

Comparative Studies on Wear Behaviour of Sintered 316L Stainless Steels Loaded with h-BN and MoS₂

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Abstract. Mechanical properties and wear behavior of stainless steel embedded with different solid lubricants were investigated. Hexagonal boron nitride (h-BN) and molybdenum disulfide (MoS₂)-embedded 316L stainless steels (SS316L/h-BN and SS316L/MoS₂) were prepared by powder metallurgy method. Various h-BN and MoS₂ contents (10, 15 and 20 vol%) were mixed with 316L stainless steel powders and then sintered at 1200°C in H₂ atmosphere for 60 min. The experimental results showed that small boride phase and h-BN powder occupied the pores in the microstructure of SS316L/h-BN composite whereas the MoS₂ second phase occupied the pores of the sintered 316L matrix in the microstructure of SS316L/MoS₂ composite. The addition of h-BN decreased the sintered density and hardness whereas that of MoS₂ gave the opposite effect. Dry sliding wear behavior of composites was investigated by using pin-on-disc test rig at the sliding speeds of 0.1 and 0.2 m/s and the applied load of 3 N. The results showed that the MoS₂ composites had higher wear resistance than the h-BN composite but the h-BN composite yielded a better friction reduction.

Introduction

One of advantages of powder metallurgy method is to combine at least two material components in powdered forms to produce a composite material with a wider range of desirable properties. The sintered composites produced by solid lubricant addition usually provide promising tribological properties [1-3]. Previous study [3] suggested that the compacts of mixed SS316L/h-BN powders sintered at a temperature of 1200°C exhibited good friction reduction and wear resistance. In this work, MoS₂ powder was added to 316L stainless steel and the results were compared with the composites of SS316L/h-BN in terms of sintered density, hardness and wear behavior. The wear properties of these two composites were tested under a wide range of conditions including applied load, test speed, content and incorporation of solid lubricants.

Experimental

In this work, the SS316L/h-BN and SS316L/MoS₂ composites were produced by powder metallurgy process. The h-BN powder and MoS₂, used as a solid lubricant, with different volume fractions ranging from 10 to 20 vol. %, were added to the 316L stainless steel matrix. Particle sizes

of stainless steel, h-BN and MoS₂ powders were in the range of 45-150 μm, 7-11 μm and 11-20 μm, respectively. Materials components in each powder formulation were mixed thoroughly using a tumbling mixer for 1 hour. The disc specimens with Ø 30 mm were produced by cold compaction under the compaction pressure of 570 MPa. In the sintering process, the green parts were de-lubricated at the temperature of 600°C under argon atmosphere for 30 min and then sintered at temperature of 1200°C under hydrogen atmosphere for 60 min. The green and sintered densities were determined according to MPIF 42 standard.

Microstructures of the sintered composites were investigated using an optical microscope. Hardness of the sintered specimens was measured by Brinell hardness tester with the spherical indenter of 5 mm and a 306 N load. Dry sliding wear behavior against the chromium steel ball with Ø 7 mm of the sintered SS316L/h-BN and SS316L/MoS₂ composites was carried out using a pin-on-disc tribometer (ASTM G99) by using loads of 3 N with sliding speed of 0.1 and 0.2 m/s at room temperature. Worn surfaces were examined by using a scanning electron microscopy (SEM).

Results and discussion

Density, microstructure and hardness

Fig. 1 shows that density and hardness of the sintered SS316L/h-BN composites were lower than those of the sintered SS316L/MoS₂ composites. This was due to lower initial density of h-BN compared to that of MoS₂ [4]. In addition, the sintering of h-BN particles themselves hardly occurred under this sintering condition due to its high melting point, good thermal and chemical resistance [5]. Majority of non-sintered h-BN particles occupied large pores in the microstructures, as given in Fig. 2a. Some h-BN powders also hindered the densification of 316L matrix because they prevented direct contacts between SS316L powder particles and hence prevented bonding of SS316L powder particles. As also given in Fig. 2a, the boride phase was observed along SS316L grain boundaries. The liquid boride was formed due to eutectic reaction at around 1195°C [6-7]. The liquid boride formation occurred in a similar manner as that of the Fe-carbide systems under high temperatures [8]. The increase of the liquid boride phase with increasing h-BN content was found in the previous report [1]. MoS₂ addition was found to improve the compressibility, as well as enhanced the sinterability of sintered high alloy steels in the previous reports [1, 9]. Thus, the sintered stainless steels with the good bonding and the presence of the second phase were found in the microstructure of the sintered SS316L/MoS₂ composites as shown in Fig. 2b. It can be concluded that the sintered SS316L/MoS₂ composites appeared to give higher density and hardness than the sintered SS316L/h-BN composites.

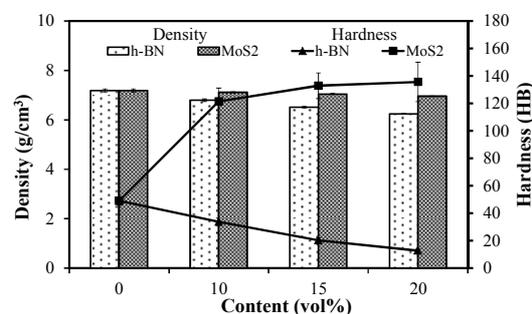


Fig. 1 Density and Brinell hardness of composites as a function of solid lubricant addition

Friction and wear characteristics

The variations of friction coefficient and specific wear rate of the sintered SS316L/h-BN and SS316L/MoS₂ composites are shown in Fig. 3. The results indicate that h-BN addition has a greater influence on the friction reduction as compared with the MoS₂ addition as shown in Fig. 3a. However, the MoS₂-added composite yielded higher wear resistance than the h-BN-added

composite and the sintered plain 316L at both speed of 0.1 m/s and 0.2 m/s, as shown in Fig. 3b. The wear rate was found to increase with increasing h-BN amount but did not change significantly with increasing MoS₂ content. Under the experimental conditions used in this work, the h-BN addition provides good friction reduction whereas the MoS₂ addition provides good wear resistance.

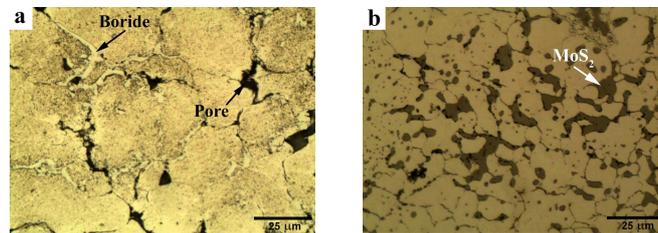


Fig. 2 Microstructure of composites sintered at 1200°C for 1 hr in H₂ atmosphere; (a) SS316L/h-BN (b) SS316L/MoS₂

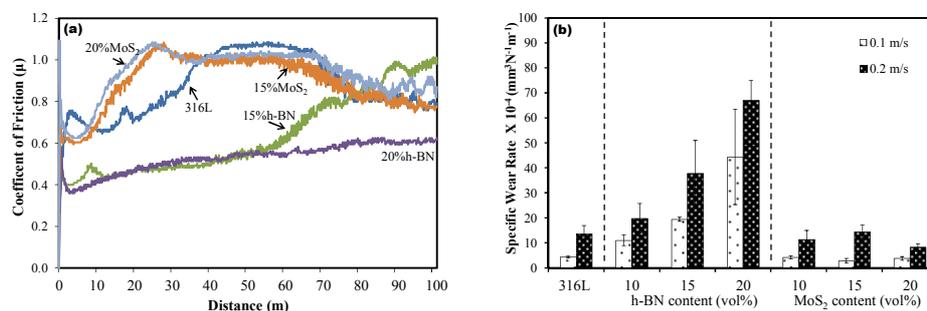


Fig. 3 The variation of friction coefficient and wear rate of composites with different solid lubricants at 3 N loads; (a) Friction coefficient at sliding speed of 0.1 m/s, (b) Specific wear rate

Worn surface morphology

The worn surfaces are shown by SEM images in Fig. 4 and suggested that the worn surface of the sintered SS316L and SS316L/20%MoS₂ composite were composed of transfer layers and fine particles (Figs. 4a and 4b). This was attributed to metal-to-metal contacts producing high friction coefficient and plastic deformation of the transfer layers. Cracks on the surface after sliding against the steel ball were also observed. The cracks on the surface after sliding are initiators of fracture leading to delamination of wear debris [10]. However, increase of MoS₂ content appeared to maintain or even increase the wear resistance of the composites (Fig. 3b). The experimental results indicate that the wear mechanism was dominated by adhesion and delamination mechanism. The worn surfaces of the 20% h-BN-added composites showed lower plastic deformation and no transfer layers. The h-BN phase (the bright phase) was also found on the worn surface (Fig. 4c). This lubricant provided good friction reduction but the soft lubricant phase deteriorated wear resistance of the composites under the conditions (Figs. 3a and 3b). High plastic deformation of the transfer layer was found in on the surfaces of the sintered SS316L and SS316L/20%MoS₂ composites at sliding speed of 0.2 m/s (Figs. 4d and 4e). The row of furrows and cracks between SS316 and h-BN interface appeared on the worn surface of the sintered SS316L/20%h-BN composite (Fig. 4f). These are signs of smearing and plastic deformation of the composites in a dry sliding wear test at a higher speed.

Conclusion

The density, hardness, wear and morphological properties of sintered SS316L composites with the additions of h-BN and MoS₂ at 10, 15 and 20 vol.% were studied and compared. The results demonstrated that the density, hardness and wear resistance decreased with increasing h-BN content, but the opposite effects were noted for MoS₂ addition. The addition of h-BN in stainless

steel provided better friction reduction than that of MoS₂ under the testing conditions used in this work. The wear mechanism of the sintered stainless steel and the sintered SS316L/MoS₂ composites involved the adhesive and delamination mechanism while the plastic deformation was alleviated by h-BN addition.

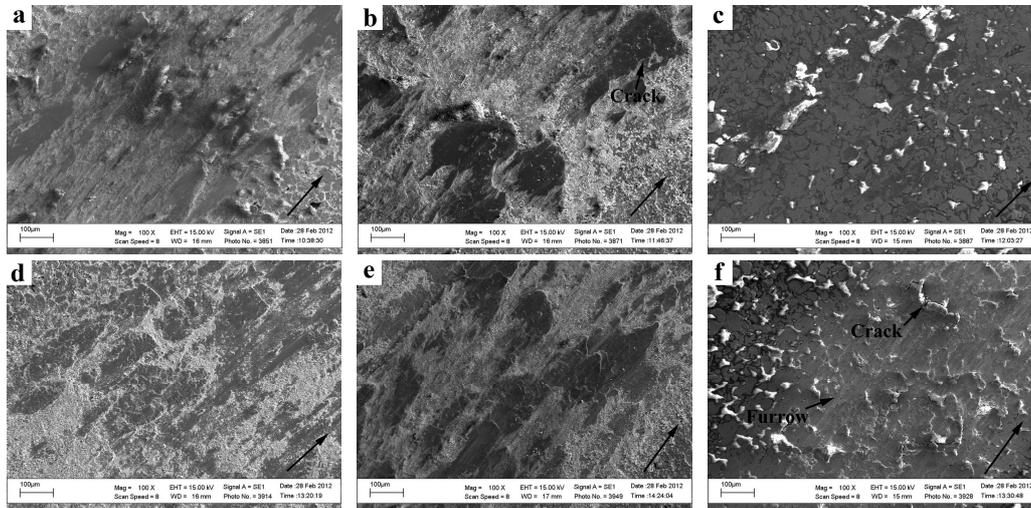


Fig.4 Worn surfaces of composite sintered at 1200°C with applied load of 3 N; (a) SS316L at 0.1 m/s, (b) SS316L/20%MoS₂ at 0.1 m/s, (c) SS316L/20%h-BN at 0.1 m/s, (d) SS316L at 0.2 m/s, (e) SS316L/20%MoS₂ at 0.2 m/s and (f) SS316L/20%h-BN at 0.2 m/s

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References

- [1] B. Sustarsic, L. Kosec, M. Kosec, B. Podgornik, S. Dolinsek, The influence of MoS₂ additions on the densification of water-atomized HSS powders, *J. Mater. Process. Tech.* 173 (2006) 291-300.
- [2] S. Dhanasekaran, R. Gnanamoorthy, Abrasive wear behavior of sintered steels prepared with MoS₂ addition, *Wear*. 262 (2007) 617-623.
- [3] S. Mahathanabodee, T. Palathai, S. Raadnui, R. Tongstri, N. Sombatsompop, Effects of hexagonal boron nitride and sintering temperature on mechanical and tribological properties of SS316L/h-BN composites, *Mater. Design*. 46 (2013) 588-597.
- [4] G. Mariani, Selection and application of solid lubricants as friction modifiers, in: L.R. Rudnick, *Lubricant additives: chemistry and applications*, Marker Dekker, New York, 2003, pp. 171-201.
- [5] K. Ichikawa, T. Noda, *United States* 5, 064, 589, 1991.
- [6] T. Van Rompaey, K.C. Hari Kumar and P. Wollants, Thermodynamic optimization of the B-Fe system, *J. Alloy. Compd.* 334 (2002) 173-181.
- [7] H. Okamoto, B-Fe (Boron-Iron), *J Phase. Equilib. Diff.* 25 (2004) 297-298.
- [8] S. Chakthin, N. Poolthong and R. Tongstri, Effect of reaction between Fe and carbide particles on mechanical properties of Fe-base composite, *Adv. Mater. Res.* 55-57 (2008) 357-360.
- [9] S. Dhanasekaran, R. Gnanamoorthy, Dry sliding friction and wear characteristics of Fe-C-Cu alloy containing molybdenum di sulphide, *Mater. Design*. 28 (2007) 1135-1141.
- [10] D. A. Rigney, Comments on the sliding wear of metals, *Tribol. Int.* 30 (1997) 361-367.