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# Surface Modification of Al Sprayed Coatings by Direct Diode Laser Remelting Process<sup>†</sup>

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## Abstract

*Aluminum materials are commonly used for high temperature corrosive applications. In this study, we treated Al coatings by laser irradiation treatment and examined their hardness in comparison with these formed by arc spraying process and wire flame spraying processes. Consequently, the average hardness of a laser irradiated aluminum coating has been found out to be higher than that of a sprayed coating. The wear resistance of aluminum coatings can be improved by laser irradiation. The Vickers hardness of all laser-treated arc sprayed Al coatings increased in comparison with the laser-treated flame sprayed Al coatings.*

**KEY WORDS:** (Direct diode laser), (Arc spraying), (Flame spraying), (Aluminum coating), (Corrosion), (Hardness)

## 1 Introduction

Modern high performance machinery parts, subject to extremes of temperature and mechanical stress, needs surface protection against high temperature corrosive media, mechanical wear and tear. Corrosion, wear and abrasion resistance of the substrate materials are significantly improved by paint coatings. These organic paint coatings, however, do not endure high temperatures and do not adhere well. Thermal spraying technology has been used for the improvement of wear resistance, erosion resistance, heat resistance and corrosion resistance<sup>1-3)</sup>. Wire spraying is predominantly the favored mode of approach, this being normally achieved by the oxy/combustible gas flame method and the electric arc process. The most commonly used materials for wire spray method are zinc and aluminum. The wire-sprayed aluminum coating system is one of the major corrosion prevention methods and control systems in new ship construction and for the maintenance, repair, and overhaul of ships<sup>4)</sup>.

Recent developments and improvements are involving spray materials, spraying devices, quality control and optimization of powders and special post-treatments of the sprayed coatings<sup>5)</sup>. Laser treatment is especially the present subject of research in order to obtain denser coatings with improved adhesion to the substrate. In this study, we treated aluminum coatings by laser irradiation treatment and examined their

hardness in comparison with these formed by arc spraying process and wire flame spraying processes. A common-used potentiostatic anodic polarization test procedure was used to measure the corrosion characteristics of the sprayed coatings.

## 2 Experimental procedures

### 2.1 Thermal spraying method and materials

Aluminum (99.9%, 4.7mm diameter) wires have been provided for wire flame spraying. This thermal spray wire has been sprayed on one side of the substrate surface (SS400, 100mm × 100mm × 3mm) with flame spraying equipment. The arc spray gun is an open arc type using 1.6mm diameter aluminum (99.9%) wire. The following parameters were used for sample preparation: arc current 220A, arc voltage 32V, atomizing air pressure 0.5MPa. The surface of treatment before spraying was carried out under the following conditions; blast powders: 20 mesh aluminum oxide, distance: 15-20 cm, air pressure: 5-6 kgf/cm<sup>2</sup>. The test pieces were then ultrasonically cleaned in acetone and dried. The thermal spraying conditions are shown in **Table 1**. The coating thicknesses were from 100μm to 200μm.

### 2.2 Diode laser irradiation

The irradiation speed was varied between 2mm/sec and 16mm/sec. The beam power was varied between

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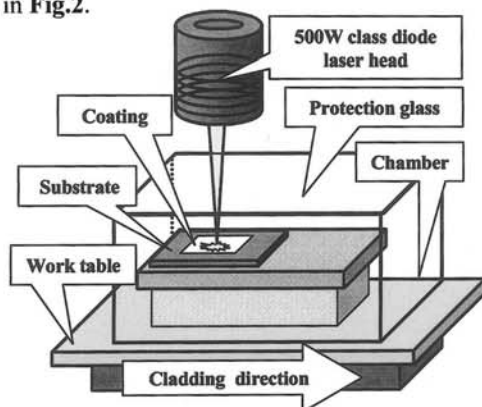
**Table 1** Thermal Spraying conditions

| Flame spraying                         |                             | Electric arc spraying |                             |
|--|-----------------------------|-----------------------|-----------------------------|
| Spray distance                         | 200mm                       | Spray distance        | 200mm                       |
| Air pressure                           | 0.5MPa                      | Voltage (DC)          | 32V                         |
| O <sub>2</sub> pressure                | 0.35MPa                     | Current               | 220A                        |
| C <sub>2</sub> H <sub>2</sub> pressure | 0.11MPa                     | Atomized air pressure | 0.5MPa                      |
| Objective thickness                    | 100 $\mu$ m,<br>200 $\mu$ m | Objective thickness   | 100 $\mu$ m,<br>200 $\mu$ m |

100W and 200W. **Figure 1** shows a schematic drawing of the experimental apparatus. The specimen was irradiated at an irradiation angle of 90 degrees. The focal length was 43.5mm from the laser head. The spot size at the focal point was 230 $\mu$ m x 1820 $\mu$ m. The structure of the coating was examined by X-ray diffraction (XRD) analysis. The microstructure of the cold sprayed coating was examined by scanning electron microscope (SEM) and electron probe micro-analyzer (EPMA). The mechanical properties of the coatings were evaluated by standard microhardness testing.

## 2.3 Anodic polarization corrosion tester

The anodic polarization testing system used is shown in **Fig.2**.

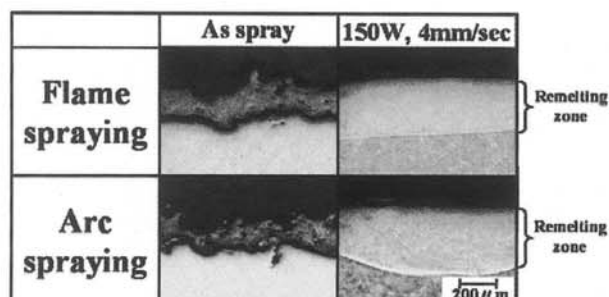


**Fig.1** Schematic experimental apparatus for laser treatment

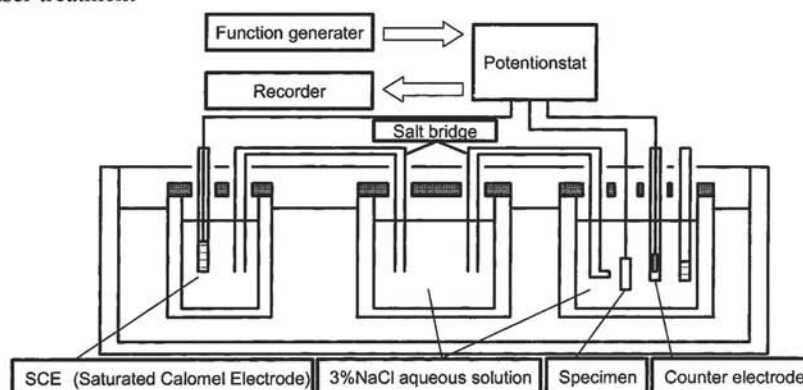
This is a normal potentiostatic polarization corrosion tester, which is driven by a Hokuto Denko, HA303 power source. A saturated calomel electrode is inserted in KCl solution and connected galvanically to the reaction cell by a self-made salt-bridge of agar embedded in KCl solution. A platinum wire used as the counter electrode is immersed in the reaction cell containing 500 ml corrosion media of 3.0 wt% NaCl aqueous solution. The specimens are held by a specially designed sample holder and immersed in the testing media for 10 min to stabilize their galvanic contact with the solution, then the sample potential is set to -1.5 V and swept to +1.5V at a rate of 100mv/s. All the tests are carried out at room temperature.

## 3 Results and discussion

**Figure 3** shows the micrograph of the cross section of sprayed aluminum coatings with and without laser treatment. The laminated constructions were recognized in the cross section of the untreated sprayed Al coating. From the photos of the cross section of laser-treated Al coatings, the remelting zone is visually recognized. In samples treated at low power and at high scanning speeds, no change in microstructure compared to the as-sprayed coating was discernible at low magnifications.



**Fig.3** Cross section of laser-treated Al sprayed coating



**Fig.2** Experimental Set-up for Polarization measurement

Figure 4 shows the remelting depths of laser-treated Al coatings with several laser powers at scanning speed of 4mm/sec. Under the power of 100W, there was no melting. The experimental results show that the remelting zone of laser-treated Al coating increases linearly with laser power. The remelting zone of laser-treated arc sprayed Al coating becomes larger than that of flame sprayed Al coating. On the other hand, the remelting zone of laser-treated arc sprayed Al coating decreases linearly with increasing laser scanning speed. Figure 5 shows the remelting zone of laser-treated Al coatings at several scanning speed with laser powers of 150W and 175W. The EPMA images of arc sprayed Al coatings treated at a laser power of 150W, and scanning speed 8mm/sec is shown in Fig.6. The coatings obtained using laser remelting are dense and free of cracks and pores. The diffusion zone can be seen in laser treated Al coating structures. Hardness test results of the laser-treated coatings are shown in Fig.7. Laser treated Al coating have high Vickers hardness values, especially on the inside of coatings. It is recognized that the Vickers hardness of all laser-treated arc sprayed Al coatings increase compared with the laser-treated flame sprayed Al coatings. The average Vickers hardness of laser-treated arc sprayed Al coatings was HV 623.

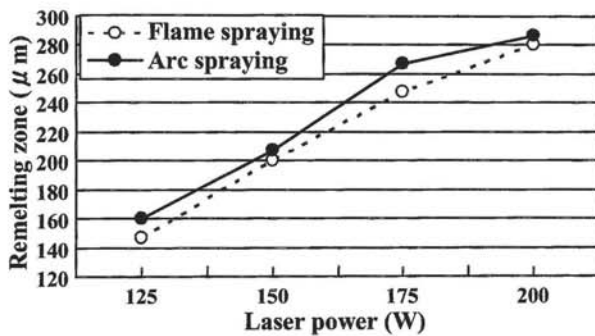


Fig.4 Effect of laser power on remelting zone of Al sprayed coatings. (4mm/sec)

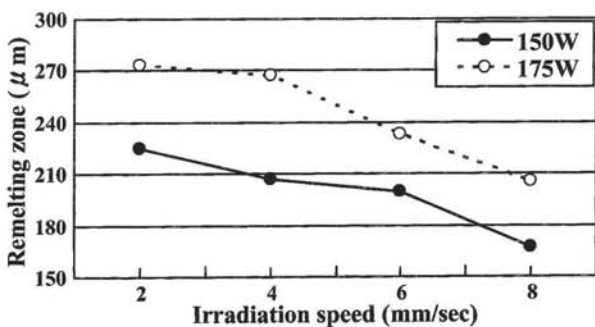


Fig.5 Effect of irradiation speed on remelting zone Al sprayed coatings. (Arc spray)

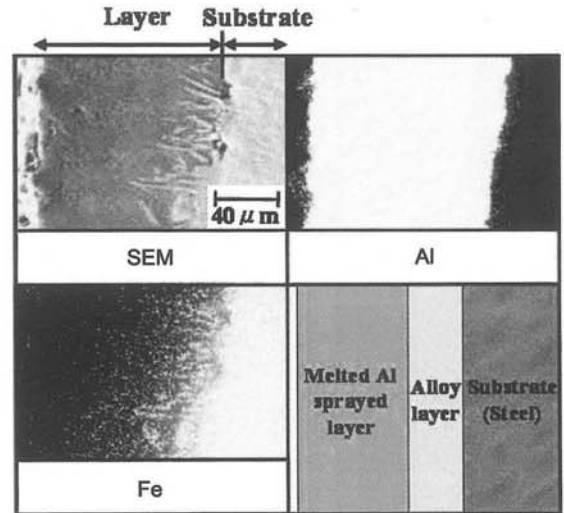


Fig.6 EPMA analysis of laser-treated Al spraying. (Arc spraying, 150W, 8mm/sec)

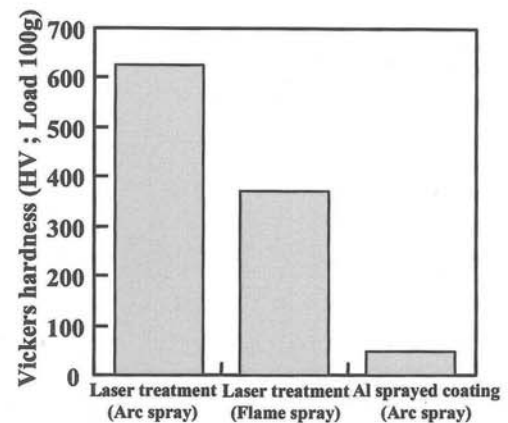


Fig.7 Vickers hardness of Al sprayed coatings

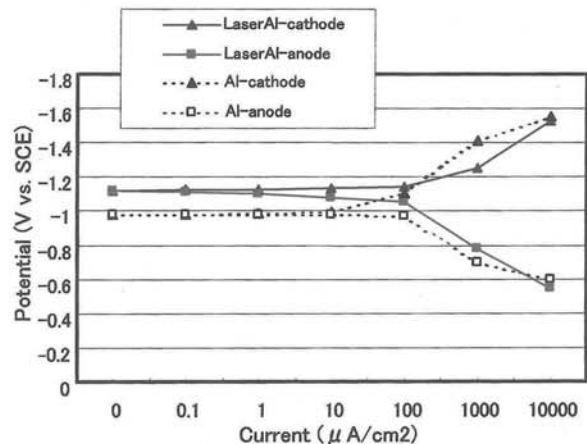


Fig.8 Polarisation curves of Al coatings

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The polarization behavior of arc sprayed Al coatings and laser-treated arc sprayed Al coatings are shown in **Fig. 8**. The thickness of the coating averaged 200  $\mu\text{m}$ . All the curves are obtained from the first polarization test cycle. It is observed that corrosion potential increases from -1140mV for arc sprayed coatings and to -982mV for the laser-treated Al coatings. The more positive potentials indicate that chemistry results in more noble overlays. They both show similar corrosion polarization curves when evaluated in NaCl aqueous solution. At the same voltage of anode polarization curve the current density of arc sprayed coatings is higher, which means that the laser-treated Al coatings are nobler and more corrosion resistant.

### 4. Conclusions

Laser beam properties of direct diode laser and its effect on surface modification of sprayed aluminum coatings were investigated. From the results the following were found:

- (1) The remelting depth of sprayed aluminum coatings was increased with increasing power of direct diode laser.
- (2) The average Vickers hardness of laser-treated arc sprayed Al coatings was HV 623, which is much higher than that of flame sprayed coatings.
- (3) The laser-treated arc sprayed Al coating results in a better corrosion resistance than that of arc sprayed aluminum coating.

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