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Laser clad lubricant layer with graphite/BN

T. Sakamoto, M. Hasegawa, S. Kakunai, M. Abo
Department of Mechanical Engineering, Faculty of Engineering, Himeji Institute of Technology, Himeji, Hyogo 671-22, Japan

ABSTRACT

A composite thin clad layer containing graphite and hexagonal boron nitride powders was tried to form on stainless steel using a continuous-wave CO_2 gas laser. The layer formed only with boron nitride has no appreciable effect on friction reduction. Increase in graphite content in the coatings led to lower friction. A good lubricant layer with the lowest friction and the longest life was obtained from the powder mixture with higher graphite content about 90 vol.%.

1. INTRODUCTION

Laser beam melts a very thin surface layer of the substrate. The molten top layer mixes with the molten cladding materials or permeates into the cladding powder with high melting point, and subsequently freezes. This process can form a good bonding between the cladding material and the substrate. In the practical usage of the laser cladding technique, a major purpose is production of hard facing, for example, to form wear resistant coatings[1]. Attempts to clad lubricant layers by laser beam are still few. A clad layer of hexagonal boron nitride on a titanium alloy was formed by Molian and Hualun[2]. This layer exhibited a substantial decrease in wear resistance and a lower friction.

The authors tried to produce a clad layer of boron nitride on a stainless steel, but no good coatings to reduce friction was obtained. Then graphite powder was chosen as an additional cladding

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material. The mixture of graphite and boron nitride powders provided a good lubricant layer. Friction tests showed that graphite is better than boron nitride for reducing friction. In the present study, the effect of graphite content in the powder mixture on friction characteristics of the clad layer was investigated.

2. EXPERIMENTAL PROCEDURE

Laser cladding was performed by preplacing the coating on an austenitic stainless steel(SUS316) substate. Graphite(C) and/or hexagonal boron nitride (BN) powders were used to form the solid lubricant layer. Both powders were mixed together in various proportions in a commercial brazing flux(Nicrobraz). The powder mixture was placed on the substrate as shown in Fig.1 and then dried in air at least for 24 h before laser processing. The thickness of the mixture after drying was 0.1 mm.

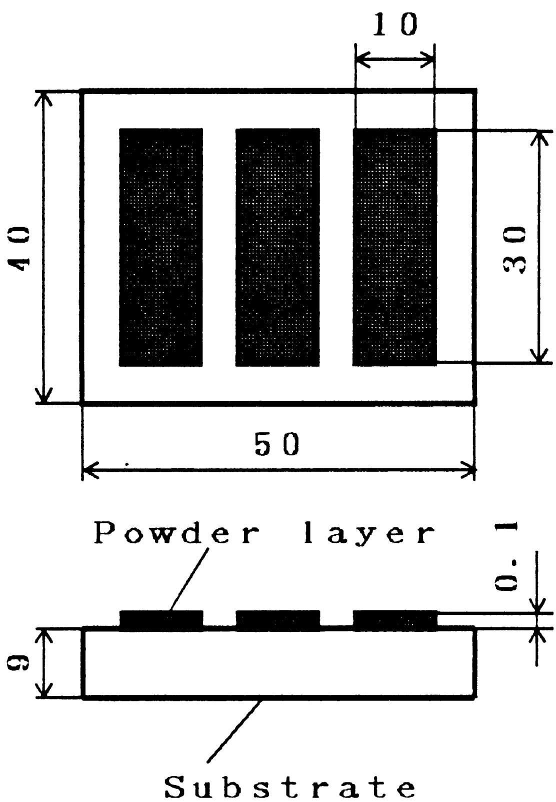

Fig.1 Specimen

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A 1.6 kW continuous-wave CO_2 laser(Mitsubishi Electric, ML806T-3016S) was used at 550 W power for the experiments. Scanned laser beam was applied to the powder layer preplaced on the substrate as shown in Fig.2. The beam diameter at the surface was 4.8 mm. The beam spot was scanned at the surface with 10 mm in scanning width at a scan rate of 2 m/s. Specimen feed rate was 40 and 60 mm/min. At the initiation of cladding process, temperature of the substrate surface was set constant at 200°C. During cladding, argon gas was introduced around the specimen to prevent heavy oxidation of the surface under high temperature induced by laser irradiation.

After laser cladding, the clad layers formed were subjected to a reciprocating friction tests. The middle area of each clad layer was rubbed, in the longitudinal direction of a layer, with a bearing steel ball, 6 mm in diameter, under a load of 8.82 N. One pass of reciprocating sliding was 10 mm and the sliding speed was 0.59 mm/s. Tests were conducted

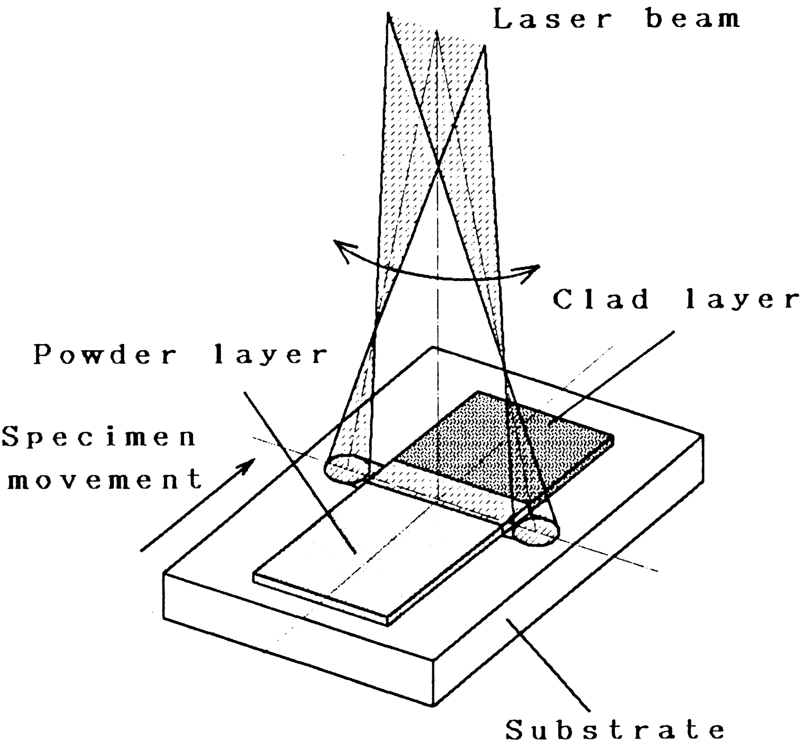

Fig.2 Laser cladding process

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under unlubricated condition with relative humidity of 60% at room temperature. X-ray diffraction and Auger electron spectroscopy(AES) were used for surface examination of the specimens.

3. RESULTS AND DISCUSSION

3.1 Friction Characteristics

Friction test result on the clad layers formed under 550 W power at feed speeds of 40 and 60 mm/min is shown in Fig.3, where average coefficient of friction at the sliding distance of 0.5 m is plotted against graphite content in the powder mixture. Friction coefficient of the SUS316 substrate is also shown with a horizontal line in Fig.3. At graphite content higher than 50 vol.%, low friction can be obtained. However, at lower content of graphite, no improvement of friction property is observed, where the friction coefficient is rather higher than that of the substrate itself.

The clad layer persisting low friction for long sliding distance can be defined as a good lubricant coating. To evaluate wear life of the clad layers, friction variation of some typical layers in Fig.3 is shown as a function of sliding distance in Fig.4. It is found from this result that the clad layers formed only with boron nitride(0%C) and with the mixture having low graphite content(12.5%C) are not wear resistant and have no desirable effect on friction reduction. The layer formed with 100% graphite(0%BN)

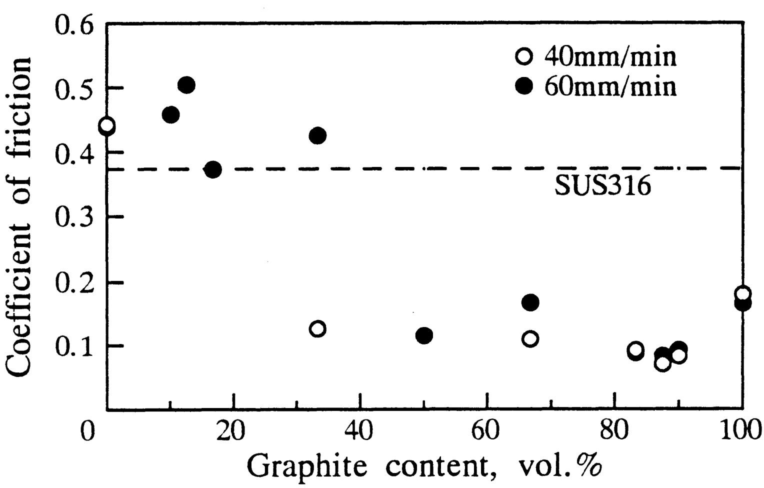

Fig.3 Friction change with graphite content

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and the equal percent mixture(50%C) give fairly low friction, but exhibit low wear resistance. In Fig.4, the best graphite content for reducing friction is found to be 87.5 vol.%, and the best coating is obtained at the feed rate of 40 mm/min. The layer formed at 60 mm/min is less resistant to wear.

For intermediate graphite content, for example 33%C, friction coefficient depends on thermal energy applied to the powder layer. The thermal energy given to the surface is higher for lower feed rate of the specimen, if laser power is kept constant. In Fig.3, low friction is obtained at the feed rate of 40 mm/min, that is, at higher energy input, whereas no friction decrease is observed at 60 mm/min. This result suggests that, at 40 mm/min, a good bonding between the clad layer and the substrate was established.

It is evident, from the friction test results of Figs.3 and 4, that the better lubricant layer can be obtained from a cladding condition with suitable laser energy and adequate graphite content of the powder mixture. Boron nitride is also thought to play an important role to form an excellent layer.

3.2 X-ray Diffraction

The friction characteristics of each clad layer given

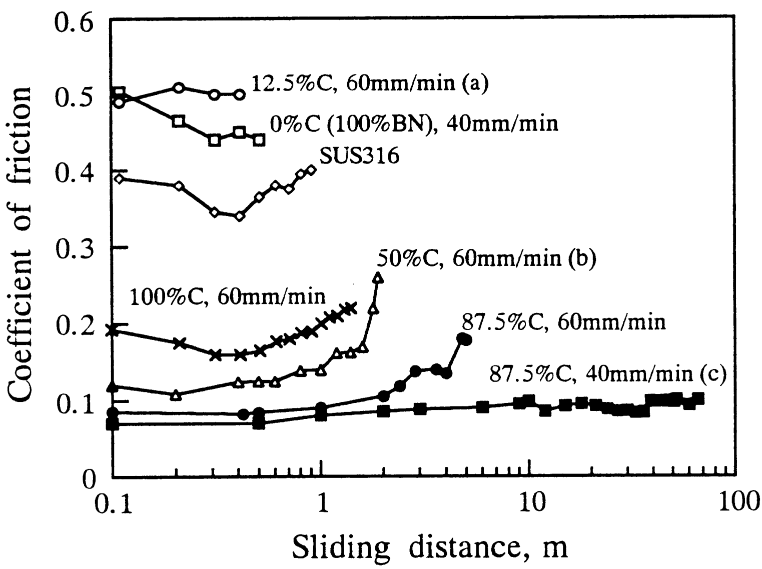

Fig.4 Friction variation with sliding

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in Figs.3 and 4 may be due to difference in material composition of the layers, then X-ray diffraction analysis was firstly employed for surface evaluation. Figure 5 shows X-ray diffraction peaks obtained from three clad layers with different graphite content:(a)12.5%, (b)50% and (c)87.5%. Each specimen is indicated with (a), (b) or (c) in Fig.4. Friction

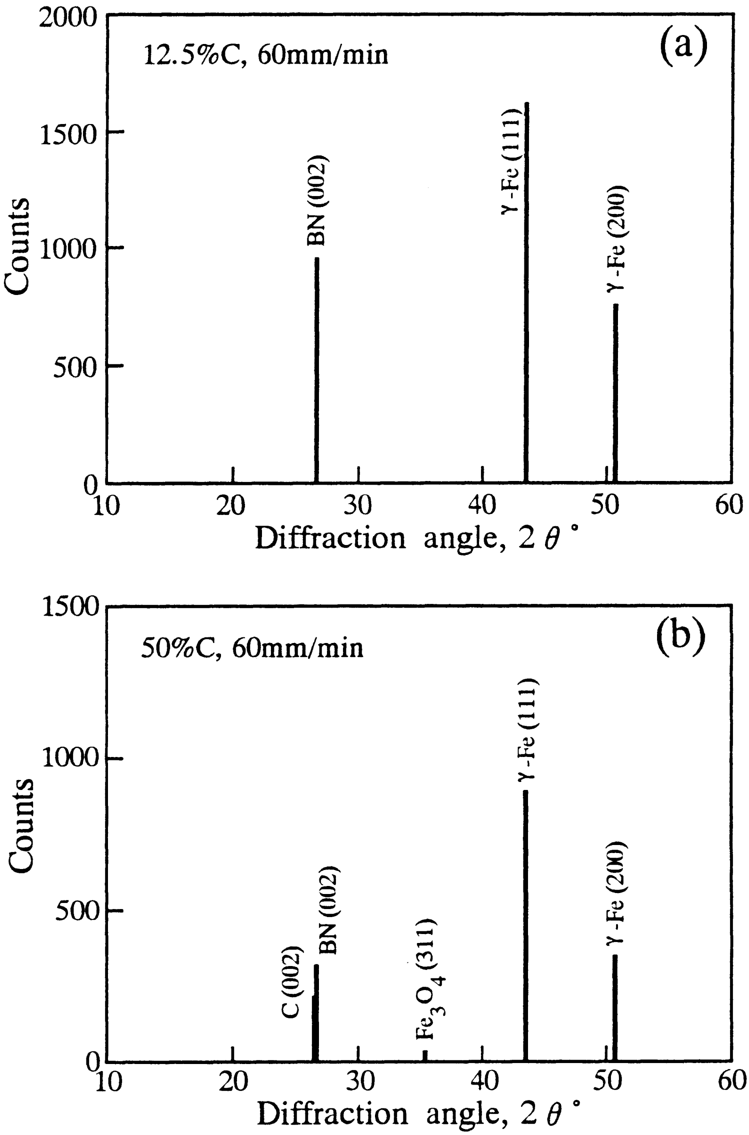

Fig.5 X-ray diffraction peaks

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coefficient decreased and wear life increased in the order of (a), (b) and (c) as mentioned previously.

In Fig.5, γ-Fe peaks are detected from SUS316 substrate. For the clad layer(a) formed by the powder mixture with lower graphite content of 12.5%, Fig.5(a), C(002) peak showing existence of graphite is not found. In this case, friction was very high, although boron nitride peak BN(002) was clearly seen. From the layer(b) formed by the mixture of the equal concentration of graphite and boron nitride, the peaks showing existence of both materials are detected as seen in Fig.5(b). In Fig.5(c), a marked C(002) peak is measured from the clad layer(c) of 87.5% that has the lowest friction and the longest life. Boron nitride still exists in this layer. The X-ray diffraction patterns in Fig.5, together with the friction characteristics in Figs.3 and 4, show that graphite is necessary to keep low friction.

3.3 AES Analysis

It was impossible, using X-ray diffraction technique, to examine the surface of small wear tracks formed on the clad layers, then Auger electron spectroscopic analysis(AES) was made for three samples which are the same as those analyzed by X-ray diffraction. Figure 6 shows AES spectra measured from the clad layers before and after slidings of each specimen

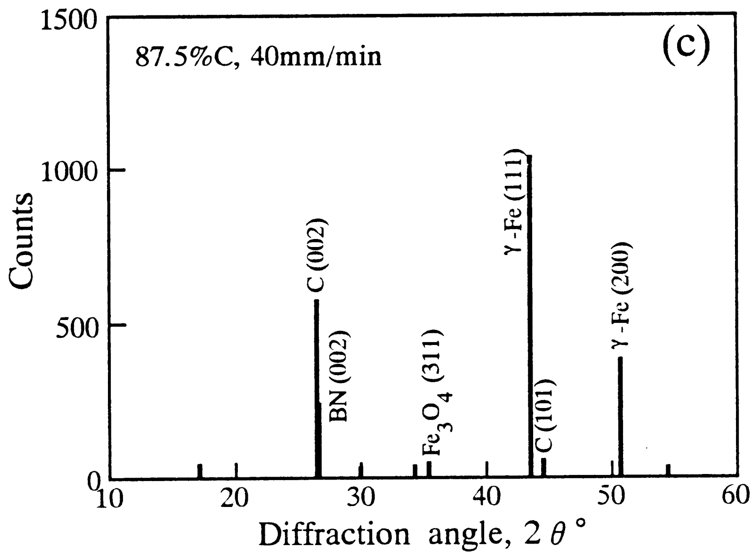

Fig.5 X-ray diffraction peaks

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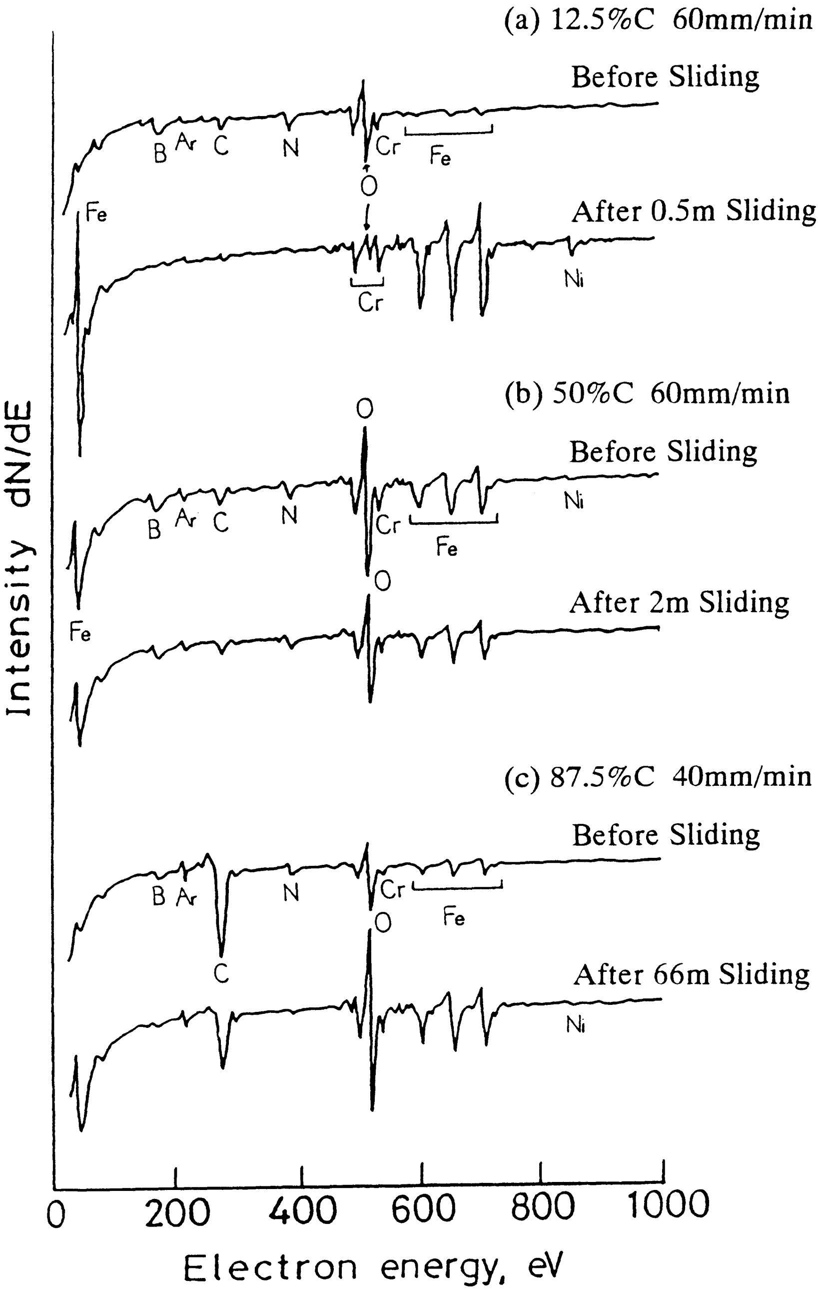

Fig.6 AES spectra

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whose surface contamination was almost removed by argon ion etching for 5-8 min. The relative peak heights of boron(B), nitrogen(N), carbon(C) and oxygen(O) to maximum iron(Fe) peak height are illustrated in Fig.7. The histograms, B/Fe, N/Fe, C/Fe and O/Fe, are derived from the spectra of Fig.6.

On the spectrum of the layer(a) before sliding, B, N, C and O are found and Fe peaks are negligibly small, suggesting the formation of some clad layer. After sliding of only 0.5 m, the former four elements disappear and Fe, chromium(Cr) and nickel(Ni) are evolved markedly. This change in the spectra reveals a rapid wearing-off of the clad layer and subsequent exposure of the SUS316 substrate, leading to high friction coefficient about 0.5 seen in Figs.3 and 4. Actually, on the spectrum(a) after sliding in Fig.6, there is almost no trace of B, N and C indicating the existence of the clad layer. Very low or no relative peak intensity of the wear track A(12.5%C) in Fig.7 introduces the same observation.

The AES spectra of 50%C clad layer(b) are quite similar before and after slidings of 2 m. Relative peak intensity of each element is also invariable in Fig.7. The layer is still present after sliding, but, in Fig.4, a rapid increase in friction coefficient is

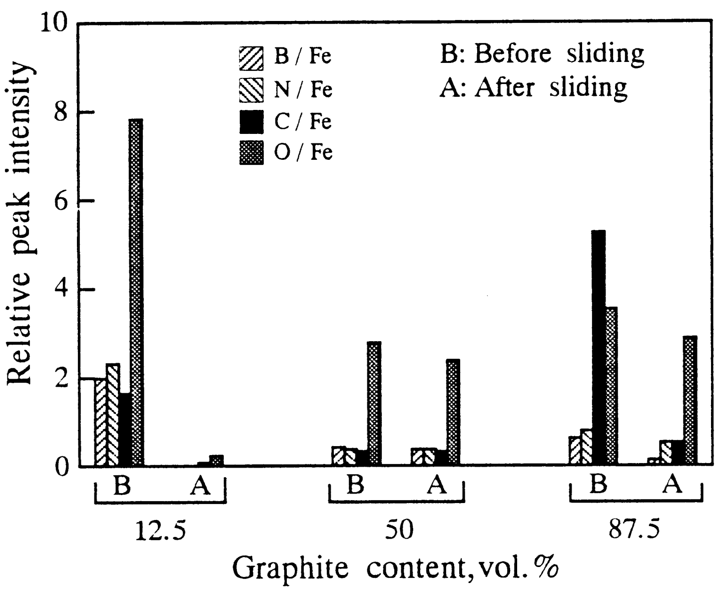

Fig.7 Relative AES peak intensity before and after sliding

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observed for sliding distance greater than 1 m. This frictional behaviour is thought to be due to an increase in real contact between the substrate and the counter steel ball, resulted from successive removal of very thin clad layer that had still a sufficient thickness for AES analysis. However, the layer(b) was supposed to be fully removed soon for further sliding contact. On the spectra of the best lubricant layer(c) of 87.5% graphite, carbon content is very high even after long frictional sliding of 66 m, indicating the formation of a thick clad layer.

Although argon gas was tried to fill around the specimen, the clad layers(b) and (c) contain oxygen as seen in Figs.6 and 7. X-ray diffraction analysis of Figs.5(b) and (c) indicates that this oxygen was mainly detected from an iron oxide Fe_3O_4. Oxide formation means that the bonding between the powder mixture and the substrate was well established as a result of melting of the substrate surface due to penetration of laser energy. Formation of the good bonding is said to be one of required conditions to produce wear resistant lubricant layer.

4. CONCLUSIONS

To produce a solid lubricant layer, laser cladding of graphite and hexagonal boron nitride on SUS316 stainless steel was performed. The friction tests and some surface analyses for the clad layers provide some results as follows:

It was possible, using laser cladding technique, to form a good solid lubricant layer from the powder mixture of graphite and boron nitride without any decomposition of both materials. The best mixing ratio of graphite to boron nitride may be 7-8. The clad layer obtained only graphite powder was less effective to reduce friction. With the coating formed by boron nitride only, no friction reduction was expected. The clad layers by the preplacement method were very thin. In order to form thick coating effective to practical use, another cladding methods, such as powder injection process, are recommended.

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