L.3: Laser directed energy deposition based additive manufacturing of functionally graded materials

Copper (Cu)-stainless steel (SS 304L) multi-material is an enduring research topic for various engineering applications such as tooling industry, aerospace, power-generation and cryogenic sector. Laser additive manufacturing using directed energy deposition (LAM-DED) is a one of the promising technologies for fabricating Cu-SS multi-material components. However, LAM-DED of Cu-SS is difficult due to the significant difference in thermo-physical properties and poor solubility of Cu and Fe. One of the methods to overcome this issue is adopting a functionally graded material (FGM) approach. The fabrication of Cu-SS FGM using the LAM-DED process with three different Cu compositional grading approaches, such as direct (GD100Cu), 50% (GD50Cu) and 20% (GD20Cu) are performed and results are shown in the Figure L.3.1. The LAM-DED process windows for single tracks and bulk deposition of Cu-SS FGM are identified by varying the laser power, scan speed and composition of Cu and SS304L (i.e. CuxSS100-x, x varies as 20, 40, 50, 60, 80). Subsequently, the identified process window is used to deposit bulk structures of Cu-SS FGM.

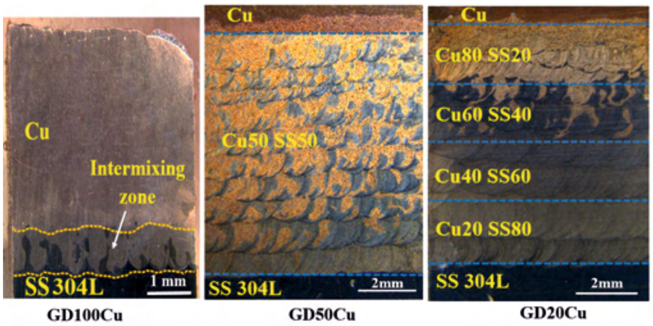

Fig. L.3.1: Cross-section view of LAM-DED built Cu-SS FGM at 100, 50 and 20 percent grading.

LAM-DED of GD100Cu is carried out by laying multiple layers of Cu at identified parameters by adopting an increasing laser power processing scheme. An increasing laser power scheme is adopted to overcome the issue of inter-layer and intra-layer porosity arising due to the higher thermal conductivity of pre-deposited Cu layers. Figure L.3.1 presents the cross-sectional view of LAM-DED built GD100Cu bulk structure. It has been found that defect free and dense bulk structure with relative area density > 99.9% is obtained in the Cu region of LAM-DED built GD100Cu. LAM-DED of GD50Cu is accomplished by introducing multiple layers of Cu50SS50 between SS and Cu at identified parameters. It is observed that GD50Cu yields defect-free deposition with a compositional transition from Fe to Cu along the build direction. Random morphology of phase-separated inter-connected Cu-Fe rich zone is observed in Cu50SS50 region of LAM-DED built GD50Cu (refer Figure L.3.1). LAM-DED of GD20Cu is carried out by introducing multiple layers of four different blended compositions of Cu-SS between SS and Cu along the build direction as per the schematic shown in Figure L.3.1. It is found that LAM-DED built GD20Cu yields a gradual transition in elemental concentration from Fe (representing SS) to Cu along the build direction. Microstructural characterization reveals, an increased cooling rate and nucleation site cause dominance of equiaxed grain in GD100Cu, whereas a higher cooling rate, increased heterogeneous nucleation site and restriction offered by Cu to the grain growth leads to fine columnar growth with cellular and dendritic morphology of Fe rich zone of GD50Cu and GD20Cu structures as shown in Figure L.3.2.

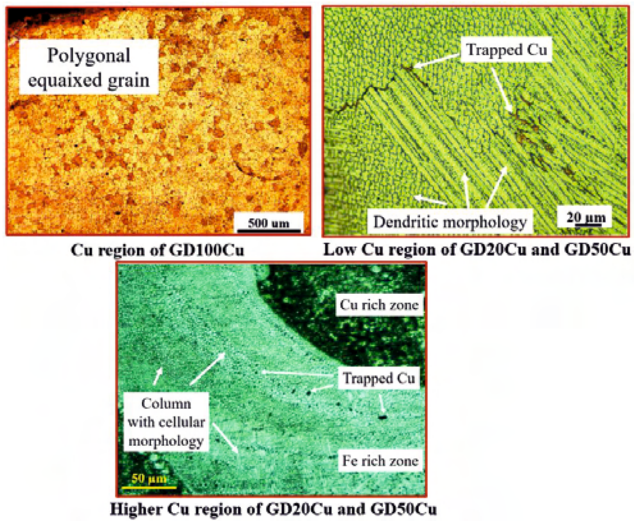

Fig. L.3.2: Microstructural transformation in different region of LAM-DED built Cu-SS FGM.

During the micro-tensile test, the evaluated ultimate tensile strength (UTS) value of GD100Cu and GD50Cu is higher than the UTS of LAM-DED built Cu. Whereas, LAM-DED built GD20Cu yields UTS lower than that of LAM-DED built Cu. Failure of the tensile specimen of LAM-DED built GD100Cu and GD50Cu occurs in the Cu region indicating defect-free deposition at the interface and graded region. The increased UTS can be attributed to precipitation strengthening due to formation of nano-precipitate. Whereas, failure of the tensile specimen of GD20Cu occurs in the lower Cu region indicating the presence of micro-crack in this region (refer Figure L.3.3). By optimizing different process parameters bimetallic structures of Cu-SS are developed successfully using LAM-DED process.

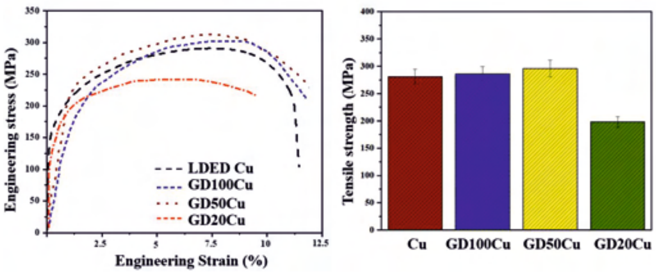

Fig. L.3.3: Results of micro-tensile test.

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