Effect of process parameters on geometrical aspects in direct metal laser deposition of Ni5Mo5Al hardface coating

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Abstract. Direct metal laser deposition of hardfacing alloys on engineering components can improve their life significantly. This work explores the role of laser power and scanning speed on the deposition geometry of Ni5Mo5Al. Variation of cross-sectional morphologies of overlapped deposition tracks with varying process parameters was examined. The results indicated that higher laser power or lower laser scanning speed improves the deposition rate. Near-uniform heights of overlapping deposition tracks were achieved for 600 W laser power and 700 mm/min scanning speed with ~50% overlap. The depth of penetration was also highest for that parameter combination. The resultant coating exhibited an almost 60% rise in microhardness from the base material, signifying the potential of the deposited material in improving the wear and erosion resistance of engineering components.

1. Introduction
In order to provide a durable, corrosion-resistant layer and load bearing capability of the core material, laser cladding shows great industrial potential. Among the laser cladding processes, direct metal laser deposition (DMLD) has a unique position because of its potential to manufacture components with a wide range of materials as well as its potential for repairing and cladding of valuable parts that cannot be repaired by other traditional methods [1]. This process is used for deposition of a variety of heat resistant, wear and corrosion protective coatings on to the substrate. It utilizes a laser heat source to deposit layers of the desired material on the substrate. This technique can produce a much better coating, with minimal dilution, minimal distortion and better surface quality as compared to conventional thermal spraying processes like plasma spraying and High-Velocity Oxy-fuel (HVOF) spraying [2].

The Ni5Mo5Al powder is typically used in thermal spraying processes for coating of surfaces requiring high toughness with moderate resistance to fretting, erosion, and scuffing [3]. Goswami et al. [4] proposed Ni5Mo5Al hardfacing alloy cladding as an alternative to cladding with alloys containing Co and B like Stellite-6, as Co becomes radioactive after irradiation and B is a neutron poison, making such alloys unsuitable for the nuclear industry. Their study revealed that laser cladding of Ni5Mo5Al material can be used to improve the wear resistance of the substrate. The aim of present work is focused on optimizing the main operating parameters (laser power and scanning speed) and studying their interactions in order to obtain high-quality coatings with high surface microhardness.

2. Materials and Methods

Materials
The powder used in this experiment was commercially available Sulzer Metco AMDRY 387 (Ni5Mo5Al) with spherical particles of diameter 90±37 µm [5]. This powder is a fully alloyed, gas atomized material which results in coatings with highly homogeneous microstructure. The substrate
material was AISI 1020, and the deposition was carried out on the flat faces of cylindrical samples of dimensions Ø40 × 25 mm. The surfaces were polished and cleaned with acetone before cladding.

**Laser cladding process**

The experiments were carried out using a 2 kW Yb fibre laser (IPG YLR 2000) integrated with a 5 axis CNC workstation (figure 1(a)). The operating wavelength of the laser was 1.07 µm. The laser beam was directed on to the flat surface of the substrate with the focal plane placed above the substrate. The incident spot diameter was controlled by changing the stand-off distance. The resulting laser irradiation created a molten metal pool on the substrate surface. Simultaneously, a jet of Ni₅Mo₅Al powder was fed into the melt pool coaxially [6] to form a solidified metallic layer (figure 1(b)). In this experiment, overlapped tracks were formed at different laser powers (600 W & 800 W) and different scanning speeds (600 mm/min, 700 mm/min & 800 mm/min), so that there was an overlap rate of approximately 50% between tracks. Argon was used as the carrier gas which also shrouded the melting pool region to prevent oxidation during the experiment. The process parameters examined in this experiment are shown in Table 1.

| Powder Flow Rate (g/min) | Stand-off Distance (mm) | Spot Diameter (mm) | Hatch Space (mm) | Laser Power (W) | Scanning Speed (mm/min) |
|--------------------------|------------------------|--------------------|------------------|-----------------|-------------------------|
| 2.38 g/min               | 10                     | 1.2                | 0.65             | 600 and 800     | 600, 700 and 800         |

Figure 1. (a) Laser cladding set-up and (b) Laser and powder delivery head.

The morphology and microstructure of the laser cladded layers were measured using an optical microscope (ZEISS Axio Imager M2M), and the deposition dimensions were measured using ImageJ [7]. The microhardness of the cladded layers deposited at 600 W laser power and 700 mm/min scanning speed was measured using a Vicker’s microhardness tester (InnovaTest Falcon 500) under 1 kgf load.

**3. Results and Discussion**

Clad track geometry is an important aspect which determines the clad quality. An understanding of the relationship between process parameters and clad track geometries helps in defining the hatching distance or percentage of overlap, processing time and selection of process parameters to obtain a predefined coating thickness. Deposition with different processing parameters led to the evolution of different deposition morphologies, as shown in figure 2.
Figure 2. Clad morphologies at different laser power and scanning speed (a) 600 W, 600 mm/min; (b) 600 W, 700 mm/min; (c) 600 W, 800 mm/min; (d) 800 W, 700 mm/min.

Variation of clad width and height with different parameters is presented in table 2 and graphically depicted in figure 3. It is evident from the graphs that as the scanning speed increases, the width and height of the deposition decreases; but with an increase in laser power the width and height increases. This signifies higher deposition rates for higher laser power and lower scanning speed combinations, i.e., for higher line energy. Line energy is defined as the amount of laser energy incident per unit length and can be calculated as laser power/scanning speed. Insufficient interaction time and coupling energy caused a lower volume of deposition for lower line energies. A relatively uniform clad track geometry was obtained for overlapping tracks with 600 W laser power and 700 mm/min scanning speed. Penetration of the deposited material into the substrate was also highest for that parameter combination, signifying the highest bonding strength.

| Table 2. Clad dimensions. |
|---------------------------|
|                           |
| **P = 600 W,**  |
| **v = 600 mm/min,**  |
| **P = 600 W,**  |
| **v = 800 mm/min,**  |
| **P = 600 W,**  |
| **v = 700 mm/min,**  |
| **P = 800 W,**  |
| **v = 700 mm/min,**  |
| Width in µm (Track 1) | 799  | 733  | 699  | 825  |
| Height in µm (Track 1) | 260  | 249  | 258  | 474  |
| Width in µm (Track 2)  | 1011 | 975  | 1089 | 1284 |
| Height in µm (Track 2) | 511  | 369  | 315  | 720  |
Figure 3. Variation of deposition width and height at different laser power & scanning speed.

Influence of line energy on aspect ratio (width/height) of the deposition was also studied and is presented in figure 4. The relative changes in track height for different parameters were much higher than those in track width for the same parameters, indicating the less lateral spread of the deposited material. Restricted increment in the molten pool size is a possible reason behind such deposition geometries.

Figure 4. Influence of line energy on aspect ratio.

Microhardness of the clad track and of the substrate at that parameter combination was found to be 244 HV and 152 HV, respectively. Therefore, the deposited layer track has around 60% more hardness as compared to the substrate. The increase in hardness can be attributed to the presence of ordered fcc(γ') precipitates of Ni3Al embedded in the matrix of Ni-rich γ. The hard precipitates act to restrict dislocation motions, augmenting the microhardness of the material [8].
4. Conclusions

The presented study on the dependency of clad track geometry on laser processing parameters in case of Ni5Mo5Al cladding on AISI 1020 steel reveals some important observations. The deposition rates were found to be increasing with higher line energy, as can be expected since the amount of delivered energy was able to melt and deposit a higher amount of fed powder. The lateral spread and penetration of the deposition also increased with higher line energy as the melt pool becomes larger. But when the scanning speed was further reduced, the mass of the powder coming into the pool became very large, causing a higher portion of the incident energy to be consumed in melting the deposited powder. Thus, the portion of energy going into the substrate became less, resulting in a lower penetration and lower aspect ratio. Based on the results, 600 W laser power and 700 mm/min scanning speed was found to be appropriate for uniform clad geometry with ~50% overlap. The cladding caused a significant improvement in the microhardness also, as the results revealed an almost 60% increase in the microhardness of the clad layer from the substrate. Therefore, future work will look into the mechanical and microstructural characterization of the deposited layers to examine their efficacy in wear and erosion resistance of engineering components.

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