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FRICTION AND WEAR BEHAVIOR OF DIRECT METAL DEPOSITION ON SUH3

Poppet valves made from high-frequency heat-treated SUH3 steel have insufficient durability, and scratches appear on the valve face in prolonged use. It is necessary to develop surface treatment technology with excellent durability to prevent the deterioration of engine performance. Therefore, a surface treatment technology with higher abrasion resistance than existing processes was developed by direct metal deposition to the face where the cylinder and valve are closed. In this study, heat pretreatment and deposition tests were performed on three materials to find suitable powders. In the performance evaluation, the hardness, friction coefficient, and wear rate were measured. Direct metal deposition using Inconel 738 and Stellite 6 powders without heat pretreatment were experimentally verified to have excellent durability.

Keywords: Direct metal deposition, Heat pretreatment, Friction test, Wear test, Micro-hardness

1. Introduction

The increasing demand for high-performance and high-durability products has led to the continuous development of long-lasting parts. Among them, there are demands for improved friction and scratch performance of poppet valve seats used for the intake and exhaust of engines.

Direct metal deposition is a technology for spraying powder and surface treatment using a laser, which enables the application of coatings with superior performance because of the small heat input and minimum deformation of base metal. The benefits of direct metal deposition include low powder loss while processing, and reduced dilution and distortion after processing.

Several studies on laser cladding technology, one of the direct metal deposition technologies, have been reported. Studies on valve seat coating using laser cladding began in the late 1980s, when Toyota carried out research on cladding of Cu-Ni alloy onto aluminum cylinders and valve seats [1]. Subsequently, Fiat reported cladding with CrC, Cr and Ni powders onto cast iron [2].

Research on laser cladding using Stellite powder has been actively carried out, and the effects of process conditions such as laser power, laser irradiation time, and feed rate [3]; microstructures and mechanical properties [4] and friction and wear have been studied [5]. Recently, studies have been conducted to confirm the characteristics of high-temperature friction by applying various compositions of Stellite alloy [6-8].

In this study, the effect of powder type used in direct metal deposition was analyzed by friction and wear tests using SUH3 steel, which is used in poppet valves. In addition, the influence direct metal deposition on heat pretreatment is examined, and a method for improving process efficiency is proposed.

2. Experimental

In order to carry out the direct metal deposition, a laser as heat source, a powder feeder, an optical device for irradiating the laser, and an attachment for spraying the powder to the laser spot are necessary. In this study, a diode laser (2 kW, TeraDiode Inc. USA) was chosen because of its high absorption on various materials and benefits to the direct metal deposition process. The laser spot is set as 2 mm and DED system setup shown in Fig. 1. A powder feeder (Metco Sulzer twin 10c, Oerlikon Metco, Switzerland) was used to maintain constant powder supply rate. Table 1 summarizes the processing conditions while Table 2 and 3 list the compositions of powders used in this study. Stellite 6 has excellent hardness and chemical degradation resistance at temperatures up to 500°C. Stellite 21 has excellent durability against heat and mechanical shock. Inconel 738 has excellent creep-rupture strength at high temperatures. The base material is SUH3, which is used in the serial production of valves; the chemical composition of SUH3 is summarized in Table 4.

Seven different types of specimens were prepared and high-frequency heat pretreatment was performed to enhance the surface characteristics; additional coatings were applied to improve the performance in serial production. The cases considered

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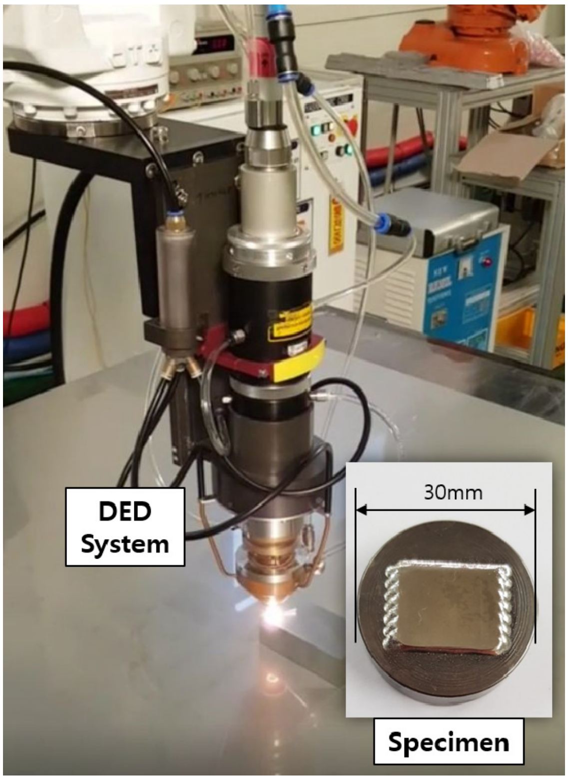

Fig. 1. DED optical system setup and test specimen

TABLE 1

Processing conditions for direct metal deposition

	Laser power (kW)	Laser scanning velocity (mm/s)	Powder feed rate (g/min)
Stellite 6	1.0	6	10
Stellite 21	1.0	6	10
Inconel 738	1.0	5	10

TABLE 2

Co base powder chemical composition (wt.%)

	Co	Cr	W	C	Ni	Mo	Fe	Si	Others	Supplier
Stellite 6	Bal.	28.5	4.6	1.2	<2.0	<1.0	<2.0	<2.0	<1.0	Kennametal
Stellite 21	Bal.	27.5	—	0.25	2.6	5.4	<2.0	<2.0	<1.0	Kennametal

TABLE 3

Ni base powder chemical composition (wt. %)

	Ni	Co	Cr	W	Mo	Al	Ti	Nb	Others	Supplier
Inconel 738	Bal.	8.5	16.0	2.6	1.7	3.5	3.5	<1.0	<2.0	Carpenter

TABLE 4

SUH3 chemical composition (wt. %)

	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Supplier
SUH3	0.4	1.93	0.21	0.29	0.08	0.12	0.27	10.11	0.71	Daido Steel

are the base material and high-frequency heat pretreatment; and the base material and three different powder depositions, with and without high-frequency heat pretreatment.

The average surface roughness of the specimens was controlled by polishing (Ra 0.15-0.2 μm) to reduce the effects of friction and wear behavior. The surface hardness of the specimens was measured using a micro-Vickers hardness tester (MVK E3, Mitutoyo, Japan) for dwell time of 10 s and load of 300 gf.

The friction and wear resistance of the specimens were investigated by a ball-on-disk friction and wear tester (General Tribometer, CSM Instruments, USA) at room temperature and under dry conditions. The counter ball was made out of SAE52100 with diameter of 12.7 mm. Table 5 lists the test conditions.

TABLE 5

Friction and wear test conditions

Normal load	Reciprocating speed	Stroke	Test duration	Temperature
10 N	2.51 Cm/s	4 mm	30 min	Room Temp.

3. Results and discussion

In order to compare the effects of deposition powder and heat pretreatment, seven different types of specimens were compared in terms of hardness, wear rate and friction coefficient. Fig. 2 shows the results for hardness and wear rate. Some variations in hardness for each case were observed. Stellite 6 and Inconel 738 specimens have approximately 5-8% higher hardness than Stellite 21 under heat pretreatment conditions. Each powder coating has excellent durability because Cr and Co present in the internal resin form a carbide by bonding with C. In particular, the increased hardness of Stellite 6 and Inconel 738 was confirmed owing to the additional distribution of tungsten carbide. In the case of Stellite 6 and Inconel 738, the specimen without heat pretreatment had greater hardness than the heat pretreated specimen. However, the case of Stellite 21 is different because P and S were removed by the reaction with Mo during heat pretreatment and direct metal deposition. The highest hardness can be observed for Inconel 738 without heat pretreatment with HRC 48.5, followed by Stellite 6 without heat pretreatment with HRC 47.81.

And Fig. 2 summarizes the wear rate of each specimen. When metal deposition was applied, the wear rate improved compared with the heat-treated raw material. In particular, it was confirmed that the coating effect of Stellite 6 and Inconel 738 powders was beneficial because of the hard carbides. Comparison of heat pretreatment effects showed that direct metal deposition without heat pretreatment resulted in better wear rates than that of heat pretreatment samples. The smallest wear volume loss was observed for Stellite 6 with 24.27×10^{-6} mm^3/Nm, followed by Inconel 738 with 25.06×10^{-6} mm^3/Nm.

Fig. 3 shows the results of the friction coefficient measurement. It was confirmed that applying direct metal deposition after heat pretreatment was worse than the case without heat

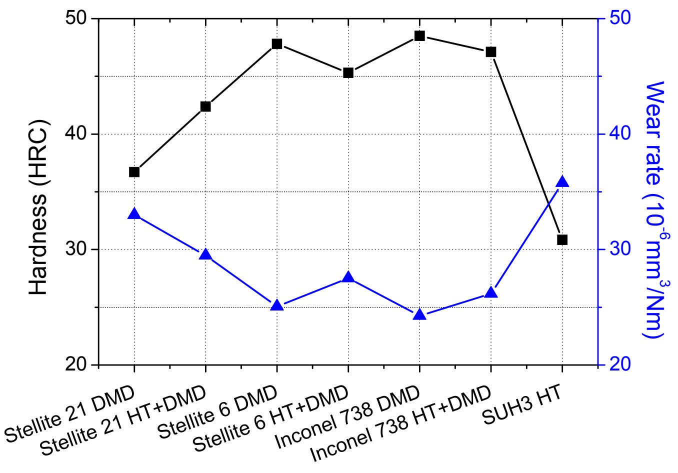

Fig. 2. Microhardness and wear rate

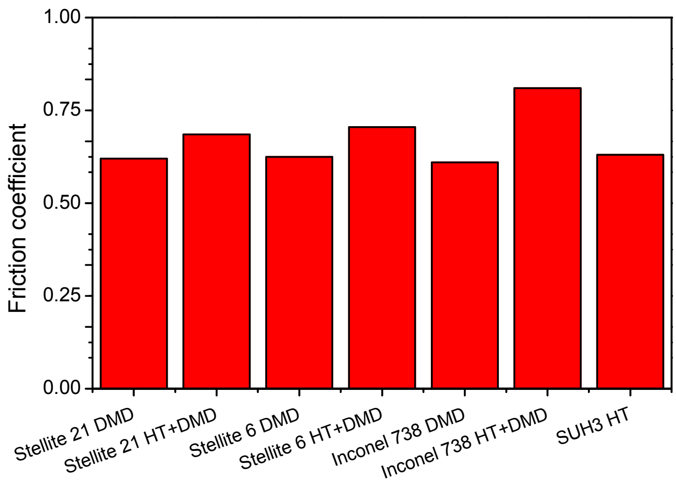

Fig. 3. Friction coefficient results

pretreatment. All direct metal deposition cases with heat pretreatment had approximately 15-20% higher friction coefficient. This is attributed to the effect of oxides generated during the heat pretreatment process [9]; however, the cause will be analyzed through further studies. Direct metal deposition with Inconel 738 and heat pretreatment had the highest friction coefficient because of the high Ni and Ti content.

Fig. 4 shows the wear track for each case. Stellite 21 samples show deeper grooves compared with Stellite 6 samples. And based on the results of low hardness and high wear rate of Stellite 21, delamination appeared to be prominent on the surface. Inconel 738 samples show the adhesion of Ni and Ti [10]. The combination of heat treatment resulted in different surface tracks depending on the powder. The performance of Stellite 21 with relatively low hardness was improved by heat treatment, but the Stellite 6 with high hardness was degraded. The frictional performance of the heat treated Inconel 738 was also degraded in small amounts.

4. Conclusions

In this study, it was found that direct metal deposition affects the hardness, friction coefficient, and wear rate, and that the surface characteristics of SUH3 can be improved. Deposition samples had 20-50% improvement in hardness, similar friction coefficients despite some fluctuations, and 10-25% reduction in wear rate compared with the base material.

However, the effects of heat pretreatment of the substrate were different. For Stellite 21, direct metal deposition with heat pretreatment resulted in higher hardness and excellent wear rate, but the friction coefficient results were worse compared

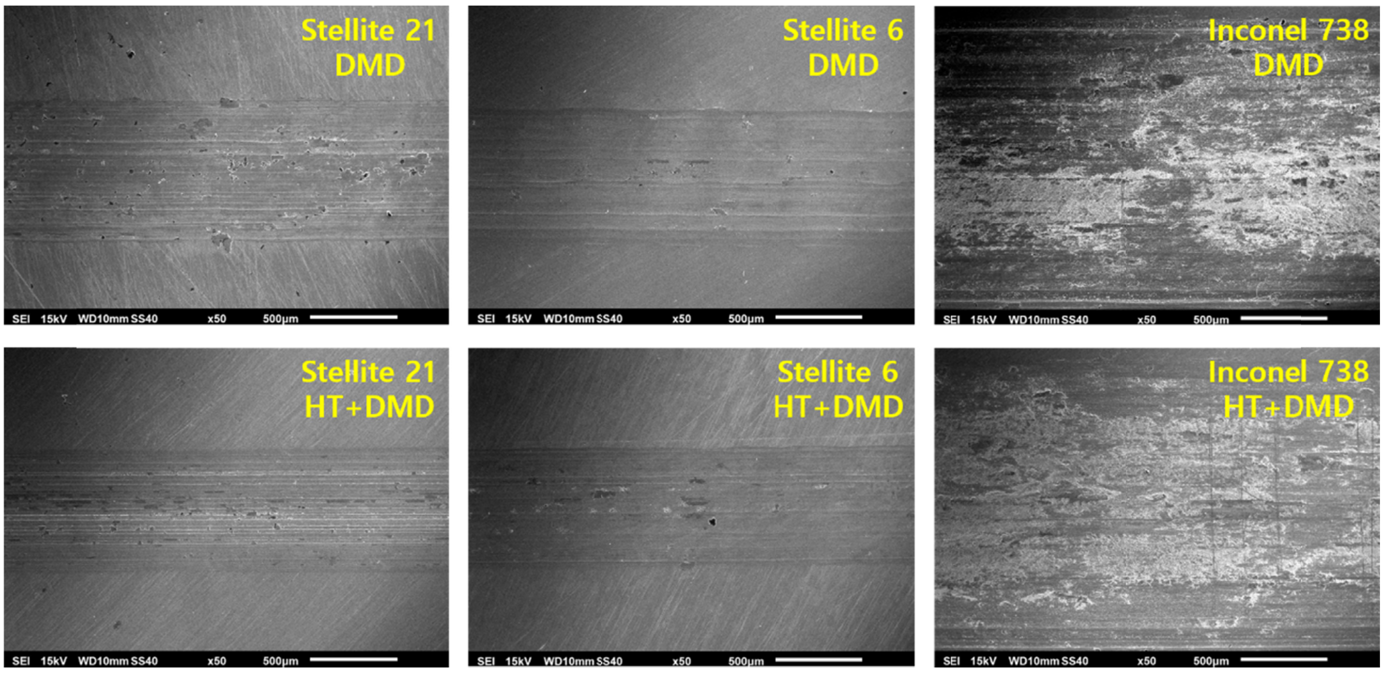

Fig. 4. Wear tracks

with the case without heat pretreatment. Stellite 6 and Inconel 738 had better performance in direct metal deposition without heat pretreatment compared with direct metal deposition with heat pretreatment.

Direct metal deposition using Stellite 6 and Inconel 738 powders without heat pretreatment has been experimentally verified to have excellent durability. In terms of cost efficiency, Inconel 738, which can be purchased at 60% the price of Stellite 6, is more suitable for serial production applications. The results can be used as basic data for durability testing of actual poppet valves. The powder and process conditions for direct metal deposition can also be applied to other parts that use SUH3 steel.

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