Wear Resistance of AlN-Al Cermet Coatings Deposited by the HVOF Spray Process †

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Abstract

AlN-Al cermet coatings were deposited by the HVOF spray process and the effect of the powder morphology on the wear resistance of the deposited coatings was investigated. Three types of agglomerated powders with AlN particle diameters of 1.8μm, 6.7μm and 13.3μm were sprayed and the Al amount in the powder was changed from 10-40 mass%. The wear resistance of the coatings was investigated using a ball-on-disc sliding tester with a SUS440 or SiC counter ball. The wear resistance of the coating is better for larger amounts of the aluminum binder phase. The larger aluminum amount is obtained when the AlN particles in the agglomerated powder are larger. The wear resistance of the coating using the 13.3μm AlN particles is equivalent to that of a sintered AlN disk.

KEY WORDS: (AlN-Al Cermet) (HVOF Spray) (Powder Morphology) (Wear Resistance)

1. Introduction

AlN has high hardness of more than 18 GPa [1] and high thermal conductivity of 200 W/mK [2]. Based on these superior properties, a lot of studies on surface modifications using AlN have been carried out [3-10]. In order to form an AlN film, several kinds of technique were applied, such as ion implantation [3,4], magnetron sputtering [5], laser surface modification [6], plasma nitriding [7-9], and the thermal spray method [10]. During ion implantation, nitrogen ions are generated in a vacuum chamber and the ions are accelerated to the sample by a high voltage. More than two hours are necessary to obtain a hard surface using this process [4]. During magnetron sputtering, an aluminum target is sputtered by nitrogen ions and the AlN is directly formed on a substrate by the reaction between the sputtered aluminum and the nitrogen ions. The deposition rate is about 50nm/min for this method [5]. The laser surface modification has an advantage that only a selected area can be nitrided. A narrow laser irradiates the sample surface, the temperature of the selected area increases, and then the surface reacts with the environmental nitrogen gas [6]. The plasma nitriding process involves the reaction with the sample in a nitrogen plasma at high temperature. However, even at high temperature, the aluminum surface is usually covered with an oxidized layer that prevents the reaction. In order to increase the reaction rate, Okumiya et al. used a fluidized bed to decompose the oxidized layer [8]. Visuttipitukul used bulk mechanical alloying to introduce more grain boundaries that can act as a fast diffusion path [9]. The disadvantage of these processes is the need for a vacuum chamber, therefore, it is difficult to form a large AlN film. On the other hand, using the thermal spray process, a large AlN film can be formed at a fast deposition rate. The problem with the thermal spray method is the decomposition of the AlN at high temperature. The decomposition of the hard particles is the problem when other kinds of hard particles are used in the thermal spray process. This issue was previously studied in a WC-Co system and a Cr_3C_2-NiCr system [11,12]. There are several approaches to prevent the decomposition of the hard particles, namely, a decrease in the process temperature, environment control, and modification of the powder morphology. The high-velocity oxyfuel (HVOF) process is usually applied as a low temperature process. In this process, a dense coating is obtained due to its higher particle velocity. In the plasma spray process, on the other hand, the obtained coating becomes porous when done at a low temperature to prevent decomposition of the particles [11]. Changing the mixing ratio of the fuel and oxygen is one way to control the environment. Li et al. used this technique in

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the HVOF process and showed that the decomposition is prevented when the amount of oxygen is low [12]. Li et al. also investigated the effect of the size of the hard particles in the agglomerated powder on the amount of carbide in the film [13]. They concluded that large hard particles rebound when they come in contact with the substrate. Therefore, the amount of carbide in the film is smaller for the larger hard particles. In the case of pure AlN, Krishna deposited an AlN film using a detonation gun system [10]. In this study, the mixing ratio of the fuel and oxygen was controlled in order to prevent oxidation of the AlN powder, but the AlN amount in the deposited film was less than 30 mass %. As described, there are many studies of AlN coatings, however, no study on the deposition of AlN-Al cermet has been carried out using any thermal spray process. In this study, three kinds of agglomerated powders are deposited by the HVOF process, and the effect of the morphology of the powder on the structure and the wear property of the deposited coatings are investigated.

2. Experiments

Three kinds of AlN-Al agglomerated powders are used in this study. AlN particles with diameters of 1.8μm, 6.7μm, 13.3μm were used to agglomerate the particle, and the produced powders were labeled type-F, M, C, respectively. In these agglomerated particles, the 1.9μm Al particles were also used, and the diameters of the agglomerated particles were about 40μm. The amount of Al is 10, 20, 30 and 40mass% for the Type-F, and 30mass% for the Type-M, and C. The powders were dried for 12 hours at 423 K in a vacuum before the deposition.

The HVOF spray process was carried out using a system called Diamond Jet developed by Sulzer Metco. C_3H_6 gas at 0.69 MPa and O_2 gas at 1 MPa were used for combustion, and N_2 gas at 0.86MPa was used for the powder carriage. The powder feed rate was 30 g/min and the spray distance was 200 mm. An A6063 disk with a diameter of 29.6 mm and thickness of 5 mm was used as the substrate that had undergone a prior blasting process using #24 alumina grit.

The powders and the coatings were investigated using SEM, EPMA, optical microscopy, and XRD. The wear resistance of the coatings was evaluated using a ball-on-disk type sliding wear tester. The test was carried out with a load of 5 N at a sliding speed of 25 m/min using counter balls of SUS440 or SiC. The wear resistance was evaluated by the weight loss of the coating after the test.

3. Results and discussion

3.1 Effect of Al binder amount on the wear resistance of coatings

Type-F powders containing 10, 20, 30 and 40 mass% Al were sprayed. Typical SEM images of the cross sections of the deposited coatings are shown in Fig.1. Depositions were successful for all the compositions. The structure is homogeneous and the

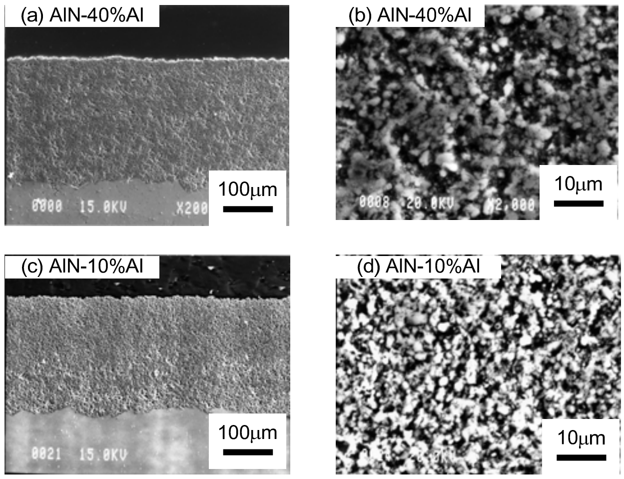

Fig. 1 Cross-section images of coatings deposited using Type-F powders. (a) (b) 40 mass% Al, (c) (d) 10 mass% Al

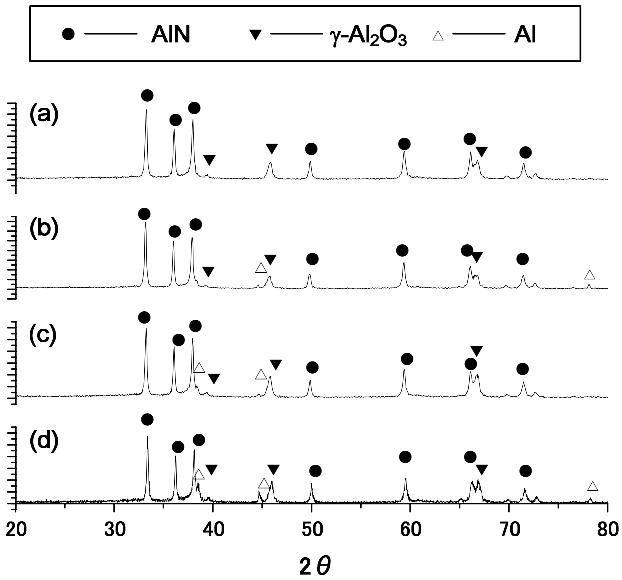

Fig. 2 XRD patterns of Type-F coatings. (a), (b), (c), (d) are 10, 20, 30, 40 mass%Al respectively.

surface of the coating is flat. A denser coating is obtained for the higher Al amounts. The XRD analysis was carried out to determine the phases in the coatings. As shown in Fig.2, no Al peak is observed in the XRD pattern of the 10mass% Al, and the Al peak becomes clearer as the Al amount increases. When the amount of the Al binder in the coating is large enough, as shown in the XRD result of Fig.2 (d), the AlN particles are strongly bonded by aluminum and the coating is denser. On the other hand, when no Al peak is observed as in Fig.2 (a), the AlN particles are bonded by γ-alumina and the coating is porous.

Figure 3 shows the result of the wear resistance test. Usually, the wear resistance is better when the amount of

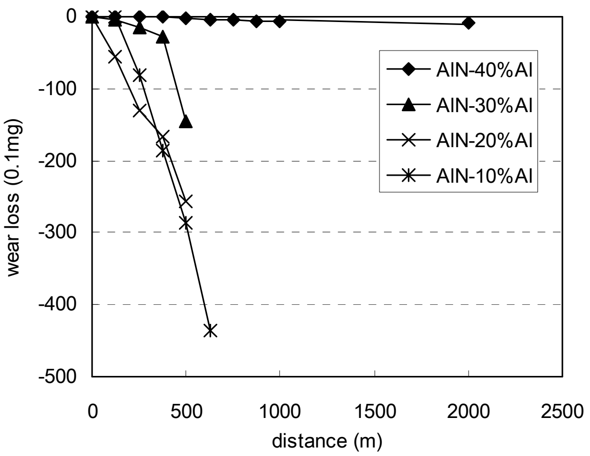

Fig. 3 Weight loss of Type-F coatings after the wear test.

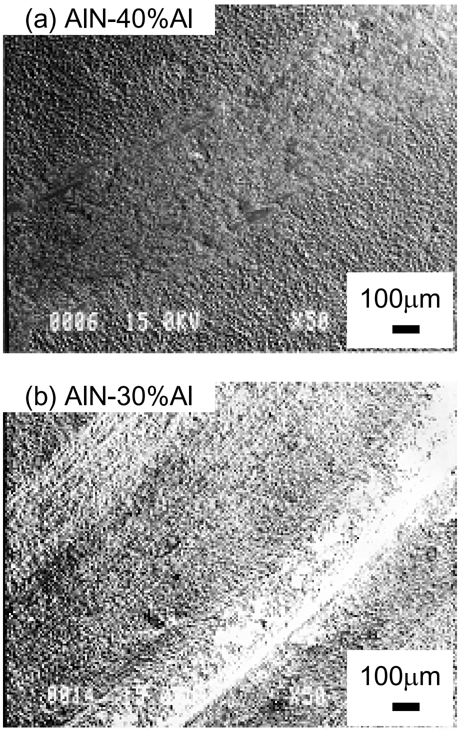

Fig. 4 Surface appearance of Type-F coatings after wear test. (a) 40 mass% Al, (b) 30 mass% Al

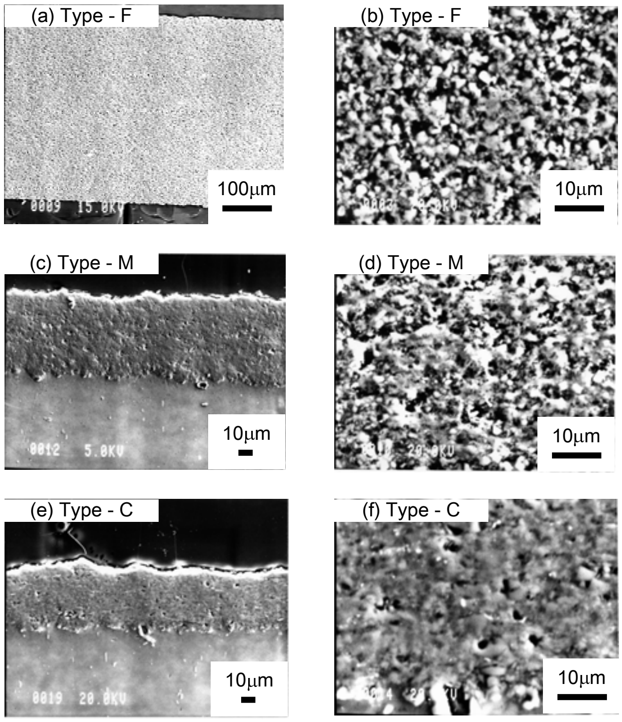

Fig. 5 Cross-section images of coatings deposited using three kinds of powders. (a)(b) Type-F, (c)(d) Type-M, (e)(f) Type-C.

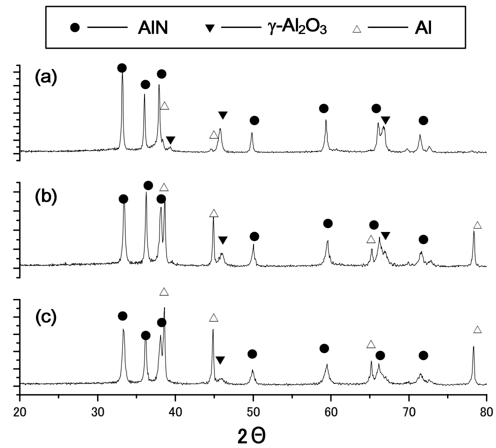

Fig. 6 XRD patterns of the coatings. (a), (b), (c), are Type-F, M, C, respectively.

hard particles is larger. However, in this case, the wear resistance of the coatings of the Al 40mass% powder is superior to the other coatings. The surfaces after the wear test are shown in Fig.4. The surface of the 40 mass% Al is flatter. On the other hand, the coatings of the 30mass% Al are shaved and the coatings of the 10 and 20 mass% Al were removed during the test. When there is not a sufficient enough amount of binder, the hard AlN particles are easily removed from the coating and AlN cannot show its good potential during the wear test.

3.2 Effect of AlN size in agglomerated powder on the wear resistance of coatings

The type-F, M, C powders were used with the 30 mass% Al. SEM images of a cross section of the deposited coating are shown in Fig.5. Depositions were successful for all the powders. The thickness of the coatings is thinner and the porosity size is smaller for the larger AlN particles. The XRD analysis of the coatings shows that the Al peaks are larger and the γ-alumina peaks are smaller for the larger AlN particles as in Fig.6. This means that when the larger AlN particles are used,

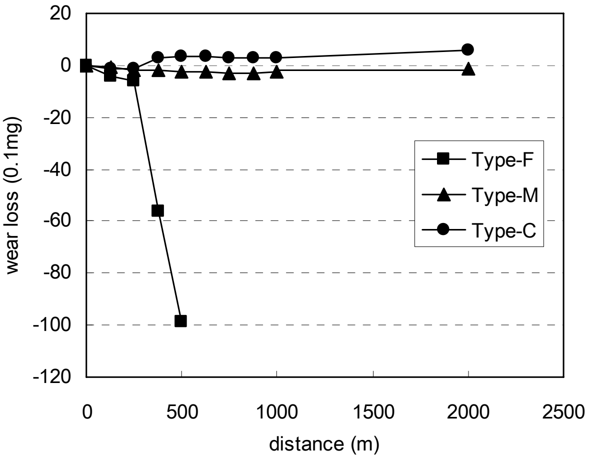

Fig. 7 Weight loss of coatings after the wear test using a SUS440 counter ball.

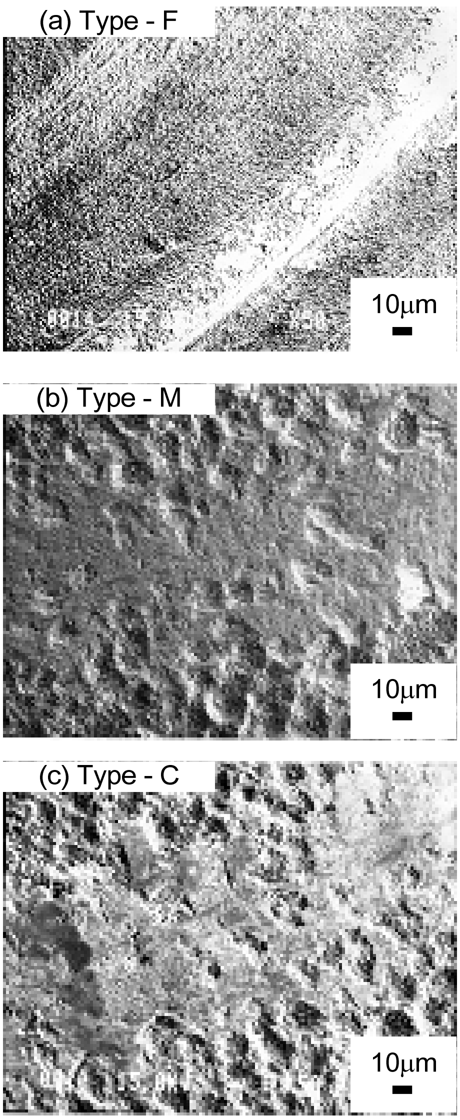

Fig. 8 Surface appearance of the coatings after wear test. (a), (b), (c), are Type-F, M, C, respectively.

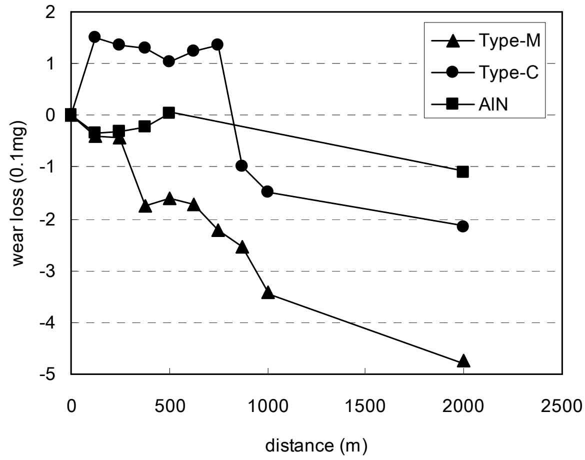

Fig. 9 Weight loss of coatings after the wear test using a SiC counter ball.

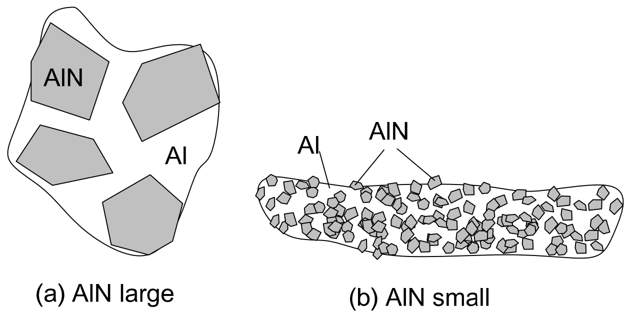

Fig. 10 Schematic drawing of the molten powder. (a) large AlN particle, (b) small AlN particle.

the amount of the Al binder is larger and a denser coating is formed as shown in Fig.5(c). Figure 7 shows the results of the wear test using the SUS440 counter ball. The type-M, and C coatings shows no wear loss, though the type-F coatings shows a high wear loss. Figure 8 shows the surface of the coatings after the test. Although the surfaces of the type-M and C coatings are flat, the type-F coatings are scratched. In order to investigate the superior wear resistance of the type-M and C coatings, a SiC counter ball was then used for the wear tests. In this case, a sintered AlN disk was also tested for comparison. Figure 9 shows that the type-C coatings have a good wear resistance similar to the sintered AlN plate.

3.3 Mechanisms of Al binder remaining

Toy et al. reported that the contact angle between the solid AlN and molten aluminum is less than 60 degrees at 1473K [14], and the contact angle should decrease with increasing temperature. Therefore, a sufficient amount of molten Al exists, the AlN is covered by molten Al, and the molten agglomerated powder forms a homogeneous mixture of AlN particles and molten Al, as shown in Fig.10. When the AlN particle is small, the area of the interface between the molten Al and the environmental gas is large and the oxidation of the molten Al quickly progresses. On the other hand, when the AlN particles are large, the interface area is small and the oxidation progresses more slowly. According to Li et al., in the WC-Co system, when the diameter of the WC particle is 18μm, the WC particle rebounds at the substrate surface and the amount of the WC in the coating decreases. This same phenomenon can occur in the AlN-Al system. As a result, more Al remains in the type-C coatings, as shown in the XRD result of Fig.7 (c), and consequently, the wear resistance is better.

4. Conclusions

AlN-Al cermet coatings were deposited by the HVOF spray method and the effect of the powder morphology on the wear resistance of the deposited coatings was investigated. AlN-Al agglomerated powders with 10, 20, 30 and 40mass% Al were sprayed. The coating with 40 mass% Al shows the best wear resistance of the four coatings. This good wear resistance is caused by the large amount of Al in the coating that can act as a good binder. On the other hand, for the 10, 20 and 30 mass% Al, the AlN particles are weakly bonded by γ-alumina. The amount of the Al binder in the coating can be increased by controlling the size of the primary AlN particles in the agglomerated powder. The larger AlN particles of 13.3mm in the agglomerated particle leads to a good wear resistance, which is equivalent to that of a sintered AlN disk.

References

1) J. H. Edgar, C. A. Carosella, C. R. Eddy Jr., D. T. Smith, *J. Mater. Sci.* **7**, (1996), 247
2) G. A. Slack, *J. Phy. Chem. Solids* **34**, (1973), 321
3) Z. Zhan, X. Ma, L. Feng, Y. Sun, L. Xia, *Wear* **220**, (1998), 161
4) T. Yamanishi, Y. Hara, R. Morita, K. Azuma, E. Fujiwara, M. Yatsuzuka, *Surf. Coat. Tech.* **136**, (2001), 223
5) A.Cachard, R. Fillit, I. Kadak, J. C. Pommier, *Vacuum*, **41**, (1990), 1151
6) C. Meneau, P. Andreazza, C. Andreazza-Vignolle, P. Goudeau, J. P. Villain, C. Boulmer-Leborgne, *Surf. Coat. Tech.* **100**, (1998), 12
7) T. Czerwiec, N. Renevier, H. Michel, *Surf. Coat. Tech.* **31**, (2000), 267
8) M. Okumiya, Y. Tsunekawa, T. Murayama, *Surf. Coat. Tech.* **142**, (2001), 235
9) P. Visuttipitukul, T. Aizawa, H, Kuwahara, *Mater. Trans.* **44**, (2003), 2695
10) L. R. Krishna, D. Sen, Y. S. Rao, G. V. N. Rao, G. Sundararajan, *J. Mater. Res.* **17**, (2002), 2514
11) C. J. Li, A. Ohmori, Y. Harada, *J. Materials Science* **31**, (1996), 785
12) C. J. Li, K. Sonoya, G. C. Ji, Y. Y. Wang, *Welding in the world* **41**, (1998), 77
13) C. J. Li, Y. Y. Wang, G. J. Yang, A. Ohmori, K. A. Khor, *Mater. Sci. Tech.* **20**, (2004), 1087
14) C. Toy, W. D. Scott, *J. Mater. Sci.* **32**, (1997), 3243