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PROCESSING OF DISSIMILAR METALS IN SELECTIVE LASER MELTING

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ABSTRACT: Selective Laser Melting (SLM) was used to fabricate sample parts made of two metallic materials, 316L stainless steel and UNS C18400 copper alloy. The novel approach, by the separation of a single dispensing coating system into two compartments, is described and the resulting samples were analyzed based on the bonding of their interface. A substantial amount of Fe and Cu element diffusion was observed in the fabricated samples, suggesting good metallurgical bonding and the feasibility of dissimilar metals processing in SLM.

INTRODUCTION

In recent years, fabrication of metallic parts using additive manufacturing (AM), also known as 3D printing or rapid prototyping methods have garnered much attention due to the improvement in technology in the field. According to ASTM Standard F2792-12a (2009), AM methods can be broadly classified under material extrusion, sheet lamination, binder jetting, direct energy deposition and powder bed fusion. In particular, methods using direct energy deposition and powder bed fusion are high in demand for direct production of metal parts as they can produce parts that are almost fully dense with good mechanical properties exceeding that of cast parts (Wohlers 2013). Selective laser melting (SLM) is one of the AM methods that uses direct energy deposition from a laser source and powder bed fusion to fabricate high density metallic parts with designs that conventional manufacturing methods cannot produce (Osakada, K. & Shiomi, M. 2006). Furthermore, with the advancement in laser technology, SLM now have the possibility of processing wider range of metallic materials, including those with high melting points, due to its high power fiber laser of up to 1 kW (Chua, C.K. et al. 2010).

Dissimilar metals processing had been carried out on systems that use direct energy deposition such as Optomec's laser engineered near net shape (LENS) system (Bandyopadhyay, A. et al. 2009, Bian, W.G. et al. 2012) as well as selective laser sintering (SLS) systems (Liew, C.L. et al. 2001, Lappo, K. et al. 2003). The LENS system utilizes nozzles to deposit the material, thus, it is relatively easy to incorporate multiple materials in one build job by filling each nozzle with a different material (Krishna, B.V. et al. 2008). However, multi material builds for powder bed fusion systems such as SLS and SLM are more challenging. In SLS, these depositions have been done by the deposition of a layer of material followed by selective removal and deposition of a second layer of a different material using the rotation roller followed by laser sintering (Vaezi, M. et al. 2013). Other methods include the incorporation of nozzle to deposit the second material at localized points followed by laser sintering (Lappo, K. et al. 2003) and the use of two coating blades available in some SLS systems to sweep a different material in the two directions onto the build platform (Regenfuss, P. et al. 2007). For SLM produced parts to be more functional, there is an inherent need for multi material processing of dissimilar metals by this process, however, there is little research done in this area (Beal, V.E. et al. 2007).

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In this paper, the concept of multi material processing in SLM which allow the material on the xy-plane to be varied along the z-axis will be described. The materials used in this study were 316L stainless steel and C18400 copper alloy. These materials were chosen because of the strength and corrosion resistance of stainless steel combined with the high conductivity of copper make the parts produced by these dissimilar metals ideal for many applications. These applications include conformal cooling channels (Dimitrov, D. et al. 2010, Spierings, A.B. et al. 2012, Wang, L. et al. 2012) and wires for specialized purposes used in high field pulsed magnets (Pantsyrnyi, V. et al. 2000).

EXPERIMENT SETUP

The SLM machine used in this work is the 'SLM 250HL' from SLM Solutions GmbH that comes with a re-coater consisting of a dispensing mechanism that works with two rotating chambers where a silicon blade is installed between and underneath them. As each chamber rotates, a controlled amount of powder is dispensed onto the substrate surface in front of the silicon blade for deposition by the pushing action of the blade. In this work, a separator, as shown in Figure 1, was designed and fitted within the re-coater.

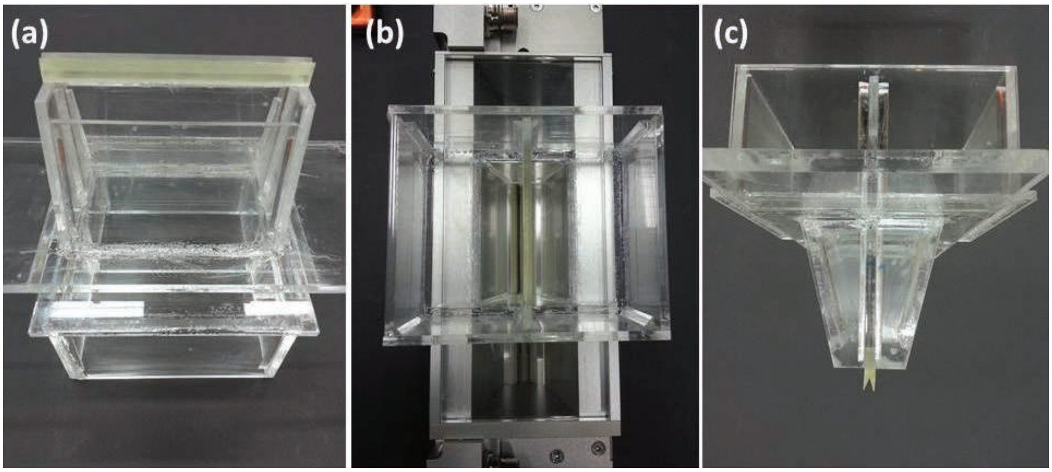

Figure 1 Re-coater separator (a) front view (b) top view (c) side view

The re-coater with the separator is then installed and filled with the two different powders, 316L stainless steel (normally distributed between 10 μm to 38μm) and UNS C18400 copper alloy (with D99 38 μm particle size distribution), as shown in Figure 2.

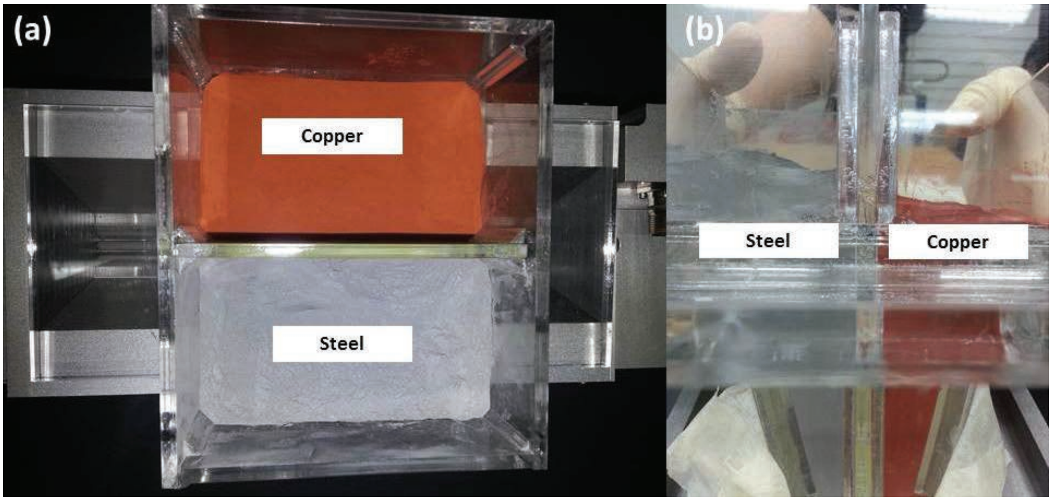

Figure 2 Re-coater filled with two different powders (a) top view (b) side view

The fiber laser used in the machine has a Gaussian beam with power up to 400 W with spot size of 80 µm. In this work, the sectorial (also known as island) scanning strategy (Yasa, E. et al. 2010) is applied during the SLM process in order to minimize the thermal stresses. This is important in processing of dissimilar metal due to the difference in material properties, such as coefficient of expansion, which will result in high residual stresses (Klingbeil, N.W. et al. 2002, Shiomi, M. et al. 2004, Mercelis, P. & Kruth, J.P. 2006, Kruth, J.P. et al. 2012). The process parameters, obtained through parameters optimization for 316L stainless steel (Morgan, R. et al. 2004) and copper C18400 alloy (Zhang, D.Q. et al. 2013) respectively, and the resultant densities of the individual components are shown in Table 1.

Table 1 SLM process parameters for 316L stainless steel and UNS C18400 copper alloy and their resultant relative densities

	316L Stainless Steel	**Copper C18400**
Laser Power (W)	125	300
Laser Scan Speed (mm/s)	150	400
Layer Thickness (µm)	50	50
Hatch Spacing (mm)	0.15	0.15
Remelting	No	Yes
Island length (mm)	5 x 5	4 x 4
Island overlap (mm)	1	1
Relative Density (%)	99.9	92.9

RESULTS AND DISCUSSION

The fabricated parts show continuous interface between the stainless steel and copper layers. An intermixed region can be observed under optical microscopy, indicating good bonding due to the bidirectional diffusion of materials into the intermixed region. This is shown in Figure 3.

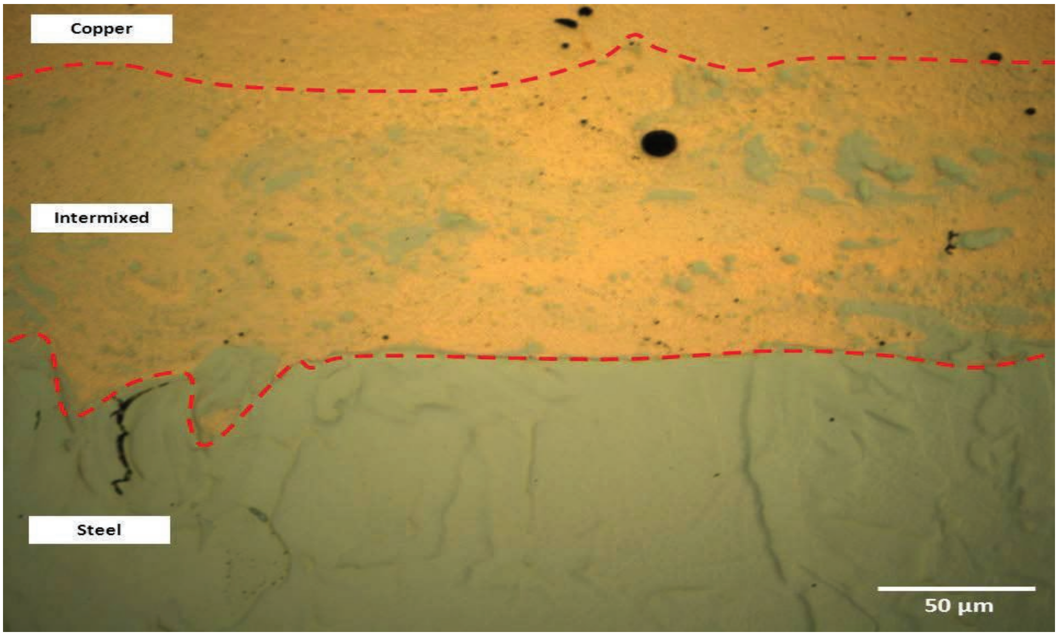

Figure 3 Optical microscopy (LOM) showing the intermixed region in steel/Cu composite

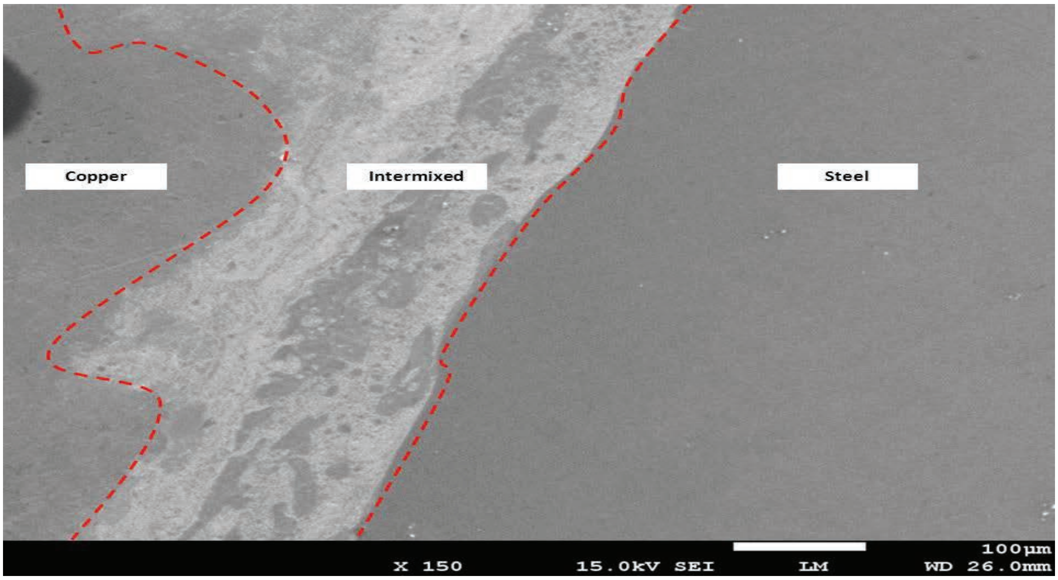

Figure 4 Scanning electron microscopy (SEM) showing the intermixed region in steel/Cu composite

The presence of the intermixed region is further supported by the mapping done using Energy Dispersive Spectroscopy (EDS), shown in Figure 5.

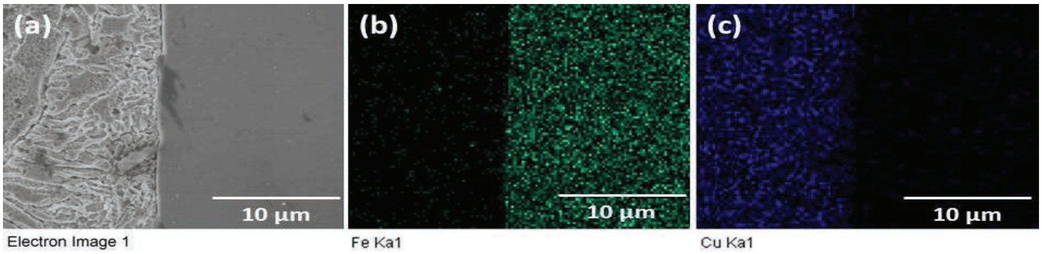

Figure 5 EDS of steel/cu composite showing (a) electron image (b) Fe diffusion into copper region on the left and (c) copper diffusing into the Fe region on the right

Laser interactions differ for stainless steel and copper. The stainless steel absorbs a higher proportion of energy from the laser compared to copper due to its' lower reflectivity and thermal conductivity. UNS C18400 copper alloy has a thermal conductivity of 171 W/mK while that of 316L stainless steel is 16.2 W/mK. This results in poorer melting of the copper which in turn accounts for the lower relative density of copper as compared to stainless steel. However, the intermixed region consisting of stainless steel and copper was dense. This is due to dilution effect, which is observed in cladding (Xie, C. 1999, He, X. et al. 2011). When a layer of copper powder is melted over the stainless steel layer formed previously, the stainless steel layer undergoes melting again and gets mixed with copper. This phenomenon is repeated for the melting of the initial layers of copper, with decreasing amount of stainless steel mixed into the melt pool. This is limited by the depth of laser penetration. Once the total deposition thickness of copper powder exceeds the penetration depth of the laser, copper powder alone undergoes melting. This phenomenon is not ideal for the SLM process. The process parameters, such as laser power and scan speeds, are material specific. Due to this phenomenon, it is hard to predict the ratio of stainless steel to copper, which in turn, makes the prediction of energy density required during the fabrication for the intermixed region difficult.

CONCLUSION

The concept of processing dissimilar metals using SLM has been shown in this paper. The stainless steel/copper bimetallic composites produced show the capabilities of SLM process in processing multi materials. However, more work need to be done in the future to further understand this capabilities, such as a more in depth studying of the interfacial characteristics of dissimilar metals processed by SLM and the limitations of this process in processing two or more metals in a single build.

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