It is also interesting to point out that, micrographs of multilayers shows that the presence of Cu better reveals the grain boundaries in multilayers, Fig. 3.

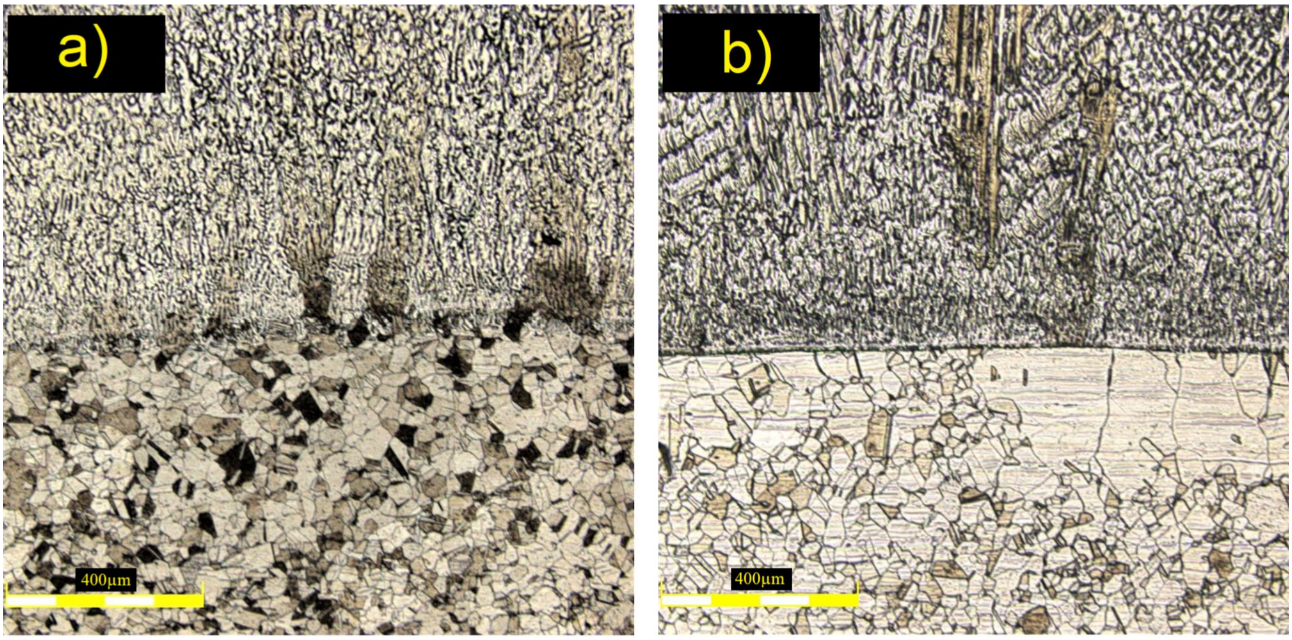

Figure 3. Interface micrographs: (a) 316SS – 100A and (b) 316SS + 5%wt Cu – 100A

Correlation between the macrostructure of multilayers shows that Cu better reveals the grain boundaries in the solidification structure of multilayers, Fig. 1. This apparent variation in microstructure is followed by hardness variations. In the as-deposit condition, multilayers containing Cu exhibited a reduction in hardness, Fig. 4. Note that the zero represents the interface between the substrate (left) and the deposited material (right). The mean hardness of the as-deposited materials processed with 80A without and with copper are, respectively, 208,75±11,48HV and 192,06±6,28HV. The greater standard deviation measured on the hardness of stainless steel without copper may be associated with the impact of thermal cycles in a material with a lower thermal conductivity, that causes heat to concentrate differently as layers are deposited.

In addition, the abnormal grain growth in the HAZ can be associated with the lower hardness across the fusion line (190HV) when processing with the Cu modified stainless steel whereas the fine grain structure observed in the steel substrate accounts for the higher hardness across the fusion line (220HV).

Both powder mixtures processed with PTA showed a higher hardness compared to the substrate, this can be associated to a structure refinement, expected from the solidification rate impose during deposition with PTA. The lower hardness for the sample with copper is in agreement with that presented by Xi et al. (2017), where the hardness of stainless steel slightly decreases while the copper is in solid solution. However, with a proper aging treatment, the hardness is expected to increase due to precipitation hardening mechanism.

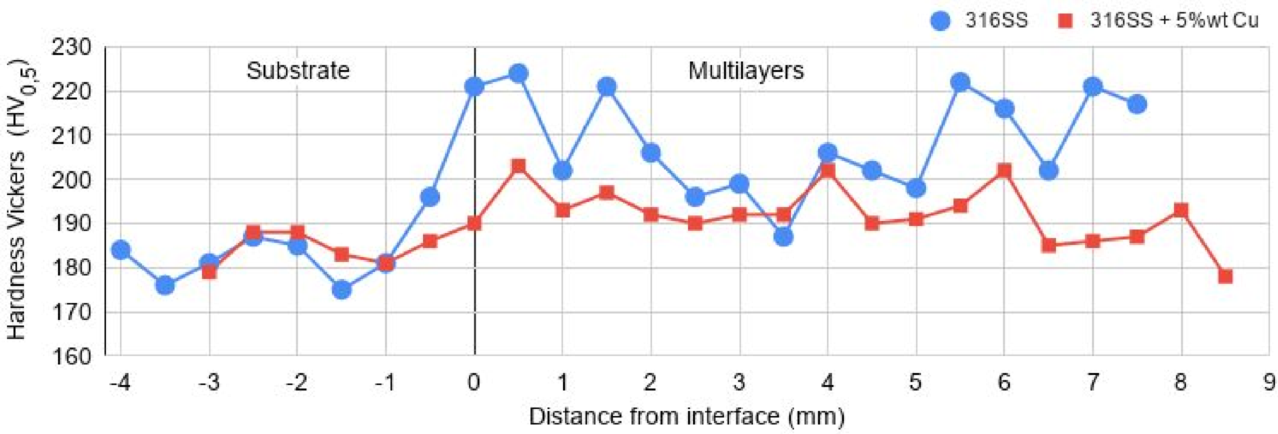

Figure 4. Hardness Vickers profile on cross section of samples processed with 80A

4. CONCLUSIONS

This study assessed the impact of adding copper to a stainless steel on the processability when depositing multilayers by Plasma Transferred Arc. Processing AISI316 stainless steel multilayers, with and without copper, allowed to conclude that: (i) adding Cu to the stainless steel increases thermal conductivity and reduces wettablility thus impacting on the geometry of multilayers assessed by their height and width; (ii) adding Cu to the stainless steel reduces the as-deposited hardness; (iii) adding Cu to the stainless steel induced an abnormal grain growth in the HAZ of the substrate.

5. ACKNOWLEDGMENTS

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