Influence of laser power on mechanical properties of FGM of SS316L and IN625 fabricated by direct metal deposition

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Abstract. Direct Metal Deposition (DMD) is a metal Additive Manufacturing (AM) process. It is used for producing sustainability Functionally Graded Materials (FGM) and repairing of sophisticated parts. In this present research, a commercially available DMD machine deposited three partial FGM blocks of size 26 mm wide × 34 mm thick × 32 mm heights. The commonly influence parameters on Ultimate Tensile Strength (UTS) are scan velocity and laser power. The powders used for deposition were Stainless Steel 316L (SS316L), Inconel 625 (IN625), and their three different compositions. ASTM E8 tensile samples were cut from those blocks by wire cut-EDM. Micro-tensile tests were carried out on ASTM E8 samples using a SHIMADZU micro-tensile machine. The results revealed that partial FGM sample-2 had high sustainability UTS of 532 MPa as compared to remaining two samples. It is illustrated that for joining two dissimilar materials to obtain high UTS thick layered (i.e., thickness more than 1 mm) gradient path method should be selected at the medium laser power available on the DMD machine. However, the sample-3 has higher hardness at high laser power.

Keywords: Functionally Graded Materials, Ultimate Tensile Strength, SS316L, IN625, Direct Metal Deposition.

1 Introduction

Human needs are increasing every day. So, new technologies were developed. Those are mechanizations, NC systems, different types of lasers, robotics, and Additive Manufacturing (AM) [1]. From last thirty five years AM is playing a crucial role for production of custom oriented components [2]. AM is a multi-disciplinary field. Generally metal AM is classified as powder bed fusion and Direct Energy Deposition (DED) [3]. DED can be produced FGM by Multi-Layer Materials (MLM) method and gradient path method [4]. They are light in

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weight, high strength, and emerging materials with superior mechanical properties [5]. The FGM samples of Stainless Steel 316 (SS316) and Inconel 625 (IN625) are produced based on MLM method and gradient path method and their tensile properties were compared with lower strength materials. The Yield Strength (YS) and UTS of a MLM sample (i.e., 298 MPa, 539 MPa) and a gradient path sample (i.e., 306 MPa, 537 MPa) are comparable to the strength of pure SS316 sample (i.e., 285 MPa, 557 MPa) and pure IN625 sample (514 MPa, 934 MPa) [6]. A DED system was directly joined the Stainless Steel SUS316L and IN625 powders and obtained UTS of 550 MPa and hardness changing from 200 HV-430 HV [7].

In powder fed DED, variation of laser power and powder feed rate can create steady state melt-pool. But complex micro-structures are formed and unable to analyze to predict the mechanical properties. So, artificial intelligence and machine learning approaches are required [8,9]. AM standards, heterogeneous CAD modeling and slicing methods are not available for DED processes till now [10,11]. Now-a-days, many industries are using hybrid manufacturing processes. It is a combination of conventional process and AM process. In this process, parts are over-built by a DED machine, and followed by secondary operations on them [12,13,14,15]. In 3D printing if the time is introduced as the fourth dimension, it is known as 4D printing. Functionally graded shape memory alloys are 4D printed parts by any DED processes [16,17,18]. Global industries are also using Industry 4.0 along with hybrid manufacturing. For saving time and cost Industry 4.0 utilizes decentralized AM processes to increase the production. It connects different AM machines with industrial IOT and cloud computing. Hence, it can use advanced materials and manufacturing processes, and supply chain management [19,20,21]. Now AM is facing problems with socio-economic and environmental sustainability. In order to assess the AM easily by a software model, Sustainable Value Roadmapping Tool (SVRT) software model was also developed [22,23].

The present research is focused on partial FGM made of Stainless Steel SS316L (SS316L) and IN625 powders used in extreme service conditions such as resistance to corrosion and existence of high temperature gradient. The present work aims to reveal micro-structural details, UTS, and hardness of partial FGM produced by Direct Metal Deposition (DMD) based thick layer (i.e., more than 1 mm) of deposition. It is concluded that sample-2 has higher UTS as compared to the remaining specimens.

2 Materials and Methodology

SS316L powder and IN625 powder are used for deposition in the DMD process. These powders are gas-atomized particles with varying sizes from 50 µm to 150 µm. Three powder compositions such as 65% SS316L + 35% IN625, 50% SS316L + 50% IN625, and 30% SS316L + 70% IN625 were prepared manually for depositing gradient layer-1, layer-2 and layer-3 respectively in the middle of the FGM blocks. A stainless-steel substrate was utilized for depositing pure SS316L powder and on top of the block pure IN625. Three partial FGM blocks 26 mm width × 34 mm thickness × 32 mm heights were deposited with bi-directional scanning by a commercial DMD machine. It has a diode laser power capacity of 100-4000 W, and scan velocity of 10-30 mm/s. One of the deposited partial FGM blocks is shown in Fig. 1. The most important parameters laser power, and scan velocity were selected for experimentation and are listed in Table 1.

Table 1. Selected parameters for FGM deposition

Experiment No.	Laser power (P), W	Scan velocity (V), mm/s
1	1500	30
2	2500	30
3	3500	30

Fig. 1. Partial FGM block

2.1 Characterization

Tensile tests were done on a SHIMADZU micro-tensile machine having maximum load applied capacity of 250 KN. The rate of load applied on the samples based on ASTM E8 standards was 15 mm/min. ASTM E8 tensile samples made from each FGM block by a wire-cut EDM are shown in Fig. 2. The ASTM E8 sample has size of 9 mm wide × 3 mm thick × 30 mm height.

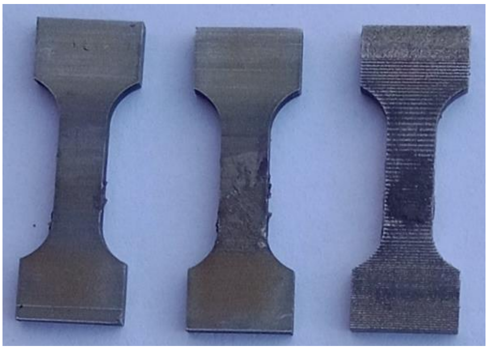


Fig. 2. ASTM E8 tensile specimens

The macrostructure of the gradient zones of the samples was captured by an Olympus optical microscope. Micro-structural examination was performed to understand the distribution of phases in various layers of the gradient zones.

3 Results and Discussions

3.1 Macrostructure

Here, partial FGM means three different gradient zones deposited in the middle of the sample. The macrostructure of the sample-1 is shown in Fig. 3. These gradient zones are known as compositional layers. There is very small deviation in the thickness of individual compositional layers due to the metal powder particles swirling by improper focusing of laser beam in the melt-pool and unavailability of closed product building chamber.

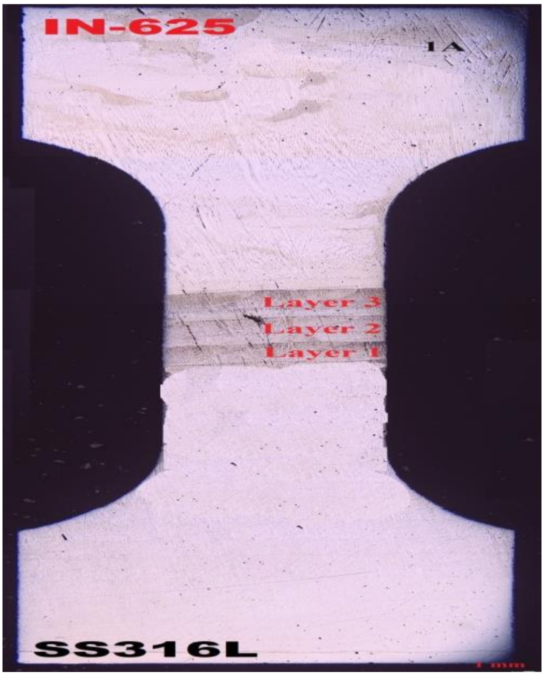
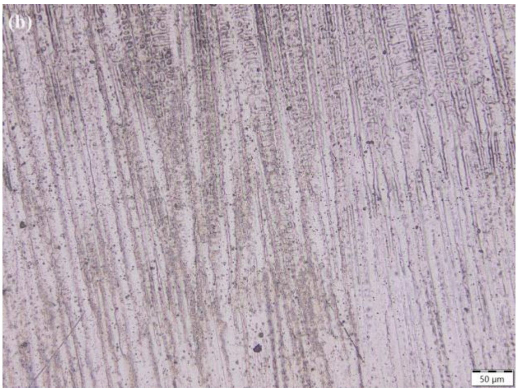


Fig. 3. Macrostructure of ASTM E8 sample-1

3.2 Macrostructure of ASTM

The microstructure of first gradient zone of sample-1, sample-2 and sample-3 have taken by an Olympus optical microscope as shown in Fig. 4. Columnar grains with micro-cracks, columnar grains, and equiaxed grains were observed in the first compositional layer of those samples as shown in Fig. 4(a), Fig. 4(b), and Fig. 4(c) respectively. Fine grain microstructures were formed as laser power is increased. In all these microstructures as shown in Fig. 4, the white regions indicate the austenite phase, dark spots of un-melted powder particles, and dark regions compounds of SS316L and IN625. Based on conventional microstructural concepts, columnar grains reduced the strength of the specimens. However, there is no evidence for increasing and decreasing the strength of a sample based on this micro-structure. So in the present research second sample had high UTS.



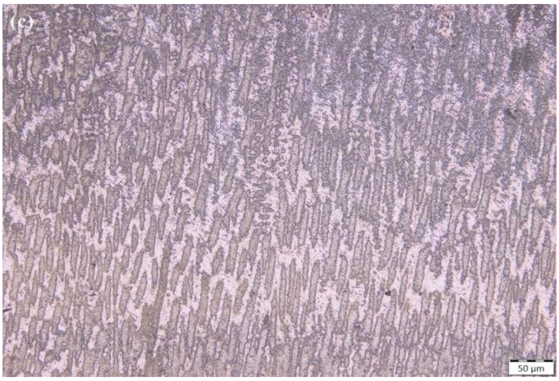


Fig. 4. Microstructure of layer-1 of (a) sample-1, (b) sample-2, and (c) sample-3

3.3 Micro-tensile Test

For each experiment three tensile tests were performed. Average values of UTS of partial FGM samples are listed in Table 2. The failure samples after the micro-tensile test are shown in Fig. 5.

Fig. 5. Failure ASTM E8 tensile specimens

Table 2. Measured values of ultimate tensile strength

Experiment No.	Ultimate Tensile Strength (MPa)			
	Trial 1	Trial 2	Trial 3	Avg. (MPa)
1	516	517	517	517
2	538	521	538	532
3	511	522	522	518

From Table 2, it has seen that second sample possessed high sustainability with UTS of 532 MPa as compared to remaining two samples and also shown in Fig. 6. In the present work the UTS of thick layered (i.e., thickness more than 1 mm) second partial FGM sample is very closer to the thin layered (i.e., thickness less than 1 mm) multi-layer materials samples of already existed research [8]. So, for joining two dissimilar materials to obtain the required properties, the selection of the thick layer partial FGM is better. However, it needs less time for part deposition and most economical.

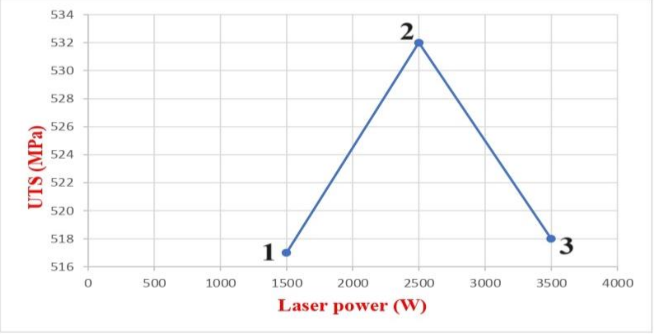


Fig. 6. Variation of UTS by varying laser power

Fig. 6 has shown the variation of UTS by changing laser power. In this graph location-1, location-2, and location-3 indicate UTS of first sample, second sample, and third sample respectively. From this graph it is also realized that second sample has high UTS (i.e., location 2) by using medium laser power. However, the UTS of first sample and third sample are almost same at the same scan velocity with lower and higher laser power respectively.

3.4 Micro-hardness

Micro-hardness is the surface property of a part. The micro-hardness of all the samples was evaluated by an ECONOMET hardness tester. Fig. 7 has shown the variation of hardness of the third sample.

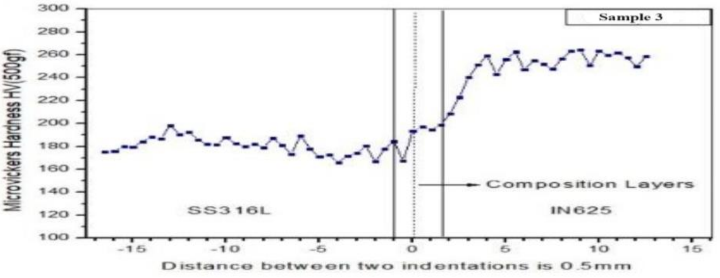


Fig. 7. Micro-hardness variation of sample-3

Outside the gradient zone of the deposited SS316L and IN625 regions (see Fig. 7), there is no significant change in micro-hardness of the third sample. The variations of micro-hardness in the gradient zones of first sample, second sample, and third sample were 177.8 HV-208.2 HV, 165.3 HV-191.2 HV, and 195.2 HV-215.7 HV respectively. A maximum micro-hardness of 260 HV was observed at top surface of the third sample.

4 Conclusion

Based on micro-tensile test and characterization done on these samples, the following conclusions were made. The micro-tensile test reports showed that second sample possessed sustainable higher UTS of 532 MPa as compared to the remaining two samples. This strength is obtained at medium laser power with thick layer of deposition. So, it is illustrated that for joining two dissimilar materials to obtain the desired properties thick layer deposition to be selected.

Coarse columnar grains with micro-cracks, coarse columnar grains, and fine equiaxed grains were observed in the layer-1 of the first sample, second sample, and third sample respectively. It also indicated that the UTS (399-522 MPa) of conventionally welded joints of SS316L and IN625 plates or rods were less than that of partial FGM sample-2. High micro-hardness of 195.2 HV was measured in the gradient compositional layer-1 of the third sample.

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