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Laser Surface Modification of Stainless Steel
— Alloying with Molybdenum —

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Abstract

Fundamental characteristics of laser surface alloying was investigated. Surface alloying carried out on SUS304 stainless steel using molydbenum powder as the alloying element, the effect of different laser irradiation conditions were studied. The structure, hardness, and chemical components of laser alloyed layer were analyzed, and the characteristics of the laser alloyed layer in terms of wear resistance and corrosion resistance were investigated.

KEY WORDS : (High Power CO_2 Laser) (Laser Surface Alloying) (Molybdenum) (SUS304 Stainless Steel) (Wear Test) (Corrosion Test) (Pitting Potential)

1. Introduction

The technology for using a laser beam to improve the mechanical, metallurgical, or chemical properties of a limited region on the surface of material has become the focus of much attention. A form of low-strain heat treatment, this technique allows the selection of the specific laser energy concentration desired from a broad range of possibilities, thereby enabling local and selective surface modification. And, through the process of rapid heating and rapid cooling, it also makes possible the creation of new characteristics unobtainable with any process close to a normal heat balance process. Various methods of using a laser beam to form a treated layer on the surface of a base material so as to improve resistance to were, corrosion, or heat, or to enhance electrical characteristics, thereby increasing the value and the quality of the product, are now being tested [1-3]. Also, from the standpoint of work execution, because the intensity and the size of the laser beam can be regulated, on-line processing that offers precise control of the thickness and the width of the part to be surface modified is possible.

SUS304 stainless steel ("SUS304"), the primary focus of this study, is a material with superior corrosion resistance; but because a hardened layer cannot be formed on its bare surface by heat treatment alone, it is often unsuitable for use in places where it would be subject to harsh environmental condition or where wear resistance is required. However, if its surface is modified by applying molybdenum and melting the surface with a laser beam to form an alloyed layer, SUS304's resistance to both wear and corrosion can be greatly improved[4].

In this study, surface alloying was carried out on SUS304 using molybdenum powder as the alloying element, and the effect of different laser irradiation conditions were studied. The structure, hardness, and chemical components of laser alloyed layer were analyzed, and the characteristics of the laser alloyed layer in terms of wear resistance and corrosion resistance were studied.

2. Test Samples and Testing Methods

As the substrate, commercially available SUS304 stainless steel with the chemical composition shown in **Table 1** was used; as the alloying element, commercially available molybdenum powder (99 %, 325 mesh or smaller) was used. Pretreatment consisted of the molybdenum powder being applied to a thickness of 100 - 200 μm, after mixing with ethyl alcohol. Then, the surface was irradiated with a laser beam in order to melt it for alloying.

In our test study, a 15 kW CO_2 laser employing the Arata laser focusing system was used. The spot diameter

Table 1 Chemical composition of materials used (wt%)

	C	Si	Mn	P	S	Ni	Cr	Mo	Cu
SUS304	0.05	0.61	0.97	0.022	0.008	8.6	18.0	0.16	0.31
SUS316	0.04	0.58	1.29	0.023	0.003	10.5	16.8	2.10	0.08

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obtained by the F10 focusing system was about 0.8 mm.

When the laser output was 2 kW, the energy density (mean power density) was about 4.0 x 10^5 W / cm^2. As the laser irradiation conditions for testing, the laser output (W_b) 2-4 kW, the travel speed (ν_b in the Y direction) was 20-60 cm per minute, and the sample was 15-20 mm from the focusing position (a_b value: 1.047 and 1.063). Argon was used as the shielding gas. The laser beam was irradiated while being shifted 2.5-3 mm in the X-axis direction (bead overlap width: about 2 mm); in this way, a laser alloyed layer was formed. **Figure 1** is a schematic diagram showing how laser surface alloying was carried out.

The macrostructure and the microstructure of the laser alloying layer thus obtained were observed and the micro vickers hardness was measured (load: 200 gf) as the hardness test.

Ogoshi's universal wear test was utilized to study the wear resistance of the laser alloyed layer. As the test conditions, the final load was fixed at 2.1 kgf and the sliding distance at 200 m, and the sliding speed was varied in the range of 0.301 to 4.36 m per second. The test was conducted by the dry method.

To analyze the corrosion resistance of the laser alloyed layer, the pitting potential for producing anodic polarization in a 3.5 % NaCl neutral solution was measured-the JIS corrosion test.

In order to further analyze the characteristics of the laser alloyed layer and make a comparative study, we used as samples bulk SUS304 and SUS316 (refer to Table 1) and samples of SUS304 alloyed with three different amounts of alloying element so that the final molybdenum content in the substrate would be 3 wt%, 5 wt%, and 10 wt%, prepared using a high frequency melting furnace.

The characteristics (hardness, wear resistance, and corrosion resistance) of each sample were then studied. The molybdenum was melted evenly in all the alloy samples. The results of analysis of the samples' principal chemical components are shown in **Table 2.** Before carrying out characteristics testing, all the samples underwent solution heat treatment (water quenching after being maintained at 1,050 C for ten minutes).

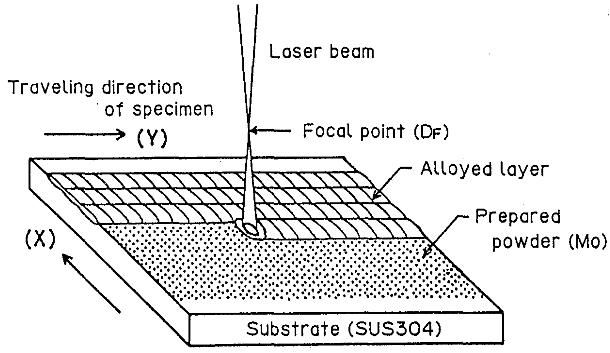

Fig. 1 Schematic diagram of laser surface alloying

Table 2 Chemical composition of samples tested (wt%)

Sample	Element content (wt%)			
	Mo	Ni	Cr	C
10%Mo+SUS304	10.5	7.46	16.0	0.07
5%Mo+SUS304	5.34	7.82	17.2	0.03
3%Mo+SUS304	2.75	8.28	17.4	0.11
SUS316	2.10	10.5	16.8	0.04
SUS304	0.16	8.6	18.0	0.05

3. Results and Discussion

The laser alloyed layer was formed as a plane by using a high power laser to repeatedly irradiate the substrate so that the overlapping width of the alloyed beads was about 2 mm. **Figure 2** (a) shows the bead appearance and a cross section of the alloyed layer. The laser alloyed layer presented a smooth surface free of defects (no cracks or no holes). Figure 2(b) is an enlargement of the cross section of the alloyed layer; the depth of the alloyed layer was 500 to 600 μm. Testing was conducted under the following laser beam irradiation conditions: laser power was 2-4 kW, travel speed was 20 - 60 cm per minute, and sample position was 15-20 mm from the focusing position (a_b value: 1.047 and 1.063). The alloyed layer obtained under these laser irradiation conditions was analyzed using EDX microanalyser. The molybdenum content was 1.0-10.5 wt%.

Figure 3 shows the laser alloyed layer obtained with a laser power of 2 kW and travel speed of 30 cm per minute; molybdenum content was 10.5 wt% and it was relatively evenly distributed in the layer.

3.1 Micro vickers hardness

The hardness distribution from the surface of the laser alloyed layer to the base metal indicated that the hardness of the alloyed layer was higher than that of the base material. **Figure 4** shows the relation between mean hardness distribution and molybdenum content in the alloyed layer; where molybdenum content is 2.5 wt% or more, hardness rises sharply. The relation between hardness and molybdenum content in the samples prepared in the high frequency melting furnace was about the same as that in the laser alloyed samples: hardness increased as molybdenum content increased.

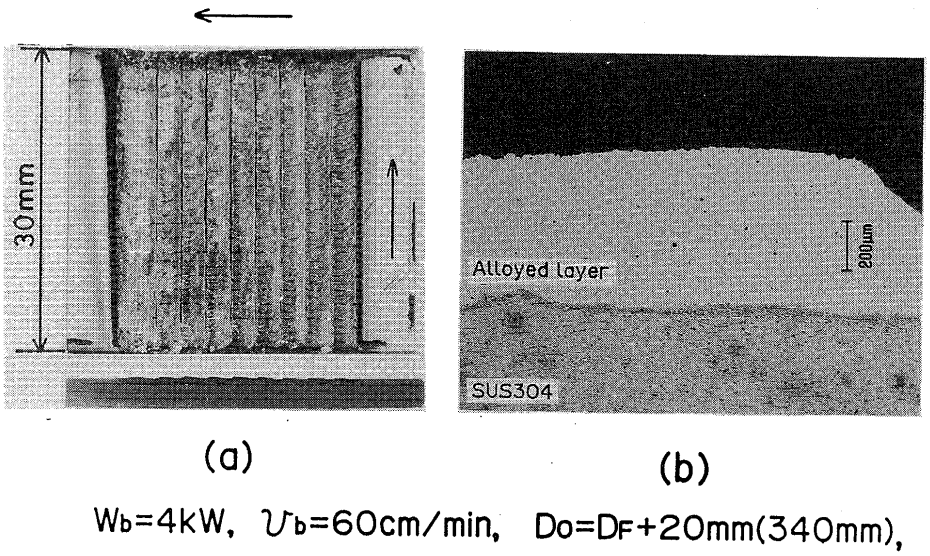

Fig. 2 Bead appearance and cross section of alloyed surface of SUS304
(a) Bead appearance and cross section, macrophotograph
(b) Cross section, microphotograph

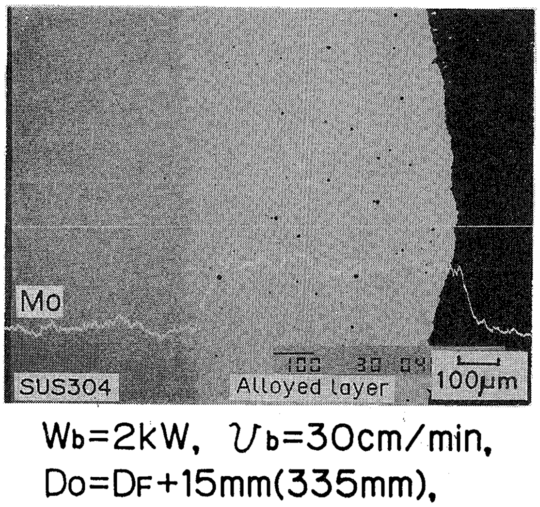

Fig. 3 SEM microphotograph and EDX line analysis for Mo of alloyed surface

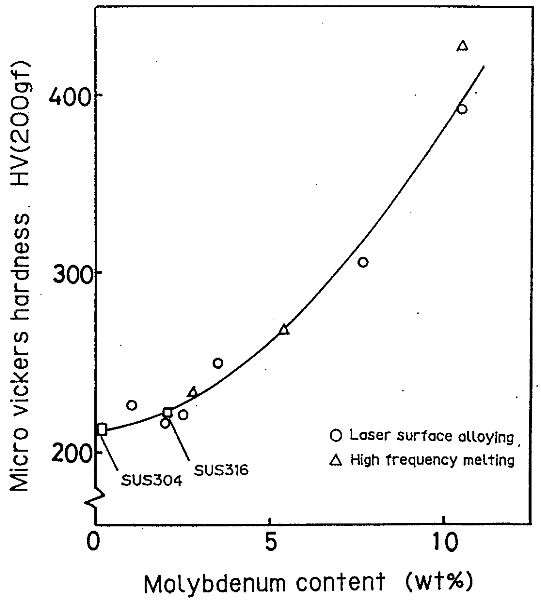

Fig. 4 Relation between molybdenum content and hardness

3.2 Wear Test

Ogoshi's universal wear test was conducted to evaluate the wear resistance of the laser alloyed layer. Initially, changes in specific wear in relation to wear speed were studied using SUS304, SUS316, and samples prepared in the high frequency melting furnace; the specific wear loss showed a more or less maximum value at a wear speed of 2.86 m per second; the difference in specific wear loss tended to increase depending on molybdenum content.

Figure 5 shows wear loss of the laser alloyed layer in relation to molybdenum content at a wear speed of 2.86 m per second. Wear loss decreases as molybdenum content increases. This is believed to be attributable to the increase in hardness caused by the increase of molybdenum content. The wear loss of SUS304 and SUS316 and the samples prepared in the high frequency melting furnace followed about the same tendency as that of the laser alloyed layer sample concerning molybdenum content: wear loss decreased as molybdenum content increased.

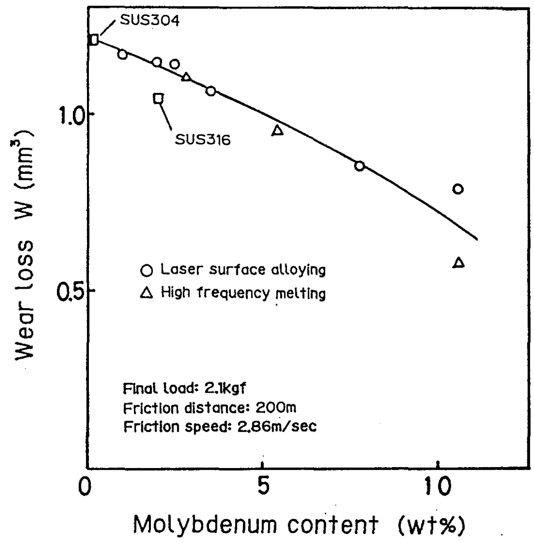

Fig. 5 Relation between molybdenum content and wear loss

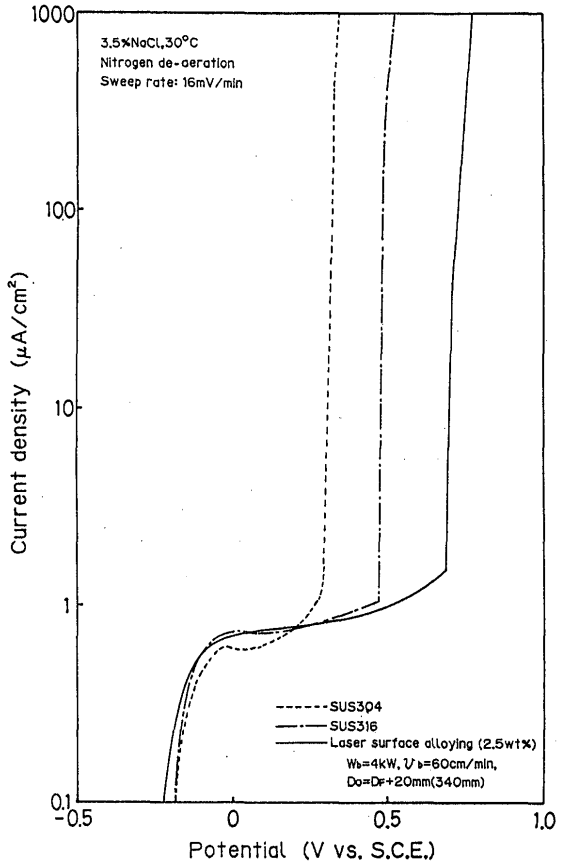

Fig. 6 Anodic polarization curves in de-aerated 3.5 % NaCl

3.3 Corrosion Test

A corrosion test was carried out to evaluate the corrosion resistance of the laser alloyed layer. **Figure 6** shows an example of the anodic polarization curve obtained by measurement of the pitting potential. Comparing the potential where the current density shows a sudden rise (pitting potential), that of the laser alloyed layer sample shifts to the higher potential side compared with SUS304 and SUS316, indicating that its pitting potential is far superior.

Figure 7 shows the relation between molybdenum content and pitting potential, measured at two different potential levels (Ve'_{10} and Ve'_{100}) when the current density was 10 $\mu A / cm^2$ and 100 $\mu A / cm^2$, respectively. It can be seen by the figure that as molybdenum content rises, pitting potential rises sharply. Pitting potential when the molybdenum content obtained by laser surface alloying was 2.5 wt% was 600-650 mV.

The laser beam irradiation conditions at this time were: a laser power of 4 kW and a travel speed of 60 cm per minute. The pitting potential of SUS304 which contained almost no molybdenum was about 300 mV and that of SUS316 which contained molybdenum at 2.1 wt% was about 500 mV.

As for the relation between corrosion potential and molybdenum content, that of the samples prepared in the high frequency melting furance was about the same as that of the laser alloyed layer samples: pitting potential increased as molybdenum content increased, up to a molybdenum content of about 3 wt%.

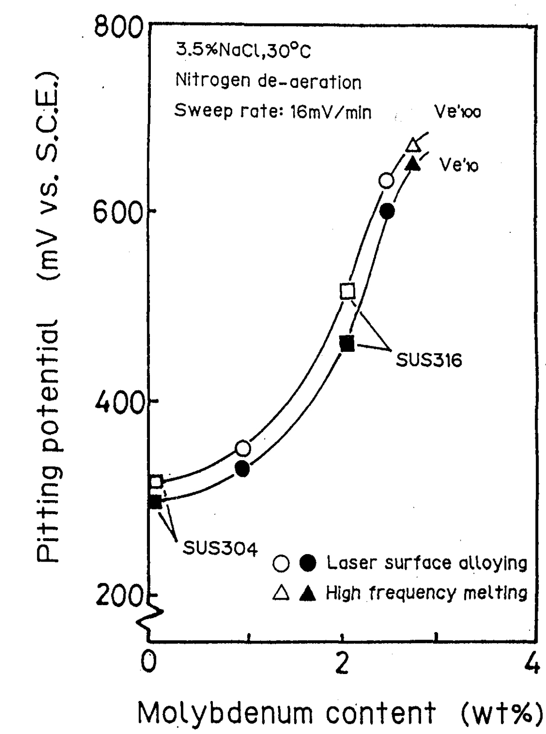

Fig. 7 Relation between molybdenum content and pitting potential in 3.5 % NaCl

4. Conclusion

Surface alloying was carried out using a CO_2 gas laser in order to study the effects of laser irradiation conditions, and to measure the wear resistance and the corrosion resistance of the alloyed layer obtained.

Our finding are as follows.

1) A stable and even molybdenum alloyed layer (depth: 500-600 μm) was obtained by applying molybdenum powder to SUS304 stainless steel and then irradiating the surface with a laser beam.

2) By varying the laser beam irradiation conditions, alloyed layer, with molybdenum content of up to nearly 10 wt% were obtained.

3) As molybdenum content increased on the laser alloyed layer, hardness (micro vickers hardness) increased and wear loss decreased; improvement of wear resistance can be expected.

4) On the laser alloyed layer, the pitting potential rose sharply as molybdenum content increased; at the laser beam irradiation conditions of a laser power of 4 kW and a travel speed of 60 cm per minute, an alloyed layer with a molybdenum content of 2.5 wt% and pitting potential of 600 - 650 mV was obtained. This suggests the possibility of greatly improved corrosion resistance.

Acknowledgments

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