LASER CLAD SOLID LUBRICANT LAYERS FORMED ON DIFFERENT METAL SUBSTRATES

T. KATOH
Akashi National College of Technology, 679-3, Nishioka, Uozumi-cho, Akashi-shi, Hyogo 674-0084, JAPAN;
e-mail: katoh@akashi.ac.jp

T. SAKAMOTO, S. KAKUNAI, M. ABO
Himeji Institute of Technology, 2167, Shosha, Himeji-shi, Hyogo 671-2201, JAPAN;
e-mail: sakamoto@mech.eng.himeji-tech.ac.jp

SUMMARY
Some solid lubricant powders were coated on metal substrates in a CO2 laser cladding process. Molybdenum disulfide (MoS2) and a mixture of graphite and hexagonal boron nitride (C/BN) were tried to coat on aluminium, copper and stainless steel substrates. Coating of the lubricants on aluminium was difficult. Some MoS2 layer was formed on copper. Formation of C/BN composite layers was possible on copper and stainless steel. The best C/BN layer with long life was formed on stainless steel.

Keywords: Solid lubricant, coating, laser, cladding, friction

1 INTRODUCTION
Laser cladding technique can be applied to form solid lubricant coating. Molian and Hualun [1] formed an excellent clad layer of hexagonal boron nitride on a titanium alloy. This layer provided a substantial increase in wear resistance and a lower friction.

The authors have tried to form composite clad layers of graphite (C) and boron nitride (BN) powders on a stainless steel substrate. Under optimum cladding conditions, good layers with low friction and high wear resistance could be obtained [2-4].

In the present study, the clad layers with molybdenum disulfide (MoS2) and a mixture of graphite and boron nitride (C/BN) were tried to form on some metal substrates using a CO2 gas laser. Difference in layer formation with substrate materials was examined and also friction and wear behaviour on the layers formed was compared each other.

2 EXPERIMENTAL
2.1 Specimen
The specimen for laser cladding treatment was prepared by spreading lubricant powder on metal substrates. Three metals with different thermal properties shown in Table 1 were used as the substrates: aluminium (JIS A1050, >99.5% Al), copper (JIS C1020, >99.96 %Cu) and austenitic stainless steel (JIS SUS316). It is noted that thermal conductivity of SUS is extremely low. The size of the substrates is 4 mm x 40 mm and 9 mm height.

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal conductivity W/(m·K)</th>
<th>Fusion point K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium (Al)</td>
<td>237</td>
<td>934</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>398</td>
<td>1358</td>
</tr>
<tr>
<td>Stainless steel (SUS)</td>
<td>16</td>
<td>1656</td>
</tr>
</tbody>
</table>

Table 1: Substrates

Mean particle size of the lubricant powders used is listed in Table 2. Graphite (C) and hexagonal boron nitride (BN) were used as a mixture with a ratio of 7:1 in vol.%. The formulated powder was mixed with a commercial brazing flux, placed on the substrate and dried in air at least for 24 hours before laser processing. The thickness of the powder layer after drying was about 0.1 mm with an area of 4 x 30 mm².

<table>
<thead>
<tr>
<th>Lubricant</th>
<th>Particle size, µm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molybdenum disulfide (MoS2)</td>
<td>10</td>
</tr>
<tr>
<td>Graphite (C)</td>
<td>3.3</td>
</tr>
<tr>
<td>Hexagonal boron nitride (BN)</td>
<td>5.73</td>
</tr>
</tbody>
</table>

Table 2: Particle size of lubricant powders

2.2 Laser cladding process
A 1.6 kW continuous-wave CO2 laser was used for cladding process. A scanned laser beam was applied to the powder layer placed on the substrate as shown in Figure 1 under the condition in Table 3.
A laser beam with 4.8 mm in diameter at the specimen surface was oscillated by the width of 10 mm at a constant frequency of 100 Hz, this corresponding to mean scan rate of 2 m/s. During laser treatment, the substrate was traversed perpendicular to the direction of laser beam scan, using a numerically controlled work table at a constant speed of 40 mm/min. Laser treatment was also conducted in an argon atmosphere to minimise oxidation of the specimen surfaces at high temperature induced by laser irradiation.

<table>
<thead>
<tr>
<th>Beam mode</th>
<th>TEM\textsubscript{00}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser power</td>
<td>50…850W</td>
</tr>
<tr>
<td>Beam diameter</td>
<td>4.8mm</td>
</tr>
<tr>
<td>Scanning frequency</td>
<td>100Hz</td>
</tr>
<tr>
<td>Scanning width</td>
<td>10mm</td>
</tr>
<tr>
<td>Specimen feed rate</td>
<td>40mm/min</td>
</tr>
<tr>
<td>Specimen feed length</td>
<td>20mm</td>
</tr>
<tr>
<td>Shield gas</td>
<td>Argon</td>
</tr>
</tbody>
</table>

Table 3: Laser cladding conditions

2.3 Friction test
For each laser treated specimen, the loose powder particles which could not tightly bond to the substrate were removed entirely with the wet absorbent cotton. The clad layers thus prepared were subjected to a reciprocated sliding test against a bearing steel ball (JIS SUJ2), 6 mm in diameter, to evaluate their friction and wear characteristics. The ball was slid on the centre part of the clad layer in the longitudinal direction. Stroke of the sliding pass was 5 mm and the sliding velocity was 0.59 mm/s. Contact load was set constant at 8.8 N. Tests were conducted under unlubricated condition with relative humidity of 60 % at room temperature.

2.4 Surface examination
Energy dispersive X-ray spectroscopy (EDS) and X-ray diffraction analysis (XRD) were used to evaluate the clad layers and the worn surfaces.

3 RESULTS AND DISCUSSION
After laser treatment, specimen surfaces were observed with the naked eye and/or rubbed lightly with fingers. Some informative results on the clad layer formation could be given from this procedure, as shown in Figure 2. Aluminium (Al) is not fit for the substrate material, because no layer formation is found in Figure 2. On the other hand, some layers can be formed on the copper (Cu) and stainless steel (SUS) substrates with suitable laser powers. No layers are formed at low laser energy, but under high laser power the substrate surface may fuse easily.

In the present experiments, good lubricant layers with low friction and long life have not always been obtained. Some typical results on friction and wear behaviour of the laser treated specimen surfaces will be shown below.

3.1 MoS\textsubscript{2} on Cu
Figure 3 shows friction variation with sliding of MoS\textsubscript{2} layers formed on Cu substrates under different laser powers. Friction of Cu itself is also plotted. The best lubricant layer in this case is formed at a laser power of 150 W. With this layer, the friction coefficient of 0.15 is kept up to about 300 times repeated sliding. After that, a gradual friction increase due to wear of MoS\textsubscript{2} layer is recognised. Wear life of this clad layer can be defined as about 300 times. The wear life of the layer formed at a low laser power of 50 W is 100 times in Figure 3, however, no appreciable layer formation was found from the observation with the naked eye. The layer seemed to be extremely thin and discontinuous. At the higher laser powers beyond 250 W, some layer was formed, but the layers have less durability than the Cu substrate itself as seen in Figure 3.

Figure 3: Friction variation of MoS\textsubscript{2} layers on Cu
An EDS compositional analysis for the clad layers was made to evaluate their friction and wear behaviour. Figure 4 shows the element content detected from each layer of Figure 3, where the sum of Mo+S, Fe and O is
100 wt.%. Mo and S could not be well divided and then are shown as Mo+S, because they have almost identical characteristic X-ray energy.

![Figure 4: EDS result of MoS2 layers on Cu](image)

In Figure 4, only the layer formed with 150 W exhibits somewhat higher Mo+S content, corresponding to the longest wear life seen in Figure 3. In the layers at higher laser energy, the increase in oxygen content can be recognized. It is also found from an X-ray diffraction result shown in Figure 5 that the layers at 150 W and 50 W contain Mo and S as MoS2. From the layers produced with 250W – 450W, MoS2 is not detected but some molybdenum and copper oxides are clearly found. The results suggest that MoS2 is decomposed by high laser energy and the layers formed cannot act as the effective lubricant. The layers at 250 W and 350 W may have some amorphous nature, since the X-ray intensities are very low in Figure 5.

![Figure 5: XRD result of MoS2 layers on Cu](image)

### 3.2 C/BN on SUS

Figure 6 shows friction changes with sliding of C/BN layers formed on SUS substrates. Friction of the substrate without coating is also plotted. The best lubricant layer with a life of beyond 10000 times is formed at 450W. A friction coefficient of 0.1 obtained from this layer is much better than that of MoS2 layers shown in Figure 3. A more lower friction coefficient is given from the layer at 350W, although its wear life of 5000 times is a half of the layer at 450W.

![Figure 6: Friction variation of C/BN layers on SUS](image)

Figures 7 and 8 are EDS and XRD results for the layers shown in Figure 6, respectively. The layers formed at 450 W and 350 W contain higher amount of graphite, resulting in low friction and long wear life. A low laser energy of 250 W is insufficient to bond strongly the lubricant powder to the substrate. With excessive energy like 550 W, the substrate surface melts easily, and no effective lubricant layer is formed.

![Figure 6: BDS result of C/BN layers on SUS](image)

![Figure 8: XRD result of C/BN layers on SUS](image)

### 3.3 Layer formation on three substrates

Friction and wear life of the layers formed on Al, Cu and SUS substrates and substrates themselves are
summarised in Figures 9, 10 and 11, respectively. In these figures, the coefficients of friction plotted are the measured values at each 10th sliding and the wear life means the total numbers of sliding until friction coefficient exceeds 0.2.

As seen in Figure 2, no desirable layers are formed on Al and then long life is not obtained in Figure 9. On Cu and SUS, some good clad layers can be formed under optimum laser powers as shown in Figures 2, 10 and 11. However, in Figure 11, genuine MoS2 layer was not formed on SUS, because of its partial oxidation to MoO2 at very high temperature due to low thermal conductivity of SUS. The best layer is formed with C/BN on SUS as seen in Figure 11.

4 CONCLUSIONS

Laser clad lubricant layer formation depends on the kinds of solid lubricants, substrate materials and their surface properties and laser energy. Several findings obtained from the present study are as follows:

1. Coating of the lubricants on aluminium is difficult.
2. Coating of the lubricants on copper and stainless steel is possible.
3. Molybdenum disulfide should be coated at lower temperature without oxidation.
4. Graphite/Boron nitride composite provides a good lubricant layer with low friction and long life.

5 REFERENCES