

## Effect of h-BN content on the sintering of SS316L/h-BN Composites

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**Abstract.** In this work, the three compositions of hexagonal boron nitride (10, 15 and 20 vol. %)-embedded 316L stainless steel (SS316L/h-BN) composites were prepared by a conventional powder metallurgy technique and then sintered at varying temperatures of 1100 to 1250°C for 60 min in H<sub>2</sub> atmosphere. The h-BN content and sintering temperature were found to affect the microstructure and hardness of the composites. The hardness decreased with increasing h-BN content and was improved by increasing the sintering temperature. Microstructure results revealed that the boride phase was formed at the grain boundary at the sintering temperature higher than 1150°C and the boride phase formation was observed to transform the h-BN in the composites.

### Introduction

Powder metallurgy is a convenient method to produce stainless steel composite materials with particulate fillers [1]. Solid lubricants filling in composite materials have extensively used due to their good tribological properties [2,3]. Solid lubricants, e.g. MoS<sub>2</sub>, graphite, and PTFE, are commonly used in many industrial applications, however, they are decomposed at high sintering temperature [4]. Therefore, hexagonal boron nitride (h-BN) powder which has excellent lubricating properties similar to graphite, good thermal and chemical properties has been replaced those solid lubricants [5, 6]. However, h-BN powders filling in stainless steel composite materials have not yet been fully reported [7]. The aim of this study is to investigate the effect of h-BN content and sintering temperature on the mechanical properties, microstructure and tribological properties of sintered AISI 316L stainless steel/hexagonal boron nitride composites.

### Experimental procedure

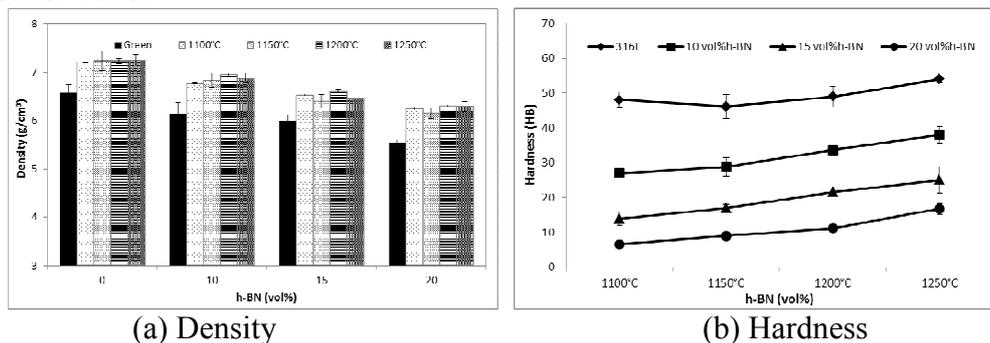
The 316L stainless steel (45-150 μm) and hexagonal boron nitride (7-11 μm) powders were used. The 316L stainless steel with additions of 10, 15, and 20 vol.% h-BN were mixed thoroughly by tumbling mixer. The mixed compositions were compacted to disc sample with 30 mm diameter. The green density of the compacts was about 80% theoretical densities. The green specimens were delubricated at the temperature of 600°C under the argon atmosphere and sintered at temperature from 1100 to 1250°C under hydrogen atmosphere for 60 min. The green and sintered densities were determined according to MPIF 42 standard. The microstructure of specimens was investigated by optical microscope (OM). The macrohardness of sintered specimen were measured by Brinell hardness tester with the spherical indenter of 5-mm diameter and a 306 N load.

Dry sliding wear test was carried out using pin-on-disc tribometer. The high chromium steel balls with 7 mm in diameter were used as the pin specimen. Wear tests were performed under a load of 5 N with a sliding speed of 0.1 m/s and sliding distance of 100 m at room temperature. The friction coefficient was continuously recorded during the test. The average of the four measurements wear track was used to calculate the wear volume loss and specific wear, respectively. After wear testing, both worn surface and balls were examined through OM and scanning electron microscope (SEM). The wear debris from each tests were investigated under SEM.

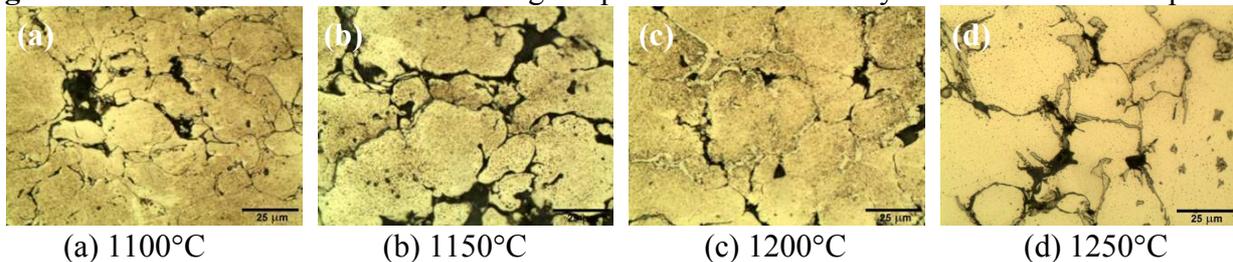
## Results and Discussion

### Density, microstructure and hardness

Green and sintered density results indicated that increasing the h-BN concentration the green and sintered densities of the composites gradually decreased as shown in Fig. 1(a). This was due to the increasing of low density h-BN content. Fig. 1(b) indicates the hardness of SS316L and SS316L/h-BN sintered materials. It can be seen that all h-BN/SS316L sintered materials exhibited significantly lower hardness than the SS316L sintered materials. In addition, the hardness slightly increased by increasing the sintering temperature. This was due to a boride phase formation at the grain boundary at high sintering temperature of 1200 and 1250 °C, as can be seen in Fig 2. The boride phase originated from a reaction between h-BN and matrix produced the liquid phase during the sintering [8] due to that the small addition of B into the Ni-Cr alloy system depressed the melting temperature to below 1100°C [9]. The increase of h-BN contents also generated more boride phase formation.



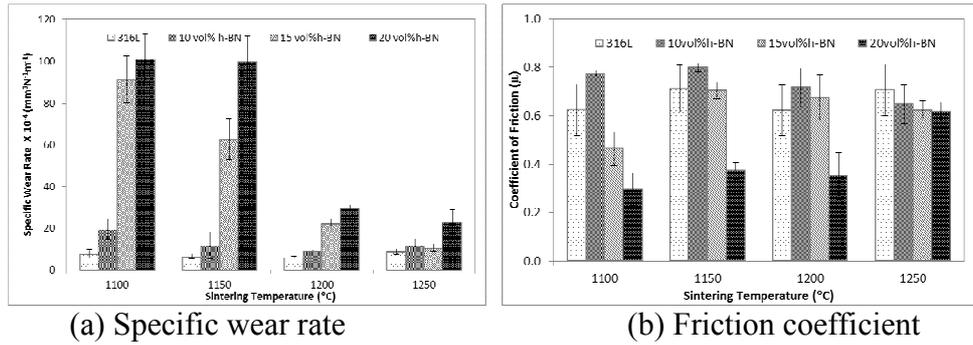
**Fig. 1** Effects of h-BN content and sintering temperature on the density and hardness of composites.



**Fig. 2** Microstructure of SS316L/15vol% h-BN sintered materials.

### Friction and Wear Behavior

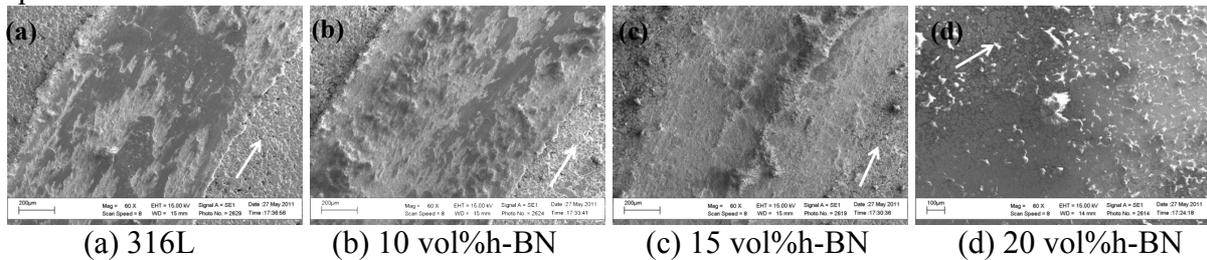
The effects of h-BN content and sintering temperature on the specific wear rate of composites are shown in Fig. 3(a). The addition of h-BN increased the specific wear rates of the composite materials. However, the specific wear rates appeared to decrease when the sintering temperature was increased. Fig. 3(b) shows the effects of h-BN content and sintering temperature on the friction coefficient of composites. It was found that the friction coefficient for 20 vol.% h-BN composite sintered at the temperature between 1100 to 1200°C was in the range of 0.3-0.4 whereas that at the sintered temperature of 1250°C was about 0.6. The increase of the sintering temperature also changed the microstructure and generated some transformation of h-BN in the composite materials.



**Fig. 3** Effects of h-BN content and sintering temperature on the specific wear rate and friction coefficient of composites at a sliding speed of 0.1 m/s and under a normal load of 5 N.

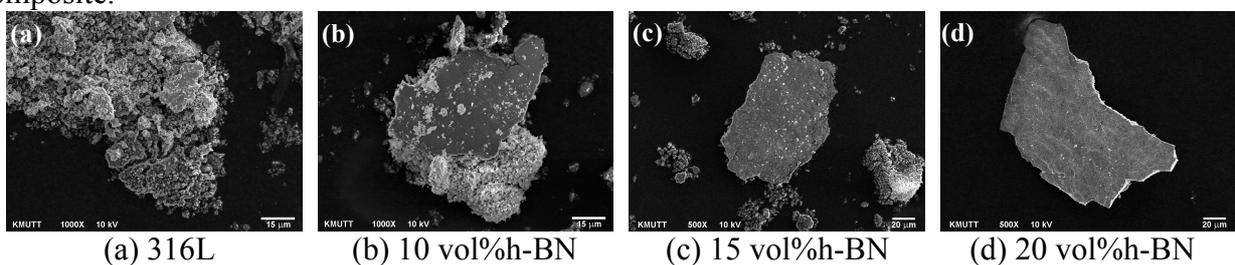
*Worn Surface and Wear Debris*

SEM images of the worn surfaces are given in Fig. 4. It was observed that the worn surfaces of base matrix was covered by smooth-dark layer which was spread along the sliding direction (see Fig. 4(a)). The deformed layer and shear lips demonstrated adhesion and delamination mechanisms, respectively. The worn surfaces for 10 vol.% h-BN composite was covered by smooth-dark film and compacted particles region (see Fig. 4(b)). The wear debris was trapped on the worn surfaces and compacted during sliding against the steel ball. However, the compacted layer was generated on loose particle covering surface then the layer could detach from the worn surfaces easily. The loose wear debris was covered on worn surfaces for 15 vol.% h-BN composite (see Fig. 4(c)). The formation of the loose particle was thought to accelerate the wear and increase the friction coefficient. Hexagonal boron nitride in the composite was partially transformed during sintering process. This was because the h-BN could react with the stainless matrix composition and formed the boride phase at the grain boundary. Therefore, the existing h-BN in the composite was insufficient to lubricate further. The addition of 20 vol% h-BN indicated a decrease in friction coefficient, this corresponding to Fig. 3 (b). One explanation was due to the remained h-BN generated sufficient lubricating film. Fig. 4(d) shows the smooth worn surfaces of 20 vol% h-BN composite.



**Fig. 4** SEM images of the worn surfaces of composites sintered at 1200°C

SEM images of wear debris are shown in Fig. 5. Three different wear particle morphology; fine particle, plate-like and severe sliding wear particle, was observed, as shown in Fig. 5(a). The severe sliding wear particle showed the high plastic deformation and rough surface due to the adhesive wear mechanism. In contrast, the surface of the plate-like wear particle from delamination mechanism was smooth. Fig. 5(b) - 5(d) shows the plate-like wear debris of h-BN addition composite.



**Fig. 5** SEM images of the wear debris of composites sintered at 1200°C

## Conclusions

The SS316L samples with the addition of h-BN at 10, 15 and 20 vol% were sintered at temperatures in a range between 1100 and 1250°C. These sintered composite materials were mechanically and tribologically tested and the results could be concluded as follows:

1. The addition of h-BN decreased the hardness, whereas the hardness was improved by increasing the sintering temperature.
2. The sintering temperature significantly influenced on the formation of boride phase at the grain boundary of SS316L/h-BN composites. The boride phase increased with increasing sintering temperature.
3. The formation of boride phase was found to transform the h-BN in the composites which then led to the increasing trend of the coefficient of friction for the composites.
4. Hexagonal boron nitride contents played an important role in modification of the tribological system responses. In particular, about 20 vol% h-BN added to the specimen, the friction coefficient of the composites was reduced.

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