EFFECT OF OVERLAP RATIO ON POROSİTY AND MİCROHARDNESS OF 42C MARTENSITIC STAINLESS STEEL ON FGS600-3A DUCTILE CAST IRON IN LASER CLADDING TECHNOLOGY

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https://doi.org/10.37904/metal.2024.4897

Abstract

Controlling the quality of coatings is a significant objective. The large area parts require the construction of multi-track laser cladding layers, which are influenced by the overlapping conditions. This investigation deals with laser cladding technology, multi-track beads of 42C martensitic stainless steel were coated on FGS600-3A ductile cast iron with different overlap ratios. The percent overlap varied from 20% - 35% - 50% - 65% - 80%, which corresponds to 2.4 mm - 1.95 mm - 1.5 mm - 1.05 mm - 0.6 mm for multi-bead production. The optimum welding parameters were kept constant for production of specimens: laser power 1.3 kW and feed speed 8 mm/s, 3 layers of production were carried out. An experimental approach to investigate the porosity rate, crack and microhardness with variable overlap conditions is presented in this paper. In addition, digital image processing method was also used to calculate the porosity rate in the transverse and longitudinal surface. Vickers method was also employed to measure the hardness from base metal to surface of the coatings. It was found that by reducing the overlap distance, it is possible to drastically reduce the pore formation. The best compromise in terms of porosity was obtained in overlap distance 1.05 mm which corresponds to 65% overlap ratio. The highest microhardness values in the coating layer were obtained as 559.7 HV in specimen with 1.05 overlap distance. Experimental results on overlapped cladding layers of stainless steel on ductile cast iron show that it is useful for upcoming repair implementation of large parts suitable in the automotive sector.

Keywords: Laser cladding, overlap ratio, porosity, microhardness

1. INTRODUCTION

Additive manufacturing is an expanding technology recently thanks to its advantages compared to traditional manufacturing. Laser cladding is one of the additive manufacturing methods that allow for the powder material deposition of coatings by utilizing a laser heat source on the base material. Especially, it leads to high-quality coatings with metallurgic bonds thanks to minimum heat input and small heat affected zone. As well as, other advantages that can be mentioned are low dilution rate, low porosity, fine microstructure, high hardness, excellent wear and corrosion resistance. For this reason, laser cladding particularly provides a solution for repairing complex parts in the mold industry. The desired mechanical properties and microstructure can be controlled by properly selecting the processing parameters.

For the sake of producing thicker coatings in wider mold areas, it is required to the partial overlapping of a single laser track. In contrast to single-track cladding, multi-track laser cladding also includes remelting a section of the prior track. As such, single-track information is insufficient for multi-track surface cladding process plans and geometry controls. The selection of overlapping parameters is essential to enhancing the quality of coating on repairing implementation. Therefore, it has been widely researched in terms of multi-track overlapping in literature. Cao et al. investigated the "step effect" to improve the application of cladding efficiency and precision. They have researched different overlap rates by adjusting the distance between the claddings. The results showed that when the overlap ratio among the cladding was approximately 20% - 30%, the cladding layers had a smooth and flat surface. It was obtained good metallurgical bonding in microstructural analysis however, the density of the cladding layer was higher than the base metal in terms of pore and crack defects [1]. Research by Zareh and Urbanic presented a novel approach for overlap ratios of deposited 420 stainless steel onto mild steel through the laser cladding method. They have investigated different overlap ratios of 30% and 50% for the multi-bead configurations. The microhardness when the overlap rate is 30% was greater than 47% overlap rate [2].

The principal purpose of this study was to determine the effect of the overlap ratio on porosity and microhardness in the laser cladding of martensitic stainless steel powder on ductile cast iron used in sheet metal forming molds. Porosity rate were calculated with digital image processing method, microhardness was also measured in all specimens for cross-sectional surfaces. Consequently, significant findings could be obtained for further studies in literature by exploring porosity rate and microhardness.

2. EXPERIMENTAL DETAILS

The laser cladding method was used to deposit Metco 42C powder material (AISI 431 martensitic stainless steel) on FGS600-3A ductile cast iron used in sheet metal forming molds. The chemical compositions of the Metco 42C powder material and FGS600-3A ductile cast iron are shown in Table 1.

Table 1 Chemical composition (wt.%) of Metco 42C powder material and FGS600-3A ductile cast iron

Material	C	Si	Mn	P	S	Sn	Cu	Mg	Cr	Ni
FGS600-3A	3.06	2.06	0.52	0.044	0.009	<0.01	0.68	0.049	--	--
Metco 42C	0.18	--	--	--	--	--	--	--	17	2

The KUKA KR 90 R3100 Extra 6-axis filling welding unit and the KUKA KL 1500-3T linear table were used in the laser cladding process by Toplas 3D V3 software (**Figure** 1). The laser LASERLINE-LDF 4000-100 has the technical properties: maximum laser power of 4000 W, laser wavelength ranging from 900- 1070 nm, a laser beam diameter of 3 mm, a laser beam quality of 30 mm-rad, a minimum focus of 450 µm at a 150 mm distance, the fiber cable distance of 12 mm, optical fiber of 600 m (NA 0.2). The DELTATHERM LTK 1-4 Laser Nozzle Cooling Device and ERLAS Gmbh laser nozzle were used. Argon shielding gas has a discharge rate of 5 lt/min. Oerlikon Twin-120A has a powder flow rate of 13.6 g/min, a powder feeder rotation speed of 3 rpm, a cooling water flow rate of 1.8 l/min, a cooling water pressure of 0.22-0.3 MPa.

Figure 1 The laser cladding unit

In this study, five-parameter groups were created to investigate the effect of the overlap ratio in terms of porosity and microhardness. The percent overlap varied from 20% - 35% - 50% - 65% - 80%, which corresponds to 2.4 mm - 1.95 mm - 1.5 mm - 1.05 mm - 0.6 mm for multi-bead production (Table 2). The optimum welding parameters were kept constant for production of specimens: laser power 1.3 kW and scanning speed 8 mm/s. 3 layers of production were carried out in all specimens, only Specimen 5 were produced as 4 layers in due to the low powder efficiency. Expertise in our commercial applications was helpful to determine the parameter values used.

Table 2 Overlap rate and overlap distance of the specimen

Specimen No	Overlap Rate (%)	Overlap distance (mm)
1	20	2.4
2	35	1.95
3	50	1.5
4	65	1.05
5	80	0.6

Laser cladding was utilized on an FGS600-3A mold size of 120 mmx30 mm that have previously been machined to a 1 mm thickness using a CNC milling machine to achieve a smooth surface. Using electrical discharge machining (EDM), the specimens were cut in the directions of cross-section. The specimens were implemented to grinding with waterproof SiC abrasive paper and polishing with Alumina suspension (1 µm and 0.3 µm) using FORCIPOL 2V metallographic grinding and polishing machine. By digital image processing, the NIS Elements-D program was used to quantitatively porosity analyze. Microhardness measurements in transverse and longitudinal surfaces were carried out using a DUROLINE-M microhardness tester, the applied load was 50 g for 10 seconds from the surface along with the depth at 100 µm intervals.

3. RESULTS AND DISCUSSION

3.1. Porosity Analysis

During laser cladding process, when the laser beam has transferred with the powder material, it irradiates the substrate's surface to create a molten pool. However, porosity problems were occurring within this process. Pore formations effect significantly the mechanical properties, which need to be controlled to obtain a minimum pore ratio. The overlap ratio have a significant effect on the pore formation and the deposition efficiency.

The porosity ratio of the multi-tracks, including the number of pores, total pore area and total clad area were measured according to the digital image processing method **Table 3**. **Figure 2-6** displays the macrostructure and digital image processing images of cross-section of deposited multi-track overlapping coatings for all specimens. The porosity of coatings deposited distribute in %0.75-%4.35. Pores can reduced significantly by different overlap ratio. The porosity ratio decreases significantly with the increment of overlap ratio. Comparatively, Specimen 1, 2 and 3 porosity rates show an downward trend with the increase of overlap ratio (**Figure 2, Figure 3 and Figure 4**). The porosity rate is only about %0.75 in longitudinal surface, and increases to about 1.25 in the transverse section in Specimen 4 (**Figure 5**). The minimum porosity rate was observed in Specimen 4 with 65% overlap ratio and 1.05 overlap distance. It has been detected that increasing the overlap ratio up to 65% can increase the wettability of the molten and reduce the porosity of the melting zone. Thus in line with, when the overlap ratio was increased above 65% in Specimen 5, the porosity rate tended to upward. Specimen 5 displays the cross-sectional morphologies of multi-track overlapping coatings, in which the pores on the surface have propagated seriously between the two coating layers, and finally transcend multiple deposited tracks (**Figure 6**). The cladding areas did not show cracks or non-metallurgical bonding.

Table 3 Results of digital image processing for total pore area, cladding area and pore fraction

Experiment No	Cross-Section	Pore Area (mm2)	Cladding Area (mm2)	Pore Fraction (%)
1	Transverse	3.4	78.13	4.35
	Longitudinal	1.21	34.99	3.46
2	Transverse	3.29	87.48	3.76
	Longitudinal	0.84	33.69	2.49
3	Transverse	3.28	86.95	3.77
	Longitudinal	0.89	53.31	1.67
4	Transverse	1.61	128.39	1.25
	Longitudinal	0.43	57.39	0.75
5	Transverse	4.86	191.39	2.54
	Longitudinal	5.23	121.68	4.30

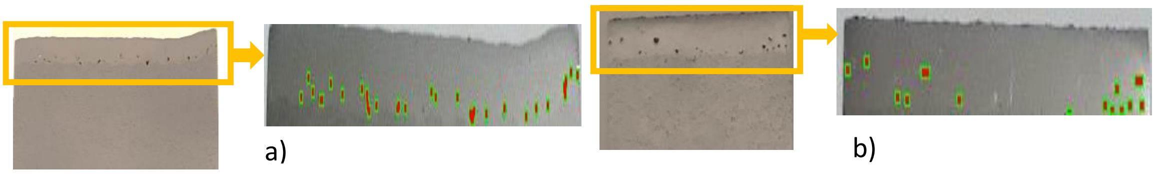

Figure 2 The digital image processing images of Specimen 1 a) Transverse surface b) Longitudinal surface

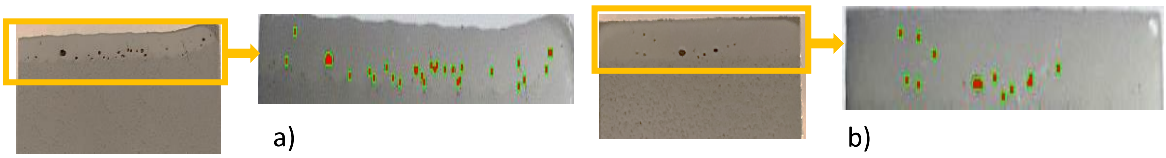

Figure 3 The digital image processing images of Specimen 2 a) Transverse surface b) Longitudinal surface

Figure 4 The digital image processing images of Specimen 3 a) Transverse surface b) Longitudinal surface

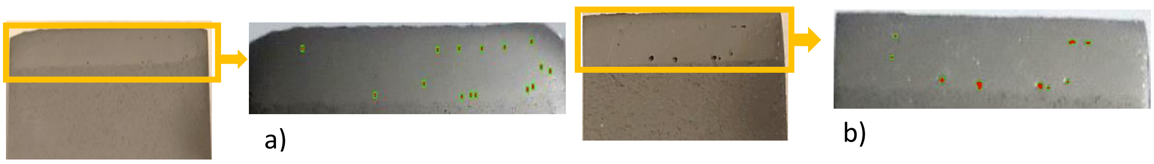

Figure 5 The digital image processing images of Specimen 4 a) Transverse surface b) Longitudinal surface

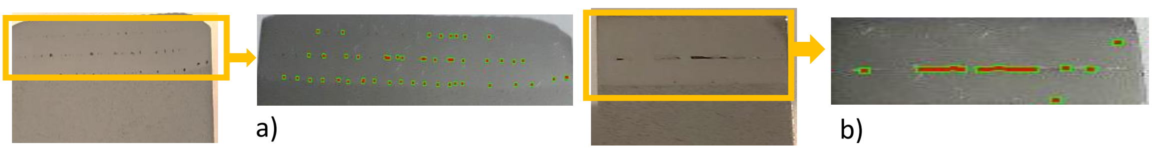

Figure 6 The digital image processing images of Specimen 5 a) Transverse surface b) Longitudinal surface

3.2. Microhardness

The microhardness results measured on the transverse and longitudinal cross-sectional surfaces of the specimens are plotted in (**Figure 7** and **Figure 8**). It can be clearly seen hardness curve of cladding layers with different overlap rate carried out along the depth. A significant increase in microhardness was observed in all coatings compared to base metal after laser cladding. The laser coatings have shown a gradual reduction in hardness from the top edge of the layers to the interior of the base metal.

Microhardness values varied between the 268.7 $HV_{0,05}$ and 559.7 $HV_{0,05}$ in all specimens. The maximum microhardness in Specimen 1 was the 479.8 $HV_{0,05}$, this value for a 20% overlap rate was the least amongst the other specimens. The maximum hardness was 507.2 $HV_{0,05}$ in Specimen 2 with a 35% overlap rate. The maximum hardness values occurred at depth 600 μm and was 510.3 $HV_{0,05}$ in Specimen 3 with a 50% overlap rate. When the examined measured data, the maximum microhardness occurred at depth 2100 μm and was 559.7 $HV_{0,05}$ in Specimen 4 with 65% overlap rate. The microhardness values are higher than others for the %65 overlap rate of 1.05 hatch distance. The maximum hardness value was at depth 2100 μm and are 534.5 $HV_{0,05}$ in Specimen 5 with a 80% overlap rate. As the overlap rate increases, it was possible to obtain higher hardness values at deeper depths. It can be seen that the high hardness values were quite deep in Specimen 5 with 80% overlap rate and 0.6 mm hatch distance. There was relatively little variation in the observed microhardness results amongst the specimens. But even so, these varied results show that the overlap ratio in cladding has a significant effect. When the cross-sectional microhardnesses were compared, it was noted that the transverse surface microhardness values were generally higher than longitudinal surface.The possible explanation for this improvement, different dendritic microstructures formed after cooling for different overlap rate of multi-tracks. The microstructure of the multi-track with different overlapping ratios takes the form of columnar dendrites growing perpendicular to the substrate [3]. Due to the variation of cooling rate, the chemical composition distribution of as-deposited parts may not uniform, and there could be composition segregation between dendrites. It should be noted that segregation is a time-dependent phenomenon influenced by various factors, especially like energy input [4].

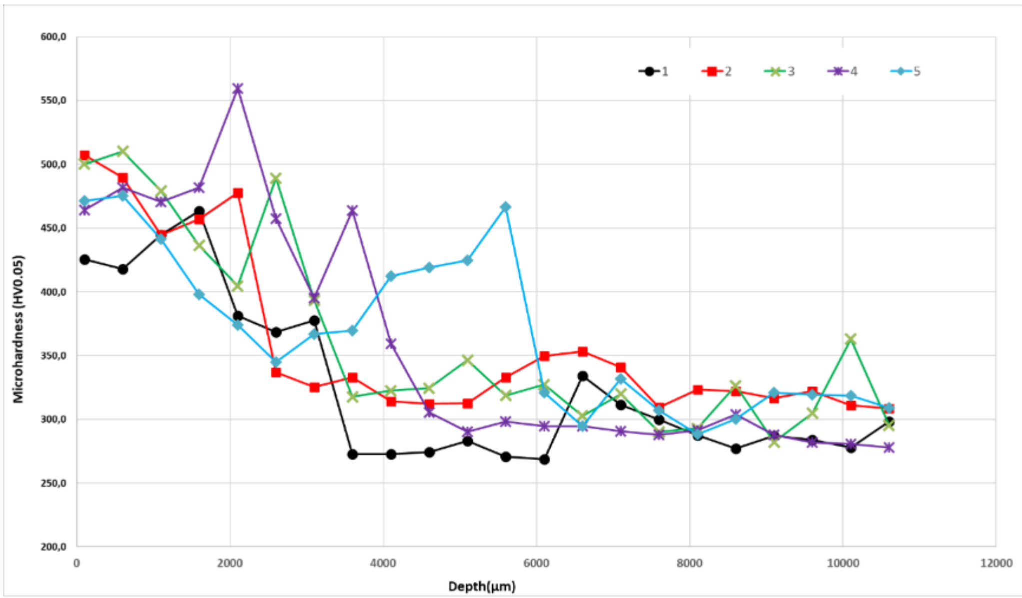

Figure 7 Microhardness measurements of the transverse surface along the depth

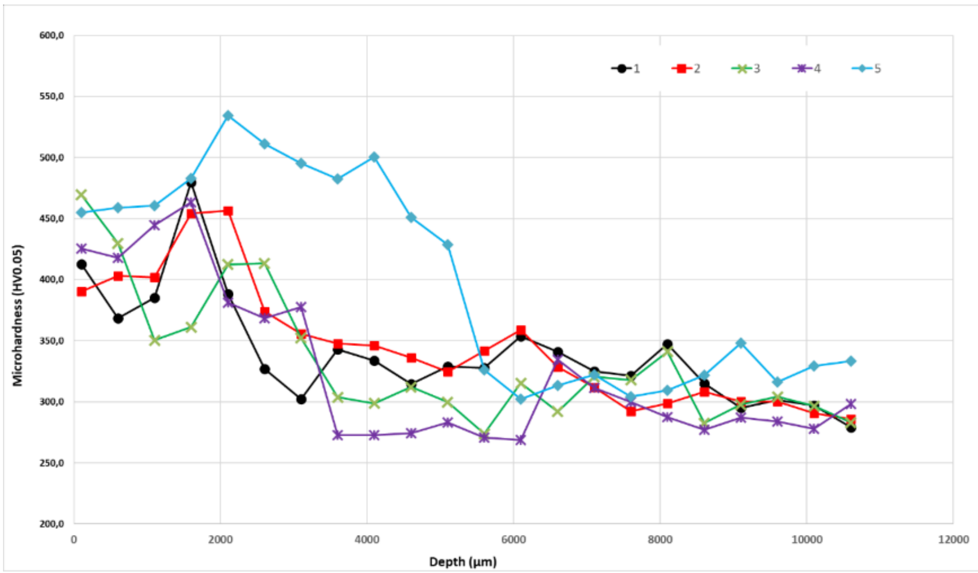

Figure 8 Microhardness measurements of the longitudinal surface along the depth

4. CONCLUSION

In this study, the porosity and microhardness in martensitic stainless steel coated on the FGS600-3A ductile cast iron were investigated in terms of different overlap ratios. The conclusions have been drawn as follows:

- The porosity ratio decreases significantly with the increment of overlap ratio.
- When the increase of overlap ratio can improve the wettability of the molten and lessen the porosity of the melting zone.
- The lowest porosity ratio was obtained in Specimen 4 with 65% overlap ratio and 1.05 overlap distance.
- The laser coatings have shown a gradual reduction in hardness from the top edge of the layers to the interior of the base metal. The maximum microhardness occurred at depth 2100 µm and was 559.7 $HV_{0,05}$ in Specimen 4 with 65% overlap rate and 1.05 hatch distance.

ACKNOWLEDGEMENTS

The authors acknowledge the Scientific and Technological Research Council of Turkey (TUBITAK) for the support by 1505 University-Industry Cooperation Support Program, and Coskunoz Mold Machine Inc. providing facilities for the laser cladding operations. (Project No: 5180090)

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