A comparative study on the properties of alloy tool steel according to the presence or absence of heat treatment using laser cladding

CheolWoo Kim[1], HyoSang Yoo[1] and YoungChan Kim[1]

[1]*Korea Institute of Industrial Technology, 34, Haeryongsandan 2-ro, Haeryong-myeon, Suncheon-si, Jeollanam-do, 58022, Republic of Korea*

The materials of the die-casting mold are usually consisting of alloy tool steel (core, SKD61) that allows the molten metal 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 using an arc welding process. However, in the arc welding process, pre-heat treatment and post-heat treatment of the mold are required. Also, there is a disadvantage in that it takes a lot of post-processing time, and thermal fatigue failure occurs due to repeated shrink/expansion. Recently, several studies are being conducted to compensate for these shortcomings, and among them, laser cladding technology was applied to restore the damaged mold or surface. However, there is still a concern about thermal fatigue damage due to the difference in hardness the clad zone and the base material. In this study, we investigated the effect of cladding on tool steel (SKD61) using 5%Cr-1.5%Mo-Fe powder (SKD61) to show economically efficient production and repair of die-casting parts. In addition, tempering heat treatment was applied according to the cladding conditions, and the difference in hardness between the clad zone and the base material was compared and analyzed. The process conditions were performed under argon atmosphere using a diode laser source with specialized wavelength of 900-1070 nm. 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 0.1 mm from the surface to core direction on the cross-sectional area.

Keywords: *laser cladding, annealing, micro-Vickers hardness, microstructure, mold restore*

Introduction

The materials of the die-casting mold are usually consisting of alloy tool steel that allows the molten metal 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 using a welding procedure. This is because it is applied to repair the surface or damaged part of the mold, and it can be cost-effective than the total replacement cost of the damaged mold[1-4]. However, in the welding procedure, pre-heat treatment and post-heat treatment of the mold are required. Also, there is a disadvantage in that it takes a lot of post-processing time. Recently, several studies are being conducted to compensate for these shortcomings, and among them, laser cladding technology was applied to restore the damaged mold or surface. In particular, laser cladding techniques can be applied in remanufacturing processes, mold and die surface repairs[5-7].

Laser cladding is a technique of depositing a cladding layer on a base material while continuously melting powder using laser output. This technology is known to have an excellent surface layer by minimizing the deformation of the base material. This laser cladding procedure creates new properties on the surface of the substrate. It has been used as a method to improve the quality and extend the life of molds in the mold industry by improving toughness and hardness. However, the cooling rate and high heating temperature generated during the cladding process generate residual stress and cause cracks on the mold surface. These residual stress causes cracks between the substrate material and the deposition layer, resulting in unexpected degradation of mechanical properties and damage of the material. Therefore, procedure temperature control is essential to reduce the crack susceptibility of the substrate, which changes the mechanical and metallurgical properties of the deposited material[8-10]. Especially, it is necessary to prevent cracks and peeling of the deposition base substrate interface through optimal laser power conditions.

This study investigated the effect of cladding on tool steel (SKD61) using 5%Cr-1.5%Mo-Fe powder (SKD61), which is expected to show financially effective manufacture and mend of die-casting parts. The microstructure, hardness and chemical composition of each zone according to the laser output change were analyzed.

Experiment

The SKD61 base material specimen was machined to a size of 100×100×25 mm. The processed samples were polished from #320 to #2000 with sandpaper, then degreased 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 diameter of 106 μm.

The laser cladding (Laserline LDF10000-100) is equipped with fiber delivery and is driven by a diode laser with a wavelength of 900-1070 nm. The laser spot size was 8.3 mm with a 72 mm collimating lens, a 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 supply speed was 15 L/min, and the powder supply speed was 30 g/min. The laser output applied to the cladding procedure is 3, 4 and 5 kW.

Samples under all conditions were analyzed for microstructure and hardness. The microstructure was analyzed for the heat-affected zone and the macrostructure and morphology of the substrate material using an optical microscope (OLYMPUS_GX51-N212D) and an emission scanning electron microscope (JEOL-JSM 700F). The mechanical properties were subjected to a hardness test and analyzed under the Hv0.1 condition of a Micro Vickers hardness tester (FUTURE TECH_FLV-10ARS-F). Measurements were performed at intervals of 0.1 mm from the surface of the substrate to the core.

Results

Figure 1. The influen[illegible] n (a) coating height and (b) dilution rate v[illegible]

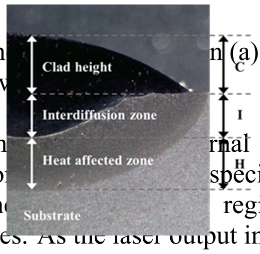

Figure 1 shows th[illegible] rnal diffusion zone and heat affected zo[illegible] specimen. Figure 1 (a) describes the h[illegible] regions based on cross-sectional images. [illegible] output increased to 2.5, 3.5 and 4.0 kW, th[illegible] t of the heat-affected zone increased to 1.32, 1.3[illegible] .50 mm and the height of the interdiff[illegible] on zone increased to 0.48, 0.71, and 0.79 mm. Also, th[illegible] clad height increa[illegible] ed to 1.87, 2.74 and 2.98 mm. In ge[illegible] s the laser outp[illegible] t increases, the coating height, width [illegible] melt depth [illegible] se almost linearly[11]. Dilution can b[illegible] ed [illegible] he [illegible] age of the surface layer's total volume contributed by its melting substrate. Figure 1 (b) shows the dilution rate as a function of the laser output. As the laser output increased to 2.5, 3.5 and 4.0 kW, the dilution rates increased to 20.4, 20.6 and 21.0. It is desirable that the dilution rate with the substrate should be minimized as little as possible in order not to deteriorate the characteristics of the abrasion and corrosion resistance on clad material[12, 13].

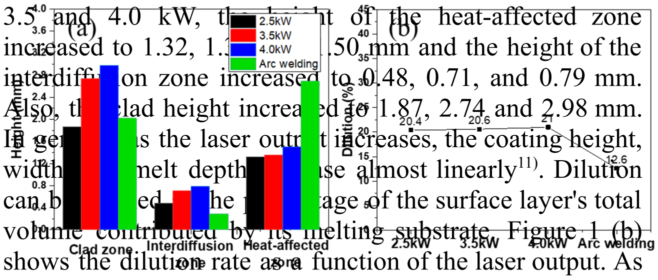

Figure 2. Variations [illegible] micr[illegible] aser output and tempering: mic[illegible] of distance from surface in laser[illegible]

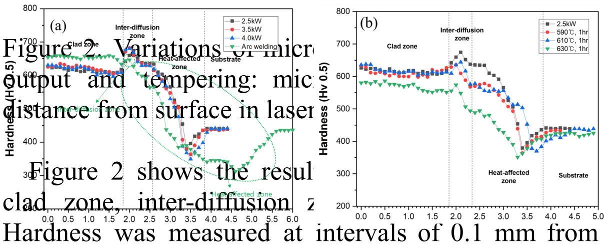

Figure 2 shows the resul[illegible] the clad zone, inter-diffusion z[illegible] one. Hardness was measured at intervals of 0.1 mm from the clad zone to the heat-affected zone. In the case of the inter-diffusion zone and the heat-affected zone, the laser output showed higher hardness values at 2.5kW and 4.0kW compared to 2.5kW. Also, in the case of the interdiffusion zone, the hardness was measured higher than that of other zones. In the clad zone, specimens under heat input conditions of 2.5, 3.5, and 4.0 kW showed little change in hardness along the cross-sectional depth direction and showed similar microhardness values. Figure 2(b) shows the hardness change according to heat treatment under the condition of 2.5kW output. Tempering heat treatment was applied according to the cladding conditions, and the difference in hardness between the clad zone and the base material was compared and analyzed. The hardness of the clad zone decreased under the tempering condition of 630 ℃, and the difference between the hardness of the clad zone and the substrate decreased from 200 Hv to 150 Hv.

Conclusions

In the case of dilution rate, laser power of 2.5kW, 3.5kW, 4kW, and arc welding showed 20.4%, 20.6%, 21%, and 12.6%, respectively. Dilution can be defined as the percentage of the surface layer's total volume contributed by its melting substrate. The dilution rate with the substrate should be minimized as little as possible not to deteriorate the base material's abrasion characteristics.

The hardness distribution of the heat-affected zone of 0 to 1mm in the interdiffusion zone toward the core direction showed a lower value for the specimen with arc welding specimen than that for laser cladding specimens. It could be due to the heat input increasing, the area of the HAZ part increasing, the cooling rate slowing down, and the grain size becoming coarse. The hardness of the clad zone decreased under the tempering condition of 630 ℃, and the difference between the hardness of the clad zone and the substrate decreased from 200 Hv to 150 Hv.

Acknowledgments

This study has been conducted with the support of the Korea Institute of Industrial Technology as "Support program for technological advancement of plastic working & surface treatment in Jeonnam province (KITECH UR-23-0044)".

References

1) Mazumder, J., et al, Closed loop direct metal deposition: art to part, (Optics and lasers in engineering 34.4-6, 2000) pp. 397-414.

2) Kattire, Prakash, et al, Experimental characterization of laser cladding of CPM 9V on H13 tool steel for die repair applications, (Journal of Manufacturing Processes 20, 2015) pp.492-499.

3) Zhang, Zhenlin, et al, Influence of heat treatment on microstructures and mechanical properties of K447A cladding layers obtained by laser solid forming, (Journal of alloys and Compounds 790, 2019) pp. 703-715.

4) Xu, Xiang, et al, Research on microstructures and properties of Inconel 625 coatings obtained by laser cladding with wire, (Journal of alloys and Compounds 715, 2017) pp. 362-373.

5) Kattire, Prakash, et al, Experimental characterization of laser cladding of CPM 9V on H13 tool steel for die repair applications, (Journal of Manufacturing Processes 20, 2015) pp. 492-499.

6) Zhang, Zhenlin, et al, Influence of heat treatment on microstructures and mechanical properties of K447A cladding layers obtained by laser solid forming, (Journal of alloys and Compounds 790, 2019) pp. 703-715.

7) Xu, Xiang, et al, Research on microstructures and properties of Inconel 625 coatings obtained by laser cladding with wire, (Journal of alloys and Compounds 715, 2017) pp. 362-373.

8) Kim, Cheol-Woo, et al, Study on improvement of surface properties of low carbon steel using laser cladding (archives of metallurgy and materials, 2021) pp. 1033-1036.

9) Farahmand, Parisa, and Radovan Kovacevic, Parametric study and multi-criteria optimization in laser cladding by a high power direct diode laser (Lasers in Manufacturing and Materials Processing 1, 2014) pp. 1-20.

10) Kim, Cheol-Woo, et al, Fabrication of Low Carbon Steel Coated with 18% Cr-2.5% Ni-Fe Powder by Laser Cladding and Its Application on Plastic Injection Mold for

Aluminum Diecasting, (Korean Journal of Materials Research 31.11, 2021) pp. 601-607.

11) Telasang, G., et al, Effect of laser parameters on microstructure and hardness of laser clad and tempered AISI H13 tool steel (Surface and Coatings Technology 258, 2014) pp. 1108-1118.

12) Liu, Zhenguang, et al, Corrosion and high-temperature tribological behavior of carbon steel claddings by additive manufacturing technology (Surface and Coatings Technology 384, 2020) pp. 125325.

13] Kim, Cheol-Woo, et al, Fabrication of Low Carbon Steel Coated with 18% Cr-2.5% Ni-Fe Powder by Laser Cladding and Its Application on Plastic Injection Mold for Aluminum Diecasting (Korean Journal of Materials Research 31.11, 2021) pp. 601-607.