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EFFECT OF OUTPUT CONDITIONS ON MICROSTRUCTURE AND PROPERTIES OF SKD61 LASER CLADDING

This study investigated the effect of cladding on tool steel (SKD61) by using 5%Cr-1.5%Mo-Fe powder (SKD61), which is expected to be economically effective when used to manufacture and mend die-casting parts. The cladding conditions were as follows: the distance between the coaxial powder supply head and the substrate surface was 20 mm, and Ar was used as the supply gas. The laser outputs applied in the cladding procedure were 3, 4, and 5 kW. The microstructure of the heat-affected zone in the processed specimens was analyzed, and the macrostructure and morphology of the substrate material were studied. Specimen hardness measurements were performed at intervals of 0.1 mm from the substrate surface to the core. As the laser output increased from 3 to 4 and 5 kW, the dilution rate increased from 10.6% to 11.8 and 13.2%. It was confirmed that the fraction of carbides increased as the laser output increased from 3 kW to 5 kW.

Keywords: Laser cladding; Micro vickers hardness; Microstructure; Mold restore

1. Introduction

Die-casting molds are usually prepared from alloy tool steels that allow molten metals to directly contact to produce products, and structural carbon steel (mold base, S45C) to protect the core for product production and injection structure application. When a mold is damaged, it is generally repaired by means of welding. This is because welding can repair the surface or damaged part of the mold, and it is more cost-effective than replacing the damaged mold [1-4]. However, in the welding procedure, pre-heat treatment and post-heat treatment of the mold are required. Moreover, the post-processing is a time-consuming endeavor. Recently, several studies have been conducted to compensate for these shortcomings, and in these studies, laser cladding technology has been applied to restore damaged molds or mold surfaces. In particular, laser cladding technology can be applied in remanufacturing processes and to repair mold and die surfaces [5-7].

Laser cladding involves the deposition of a cladding layer on a base material while continuously melting metal powder by using the power output of a laser. This technology forms an excellent surface layer by minimizing deformation of the base material. Moreover, laser cladding creates new properties on the surface of the substrate [8]. Therefore, this method has been used to improve mold quality and extend mold life in the mold industry by improving toughness and hardness. However, the steep cooling rate and high heating temperature generated during the cladding process generate residual stresses and cause crack formation between the layer deposited on the mold surface and substrate material. These cracks induce unexpected degradation in the mechanical properties and cause damage to the material. Therefore, temperature control during the laser cladding procedure is important for reducing the crack susceptibility of the substrate, which changes the mechanical and metallurgical properties of the deposited material [9-11]. Especially, it is necessary to prevent cracks and peeling of the deposition base substrate interface by employing the optimal laser power conditions.

This study investigates the effect of laser cladding on tool steel (SKD61) by using 5%Cr-1.5%Mo-Fe powder (SKD61), which is expected to be economical for manufacturing and repairing die-casting parts. The microstructure, hardness, and chemical composition of each zone are analyzed as a function of the change in laser output power.

2. Experimental

An SKD61 base material specimens were machined to a size of 100×100×25 mm. The processed samples were polished with sandpapers of grits ranging from #320 to #2000, degreased,

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and washed with acetone rinse to improve laser absorption. The alloy powder used in this study was spherical SKD61 powder (5%Cr-1.5%Mo-Fe) with an average particle diameter of 106 μm.

The laser cladding machine (Laserline LDF10000-100) was equipped with fiber delivery and driven by a diode laser with a wavelength range of 900-1070 nm. A laser spot size of 8.3 mm was achieved using a 72-mm collimating lens, 400-mm focusing lens, and a 1500-μm laser fiber core. The distance between the coaxial powder supply head and the substrate surface was 20 mm, and Ar was used as the supply gas. The gas flow rate was 15 L/min, and the powder supply rate was 30 g/min. The laser output powers used in the cladding procedure were 3, 4, and 5 kW.

All the samples processed under different conditions were analyzed for microstructure and hardness. The microstructure of the heat-affected zone (HAZ) and the macrostructure and morphology of the substrate material were analyzed using an optical microscope (OLYMPUS_GX51-N212D) and a field emission scanning electron microscope (JEOL-JSM 700F). The mechanical properties of the samples were determined by conducting a hardness test under the Hv0.1 condition of a micro-Vickers hardness tester (FUTURE TECH_FLV-10ARS-F). The hardness measurements were performed at intervals of 0.1 mm starting from the surface of the substrate and going all the way to the core.

3. Results and discussion

Fig. 1 shows the clad height, internal diffusion zone, and HAZ of a laser-clad specimen. The cross-sectional images in Fig. 1(a) show the locations of the three regions. As the laser output increased from 3 to 4 and 5 kW, the height of the HAZ increased from 1.03 to 1.28 and 1.35 mm, respectively, and the height of the interdiffusion zone increased from 0.27 to 0.36, and 0.45 mm. Moreover, the clad height increased from 2.29 to 2.69 and 2.95 mm, respectively. In general, as the laser output increased, the coating height, width, and melt depth increased almost linearly [12]. Dilution was defined as the percentage of the surface layer's total volume contributed by the melting substrate.

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

where C is clad height (mm), and I is the interdiffusion zone height (mm).

Specimen dilution under different laser powers was calculated as follows, and the result is depicted in Fig. 1(c), which shows dilution rate as a function of laser output. As the laser output increased from 3 to 4 and 5 kW, the dilution rate increased from 10.6% to 11.8% and 13.2%, respectively. It is desirable that the dilution rate with the substrate should be minimized to ensure that the abrasion and corrosion resistance characteristics of the cladding material do not deteriorate [13,14].

Fig. 2 shows the microstructure of the HAZ and substrate as a function of the laser output power (3, 4, and 5 kW). Under all laser output conditions, the microstructure of the HAZ consisted of martensite and bainite. The martensitic region increased as the laser output increased from 3 to 4, and 5 kW. It exhibited different microstructures depending on the martensite and bainite fractions in the interdiffusion region. A high laser output greatly increased the specimen temperature. As the specimen temperature increased, the specimens were able to cool at a faster rate than those under other conditions to form the martensitic structure [15].
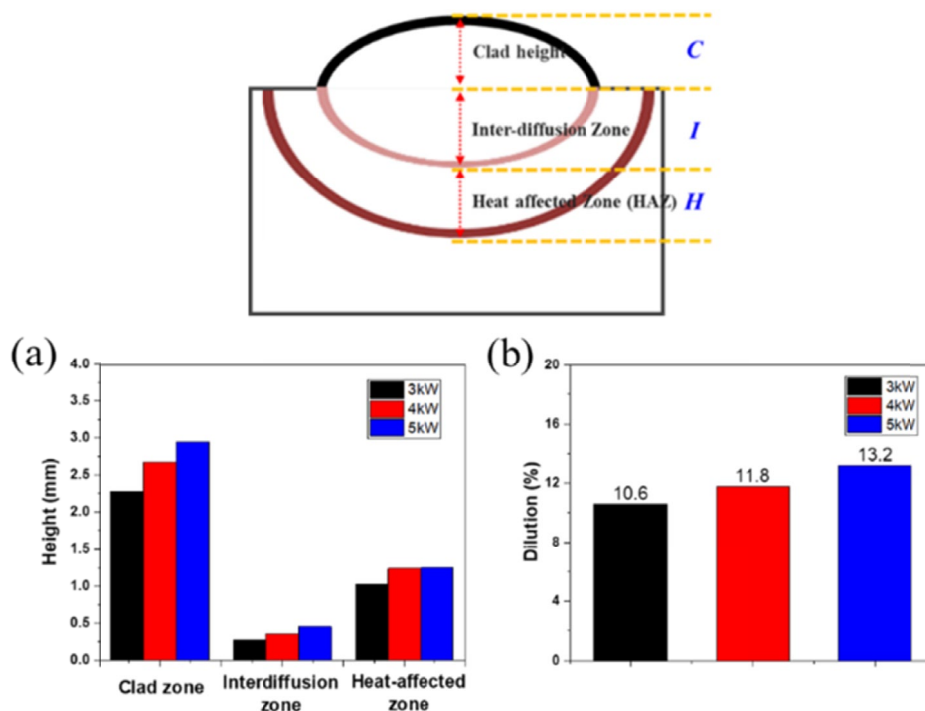

Fig. 1. The influence of laser output on (a) coating height and (b) dilution rate with the substrate
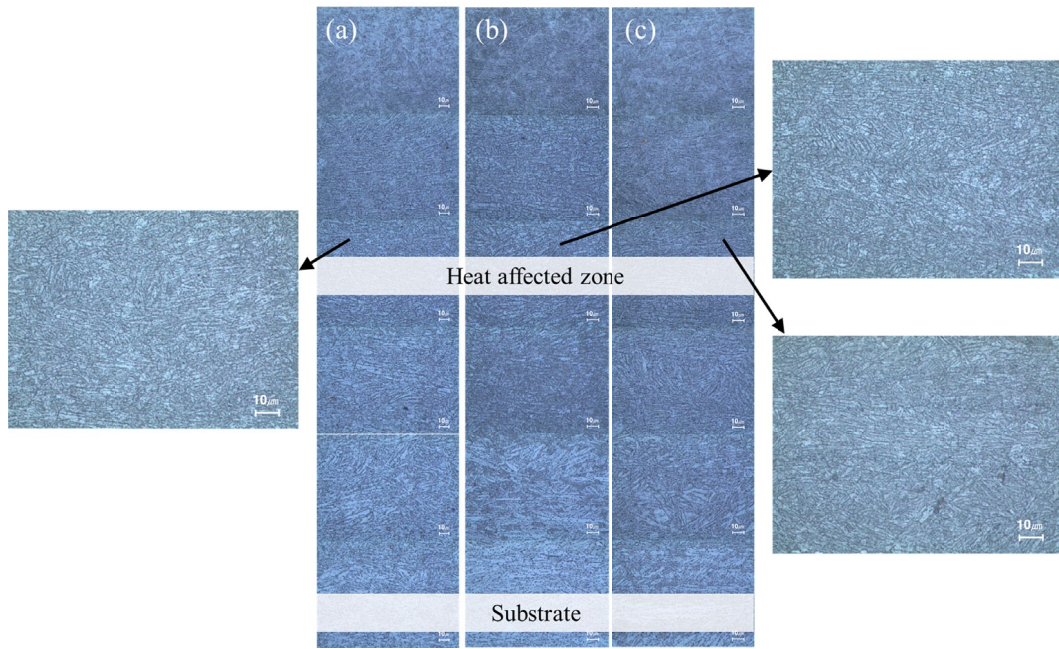
Fig. 2. OM images of Heat affected zone (HAZ) and Substrate material: (a) 3 kW, (b) 4 kW, and (c) 5 kW

Fig. 3 shows the SEM/energy-dispersive X-ray analysis (EDX) results of the HAZ formed under the laser outputs of 3, 4, and 5 kW. It was confirmed that the fraction of carbides increased as the laser output increased from 3 kW to 5 kW. Its wear-resistance was closely related to the presence of transition-metal carbides, especially the carbide M_7C_3 (M = Fe, Cr). M_7C_3 carbide formed via rapid cooling can remarkably increase the hardness of the alloy, and its wear-resistance and corrosion-resistance improve accordingly [16]. The hardness and wear resistance of the alloy are expected to increase as the fraction of M_7C_3 increases.
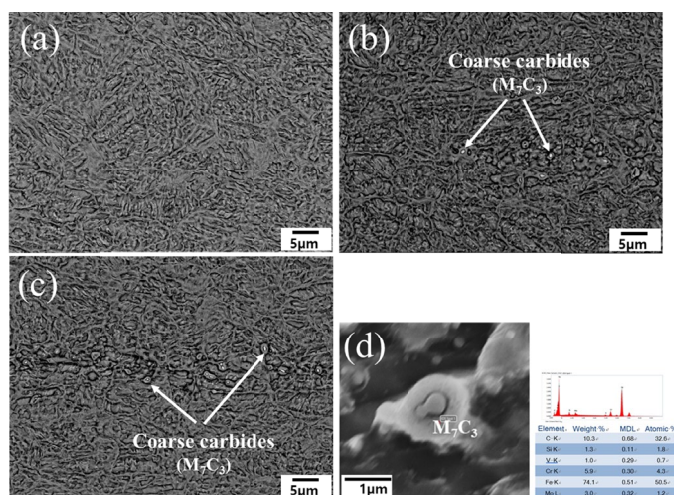
diffusion zone and HAZ, the hardness values achieved with the laser outputs of 4 kW and 5 kW were higher than that achieved with the laser output of 3 kW. Moreover, in the interdiffusion zone, the measured hardness was higher than those of the other zones. In the clad zone, the specimens subjected to the heat input conditions of 3, 4, and 5 kW exhibited little change in hardness along the cross-sectional depth direction, and their microhardness values were similar.
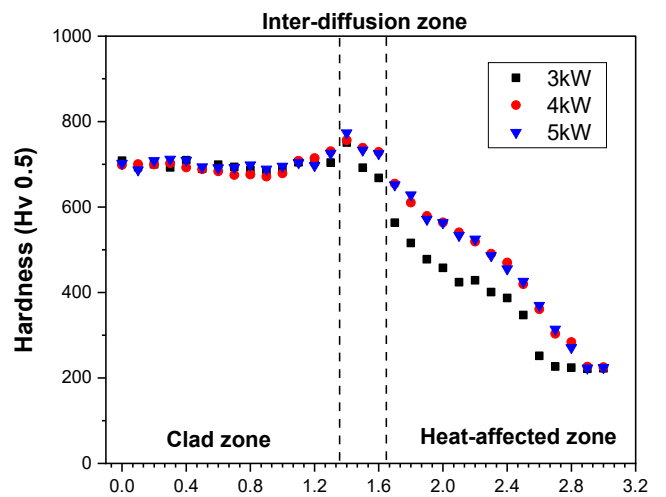

Fig. 3. SEM (a, b and c) / EDX (d) results of H eat affected zone (HAZ) with different laser output: (a) 3 kW, (b) 4 kW, and (c, d) 5 kW

Fig. 4. Variations of micro-hardness with different laser output: micro-hardness as a function of distance from surface in laser cladding specimens

Fig. 4 shows the results of a hardness analysis of the clad zone, inter-diffusion zone, and HAZ. Hardness was measured at intervals of 0.1 mm from the clad zone to the HAZ. In the inter-

4. Conclusions

In this study, we investigated the effect of laser cladding on alloy tool steel (SKD61) by using 5%Cr-1.5%Mo-Fe powder (SKD61); the layer clad on the die surface exhibited

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high hardness. The results of this study are summarized as follows:

1. The dilution rates achieved with the laser power outputs of 3, 4, and 5 kW were 10.6, 11.8, and 13.2%, respectively. Dilution can be defined as the percentage of the clad surface layer's total volume contributed by the melting substrate.

2. The dilution rate with the substrate should be minimized to the extent possible to preserve the abrasion-resistance and corrosion-resistance characteristics of the clad material.

3. The hardness distribution in the HAZ ranging from 0 to 1 mm in the interdiffusion zone toward the core direction was lower for the specimen processed using the laser output of 3 kW than those of the specimens processed using the laser outputs of 4 and 5 kW. This lower hardness of the specimen processed under the 3-kW condition could be attributed to the relatively short carbon diffusion time under this condition compared to those under the 4- and 5-kW conditions.

4. As the laser output increased, the fraction of M_7C_3 increased, which contributed greatly to the improvement in specimen hardness.

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