DOI: https://doi.org/10.24425/amm.2022.141075

CHEOL-WOO KIM[1], HYO-SANG YOO[1*]

STUDY ON IMPROVEMENT OF SURFACE PROPERTIES OF SKD61 POWDER ON S45C USING LASER CLADDING

In this study, we investigated the effect of cladding on structural carbon steel (S45C) using 5%Cr-1.5%Mo-Fe powder (SKD61), which is expected to show economically efficient production of die-casting parts. The process conditions were performed under argon atmosphere using a diode laser source with specialized wavelength of 900-1070 nm, and the output conditions were 3, 4, and 5 kW, respectively. After the cladding was completed, the surface coating layer's shape and the microstructure were analyzed. The hardness test was carried out with Micro Vickers hardness tester under 500 gram-force along the normal line at the interval of 0.2 mm from the surface to core direction on the cross-sectional area. In addition, polarization curve test of the surface coating layer was performed to investigate the corrosion resistance characteristics.

Keywords: Laser cladding; Micro vickers hardness; Microstructure; Polarization curve

1. Introduction

Laser cladding method is a direct energy deposition technique that depositing a cladding layer on the base material while melting powder using laser power. This laser cladding method has been utilized as a method to improve the quality and prolong the life time of mold in the mold industry, which is essential to the basic industries. It is applied to repair the damaged part or surface of the mold, and it can be cost-effective than the total replacement cost of the damaged mold [1-4]. Recently, research is being conducted to minimize repair costs by forming an alloy layer on the surface of a specific part of the mold to improve the performance, and by reprocessing the alloy layer after using the mold for a certain period of time [5]. However, in the case of laser cladding, since the substrate material and the cladding powder are melted and then solidified rapidly, there may be a tensile residual stress that causes fatigue cracking and stress corrosion cracking in the cladding layer. These residual stress cause cracks between the deposit and base material, resulting in unexpected fracture and deterioration of the material's mechanical properties. Therefore, many researchers are trying various approaches to prevent delamination and cracking at the deposition base substrate interface through laser power conditions [6-8].

In this study, we investigated the effect of cladding on structural carbon steel (S45C) using 5%Cr-1.5%Mo-Fe powder (SKD61), which is expected to show economically efficient production of die-casting parts. Metallurgical bonding, Chemical composition between the clad layer and substrate, and the clad layer's hardness are presented.

2. Experimental

S45C base material specimen with 100×100×25 mm dimensions were prepared by grinding the surface with sandpaper from #320 to #2000, followed by acetone rinsing for degreasing the specimen and improvement of laser absorptivity on the surface. The alloy powder used in this study is the SKD61 powder (5%Cr-1.5%Mo-Fe) with an average diameter of 106 μm and size distribution in spherical shape. The chemical composition of substrate steel (S45C) and powder (SKD61) and are presented in TABLE 1.

Laser cladding(LASERLINE_LDF10000-100) was performed using a solid laser system (Laserline LDF10000-100) 10 kW powered by a diode laser in the wavelength of 900-1070 nm equipped with fiber delivery. The laser spot size was 8.3 mm with 72 mm collimation lenses, 1500 μm laser

[1] SUNCHEON PPURI TECHNOLOGY SUPPORT CENTER, KOREA INSTITUTE OF INDUSTRIAL TECHNOLOGY, 34, HAERYONGSANDAN 2-RO, HAERYONG-MYEON, SUNCHEON-SI, JEOLLANAM-DO, 58022, KOREA

* Corresponding author: yoohs@kitech.re.kr

TABLE 1

Chemical composition of S45C steel and SKD61 steel powder in wt.%

Element	C	Mn	Si	Cr	Mo	Ni	Cu	Al	Fe
Substrate	0.472	0.732	0.197	0.029	—	0.009	0.018	0.024	Bal.
Powder	0.35	0.35	1.0	5.0	1.5	—	—	—	Bal.

fiber core, and 400 mm focusing lenses. The distance between the substrate surface and the coaxial powder feeding head was 20 mm. The Ar was used as the supply gas, and the gas supply rate was 15 L/min. The powder feeding rate was 30 g/min, and the laser power applied to the cladding process was 3, 4 and 5 kW.

In order to observe their microstructures, all of the specimens were longitudinally cross-sectioned, ground by sandpaper, and the specimens were polished using a diamond suspension of 3 μm and 1 μm with a silica was then used for the final polishing. SKD61 and S45C steel were etched with natal 5% solution to observe the interdiffusion zone and heat-affected zone. The hardness test was measured under the conditions of the Micro Vickers hardness tester (FUTURE TECH_FLV-10ARS-F) Hv0.5 at the interval of 0.2 mm from the surface to the core direction of the substrate. The macromorphology, composition, and microstructure of each clad layer and bonding area were investigated using optical microscopy (OLYMPUS_GX51-N212D). The corrosion behavior was studied by potentiodynamic polarization tests (ZIVE LAP_ZIVE SP2). Potentiodynamic polarization measurements were performed in 3.5 wt.% NaCl solution at 25°C, it was analyzed at a rate of 5 mV/sec. A saturated calome electrode was used as the reference electrode, and a high-density carbon rod was used as the auxiliary electrode.

3. Results and discussion

Fig. 1 shows the clad height, internal diffusion region, and heat-affected region of a laser clad specimen. Fig. 1(b) shows the height of the clad height, internal diffusion zone, and heat-affected zone. As the laser power increased by 3, 4, and 5 kW, the heights of the clad zone and the heat affected zone showed similar values. However, as the laser power increased, the inner diffusion area increased to 0.12, 0.26, and 0.82 mm, respectively, because the molten pool in the matrix increased. In general, it was reported that the melt depth and width increase almost linearly as the laser power increases [8].

Dilution can be defined as the percentage of the total volume of the surface layer contributed by the melted substrate. The dilution of specimens with different laser powers was calculated as follows, and the result was shown in Fig. 1(c).

$$\text{dilution}(\%) = \frac{I}{C+I} \times 100 \tag{1}$$

Where C is clad height (mm); I is interdiffusion zone height (mm).

From the Fig. 1(c), it was confirmed that the dilution increased as the power increased.

The microstructure of the heat-affected zone and substrate as the laser power increased to 3 kW, 4 kW, and 5 kW is shown in the Fig. 4. It is shown that a mixture of pearlite and bainite was formed at the heat-affected zones of the specimens at the power condition of 3 kW. After 4 kW and 5 kW are applied to the substrate, only pearlite microstructure was observed in the heat-affected zone. It could be due to the high laser power of 4 kW or more significantly increases the temperature of the specimen and slows down the cooling rate [9].

Fig. 3 shows the micro-hardness depth profile perpendicular direction to the surface in the cross-section of the cladding layers. It was measured at 0.1 mm intervals from the interdiffusion zone to the heat-affected zone. In the case of the interdiffusion zone, the micro-hardness decreased sharply at laser power of 5 kW compared to 3, 4 kW. It is considered to be due to the relatively high dilution rate of 5 kW compared to 3 kW and 4 kW, as shown in Fig. 1(c).

In the heat-affected zone, the specimens at the condition of the heat inputs in all of the 3 kW, 4 kW and 6 kW show little hardness variation according to cross-section depth direction and show similar micro-hardness values to each other. On the

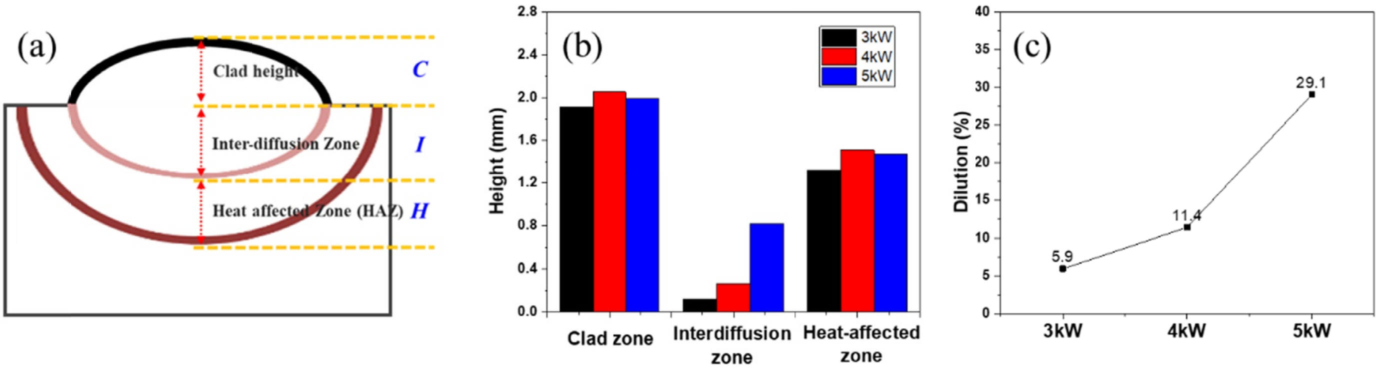

Fig. 1. The cross-sectional image of laser-cladded specimen (a) showing distinct three areas – (1) clad, (2) interdiffusion, and (3) heat affected zone – coating height (b) corresponding to distinct area (a), and dilution rate (c) with various laser powers, 3, 4, 5 kW

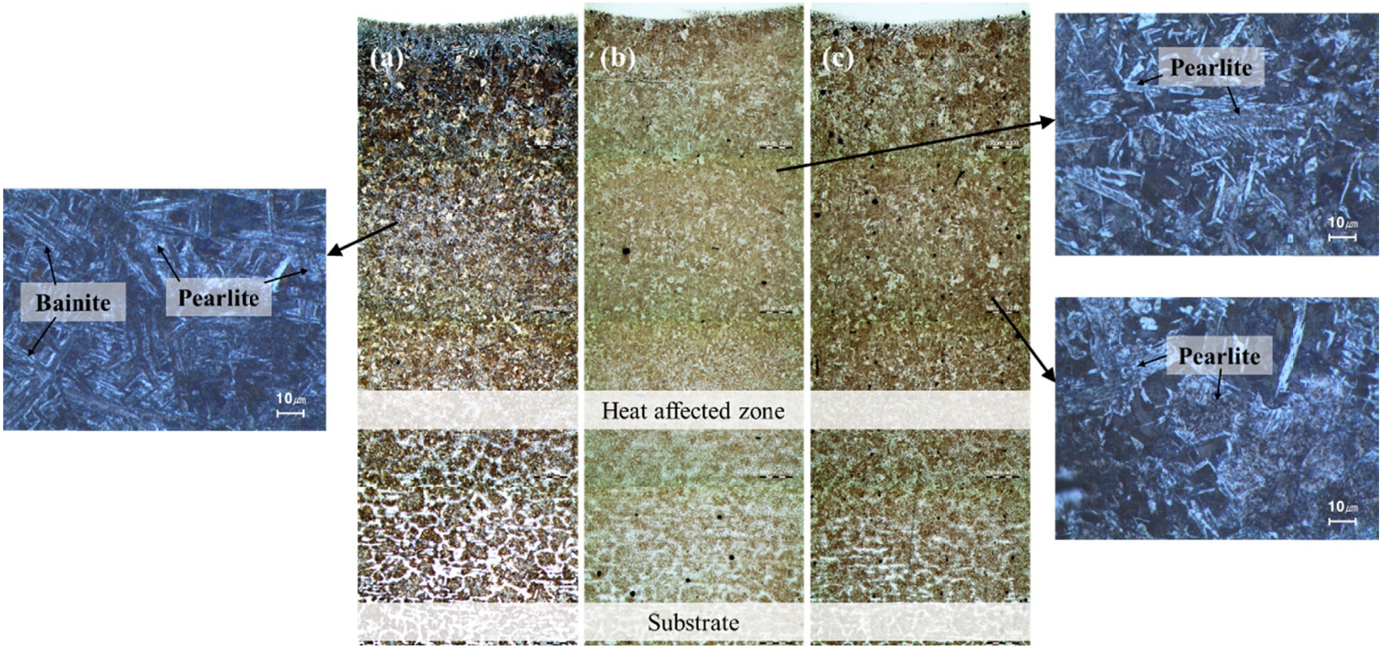

Fig. 2. OM images of Heat affected zone (HAZ) and Substrate material: (a) 3 kW, (b) 4 kW, and (c) 5 kW

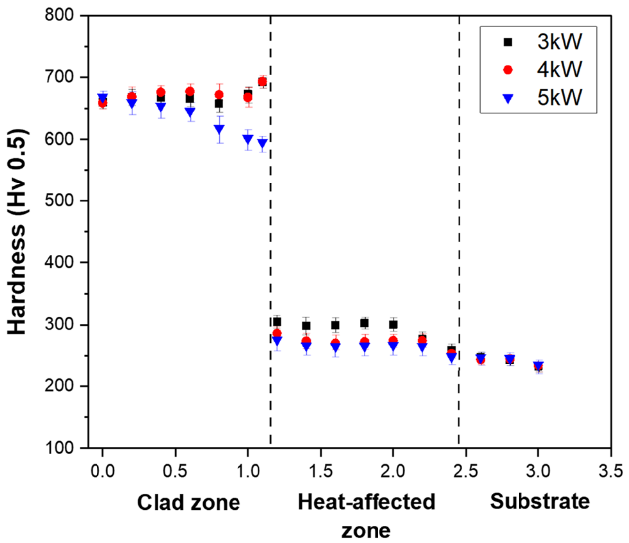

Fig. 3. Variations of micro-hardness with different laser powers: micro-hardness as a function of distance from surface in laser cladding specimens

other hand, the specimen at the 3 kW heat input condition shows a slightly higher micro-hardness value compared to laser power of 4, 5 kW. The above results well corresponded to microstructure changes shown in Fig. 2.

To investigate the corrosion behavior of all specimens coated with SKD61 powder by laser cladding at various condition and SKD61 bulk materials, potentiometric polarization measurements were carried out in 3.5 wt.% NaCl solution at 25°C. The potentiodynamic polarization curves are shown in Fig. 4 and the corrosion parameters such as corrosion potential and current density, showed in TABLE 2. The SKD61 cladding layer has the same chemical composition as the bulk material, but as a result of the potentiometric polarization test, it showed stronger corrosion resistance than the SKD61 bulk material. Corrosion potentials of the clad SKD61 under 3, 4, 5 kW conditions and bulk SKD61 specimens confirmed in Fig. 4 were –0.350 V, –0.413 V, –0.438 V, and –0.516 V, respectively. The maximum corrosion current densities of each specimen were 1.03E–8 A/cm^2, 1.57E–7 A/cm^2, 1.88E–8 A/cm^2, and 1.14E–7 A/cm^2, respectively.

TABLE 2

Electrochemical evaluation results

Element	*E* (mV)	*I* (A/cm^2)
3 kW SKD61	–350	1.03E–8
4 kW SKD61	–413	1.57E–7
5 kW SKD61	–438	1.88E–8
Bulk SKD61	–516	1.14E–7

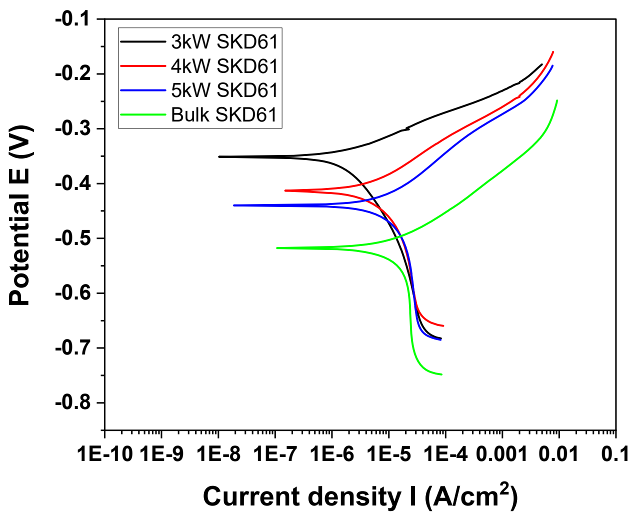

Fig. 4. Polarization curves of specimens after potentiodynamic test in NaCl solution at 25C°

4. Conclusions

In this study, we investigated the effect of cladding on structural carbon steel (S45C) using 5%Cr-1.5%Mo-Fe powder (SKD61), which showed high hardness and corrosion resistance on the die surface. Obtained results are summarized as follows:

1. In the case of Dilution rate, 3 kW, 4 kW, and 5 kW were 5.9%, 11%, and 29.1%, respectively. The dilution layer was formed more than about three times thicker at 5 kW than 3 and 4 kW, and higher input energy at 5 kW could be attributable to lower hardness of interdiffusion zone.
2. The hardness distribution of the heat-affected zone from 0 to 1 mm in interdiffusion zone toward core direction showed a higher value for the specimen with 3 kW output condition than that for 4, 5 kW specimens. This is deduced that the higher hardness of the specimen at 3 kW condition could be due to high fraction of Bainite which would be transformed by lower heat input and fast cooling rate, compared with that of 4, 5 kW.

As a result of analyzing the corrosion characteristics of all specimens coated with SKD61 powder by laser cladding at various condition, it was found that the lower the output condition, the better the corrosion resistance. It is analyzed that the laser cladding coating layer has excellent characteristics compared to the SKD61 bulk material.

Acknowledgments

This research was a part of the project titled 'The development of marine-waste disposal system optimized in an island-fishing village', funded by the Ministry of Oceans and Fisheries of the Republic of Korea.

REFERENCES

[1] J. Mazumder, Optics and Lasers in Engineering **34**, 397 (2000).
[2] P. Kattire, Journal of Manufacturing Processes **20**, 492 (2015).
[3] Z. Zhang, Journal of Alloys and Compounds **790**, 703 (2019).
[4] X. Xu, Journal of Alloys and Compounds **715**, 362 (2017).
[5] L. Li, Optics and Lasers in Engineering **34**, 231 (2000).
[6] C. W. Kim, Archives of Metallurgy and Materials **66**, 1033 (2021).
[7] P. Farahmand, Lasers in Manufacturing and Materials Processing **1**, 1 (2014).
[8] C. W. Kim, Korean Journal of Materials Research **11**, 601 (2021).
[9] G. Telasang, Surface and Coatings Technology **258**, 1108 (2014).
[10] H. Zhizhong, The Handbook of Steel and Its Heat Treatment Curve (1987).