Sliding Wear Behavior of Plasma Sprayed Zirconia Coatingagainst Silicon Carbide Ceramic Ball

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ABSTRACT

The sliding wear behavior of ZrO_2-22wt%MgO (MZ) and ZrO_2-8wt%Y_2O_3 (YZ) deposited on a casting aluminum alloy with bond layer (NiCrCoAlY) by plasma spray against an SiC ball was investigated under dry test conditions at room temperature. At all load conditions, the wear mechanisms of the MZ and the YZ coatings were almost the same. The wear mechanisms involved the forming of a smooth film by material transferred on the sliding surface and pullout. The wear rate of the MZ coating was less than that of the YZ coating. With an increase normal load the wear rate of the studied coatings increased. The SEM was used to examine the sliding surfaces and elucidate likely wear mechanisms. The EDX analysis of the worn surface indicated that material transfer was occurred from the SiC ball to the disk. It was suggested that the material transfer played an important role in the wear performance.

Key words: Plasma spray, Wear mechanism, Zirconia, Fracture toughness

1. Introduction

Plasma sprayed zirconia ceramic coating has been widely used for heat engine, gas turbine part, aerospace seal and lubrication system because of their special mechanical, chemical and thermal properties.

Previous studies of the friction and wear of zirconia and its property coatings have been reported [1-8,12-17]. The wear behavior of zirconia ceramics seems to be very sensitive to the structure of the materials, and to the test parameters, such as temperature, environment and sliding speed [1]. Some works reveal that microstructure and mechanical properties, such as grain size [2,17], fracture toughness [3,4], have strong effect on abrasive/sliding wear resistance of bulk ceramic and coatings under dry or lubrication test. The friction and wear of ZrO_2 coating showed a strong dependence on temperature [5,12,14]. Applied loads played a significant role in the wear behavior of functionally gradient layers [6]. The observed a predominantly tribochemical wear mechanisms for zirconia sliding on both steel and zirconia toughened alumina counter faces in a low load tribological regime [7]. With the increasing of the sliding speed and hence of the contact temperature, a tribochemical reaction can take place on the worn surfaces [8]. The material transferred from mated ball or pin played an important role wear resistance of zirconia ceramics [2-4,7,8,13-15] and the layer of oxidation was forming during the test, which was a significant factor in the wear process [8,9]. Although a number of researchers have investigated the factors influencing the wear of zirconia [1-8,12-17] and relatively little work has been focused on understanding wear behavior of the coatings under dry test condition at room temperature with material transfer on the worn surface between self mated ceramics. The goal of this study is to investigate the wear behavior of plasma sprayed ZrO_2-22wt%MgO and ZrO_2-8wt% Y_2O_3 coatings. In particular, the materials transferred on friction and wear behavior were examined.

2. Experimental procedures

2.1 Specimen preparation

The casting aluminum (ASTM A413) was provided by a commercial supplier. The casting aluminum alloy was machined to make disk specimens with 25 mm diameter and 10 mm thickness. The uniform thickness of all specimens was ensured by grinding less than 0.1 mm of tolerance from both sides of the disk surfaces. One side of the disk was ground and polished to remove the grinding damage and any surface irregularities. The surface roughness of the polished surface was 0.05 μm *Ra*.

Table 1. The spraying parameters and properties Hexa plasma

Parameters	ZrO_2-22%MgO	ZrO_2-8%Y_2O_3	NiCrCoAlY
Current /A	600	600	600
Power /kW	34	34	34
Primary gas (Ar) / mim^{-1}	30	30	55
Secondary gas (H_2) / mim^{-1}	8	8	8
Feed rate / $g.min^{-1}$	46	46	40
Spray distance/mm	70	70	100
Powder inlet position	internal	internal	external

Table 2. Mechanical properties of the coatings

Material	Notation	Hardness $HV_{0.1}$ Mpa	Fracture toughness $Mpa.m^{1/2}$
ZrO_2-22%MgO	MZ	3200 ± 100	2.5
ZrO_2-8%Y_2O_3	YZ	5200 ± 125	1.7

The materials used in the coating process were commercial powders ZrO_2, MgO, and Y_2O_3. They consisted of small particles fused in a furnace crushed after fusing and had irregular grain shapes. For coating, grain sizes ranged between 15 and 45 μm. The studied coating materials were ZrO_2 – 7%wt Y_2O_3 and ZrO_2 – 22%wt MgO. Thickness of the top coatings was 350μm. The NiCrCoAlY (46.5Ni-22Co-17Cr-13Al-0.5Y) layer was applied as bond coating to enhance adhesion and reduce thermal expansion mismatch between the substrate and the ceramic coatings. Thickness of the bond coating was around 150 μm on average. The spray equipment selected was a Hexa plasma system (New Tech. Co., South Korea). The spraying parameters were shown in Table 1.

The micro-hardness of the specimens was measured by using a Vickers hardness tester (MVK-H2 Shimadzu). The fracture toughness was evaluated by following [10]. Notation and mechanical properties of the specimens used in these experiments were shown in Table 2.

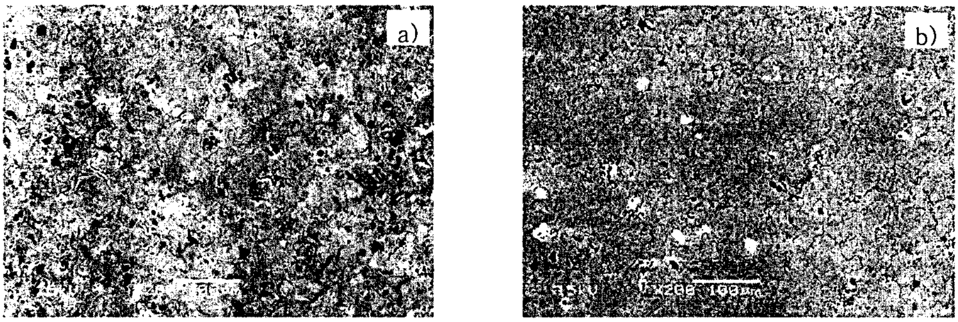

Figure 1. Coating structure before wear test polished surface of a) ZrO_2-22wt%MgO and b) ZrO_2-8%Y_2O_3

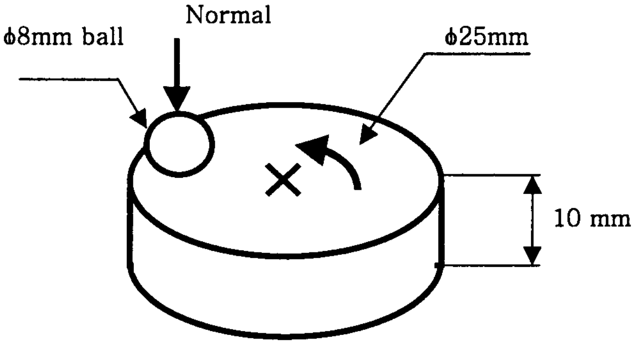

Figure 2. Schematic illustration of ball-on-disk type wear test

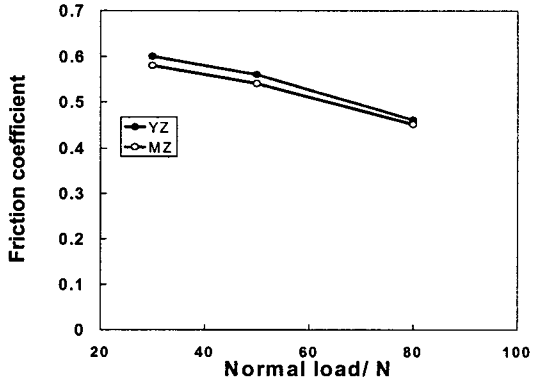

Figure 3. Friction coefficients versus different load under dry test

2.2. Analysis of coating surface.

The surface of the coating was observed with SEM to investigate the condition of the sprayed molten particles. The microstructure of the coating was shown in Fig. 1. Fig. 1a showed that the structure of the MZ coating and Fig. 1b was the YZ coating before wear test. The main defect structures in the coatings were pores, micro-crack, internal boundaries and foreign inclusions. The voids are seen clearly in all specimens. These voids may be due to the pullout effect, while polishing, the weakly bound between unmelted particles and partially melted particles pull out from the coatings.

2.3. Wear test.

2.3.1. Test machine.

The wear machine (TOYO BALDWIN Co EFM-3E) was designed to carry out unidirectional sliding friction and wear test. The friction force was detected by a load cell through a friction force measurement arm. A normal load was applied with a spring and the actual load was measured by a load cell before the test. The voltage signals of the load cell were saved every second through an A/D converter using a compatible IBM PC. The contact point was designed at an eccentricity of 8mm from center of the rotary motion, which created a round of worn track 16mm in diameter on the surface of the disk, as shown in Fig. 2.

2.3.2. Wear experimental procedures.

The ball-on-disk sliding test was carried out between coated aluminum alloy disks and silicon carbon ball with 8mm diameter and its surface roughness and Young's modulus are 0.1 μm and 440 GPa, respectively. Before each sliding test, the ball and disk were ultrasonically cleaned in acetone for 10 min and then rinsed in acetone to remove residual dust, grease and other solid contaminants to keep the surface conditions as identical to each other as possible. The friction and wear tests were carried out at room temperature under dry condition. The loads used in this experiment were 30N, 50N and 80N and the sliding speed was kept at a constant value of 100 mm/s by adjusting the rotating speed of the disk specimen. The wear volume was determined by using a surface profilometer.

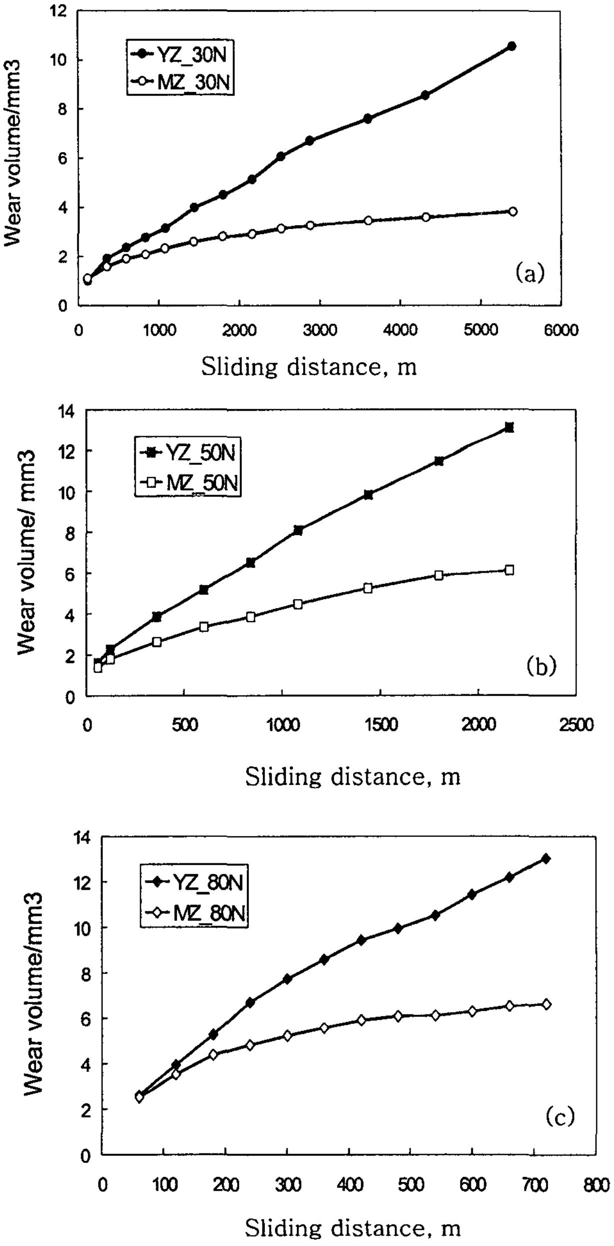

Figure 4. Variation in wear volume for the YZ and MZ coatings versus sliding distance under dry test a) at 30N; b) at 50N and c) at 80N

3. Results

3.1. Friction behavior

The friction coefficients of all coatings against SiC ball at room temperature were shown in Fig.3. they were almost the same. It can be seen that friction coefficients of the MZ and the YZ coatings were about μ=0.45-0.6 at room temperature. With the increase of load from 30N to 80N, coating exhibited a decrease trend in friction coefficients slightly from 0.6 to 0.45 for these coatings

3.2. Wear behavior.

The variations of wear volume for the MZ and the YZ coatings vs the sliding distance under dry test normal loads of 30N, 50N and 80N were shown in Fig. 4. It is clear that the wear volume of the MZ coating was less than that of the YZ coating very much and they increase with an increase sliding distance and the normal loads. The wear rate of the MZ and the YZ coatings were shown in Fig. 5. It pointed out that the wear rate of the MZ coating was less than that of the YZ coating very much and both of them increase with an increase normal loads. Fig. 4 and Fig. 5, indicating that the wear resistance of the MZ coating against SiC was better than that of the YZ coating in the same testing conditions.

3.3. Observation of worn surfaces

The worn surfaces of the MZ and the YZ coatings were observed by SEM. They were very similar under differenrent load conditions. The examination of the worn surfaces in the SEM showed material transfer from the ball onto the disk and pull-out. The worn surfaces of the MZ and the YZ coatings at 50N were shown in Fig.6 and Fig.7. They included two regions. The first region is smooth region (A) which is material transfer, another one (B) is rough region that is new surface process and the wear mechanism is pull-out. The individual area of the smooth region on the worn surface of the MZ coating is apparently larger than that on the worn surface of the YZ coating. The smooth region (A) of the YZ coating is evidience of observed striation marks on the worn surfaces but not on the worn surface of the MZ coating because of higher fracture toughness of the MZ coating

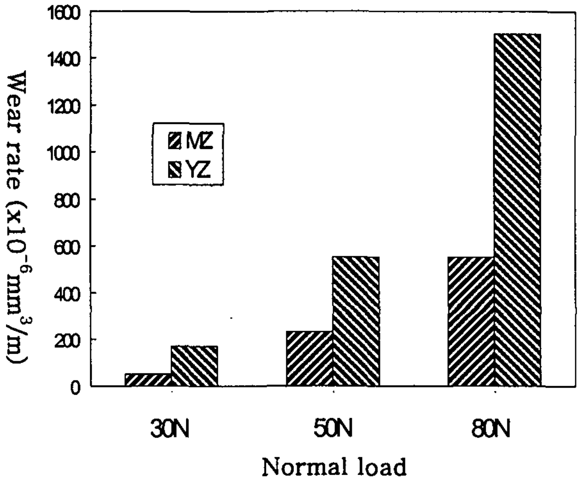

Figure 5. Wear rate versus normal load

4. Discussion

Under dry test condition, the SEM images (Fig. 6 and 7) showed that except for the area of the relatively smooth region (A), there was no substantial difference on the worn surfaces of the two coatings. Thus no obvious difference in the friction coefficients of the coatings can be found above. The friction coefficient of zirconia ceramic sliding against ceramics or metals, which was about from 0.3 to 0.6 [4,6,16,17].

The film of transferred material can be formed either back transferred of its own material or by the wear debris entrapped in the contact interfarce. The smooth wear track was very important for wear resistance, which was formed by debris particles compaction; the zirconia debris particles were compacted after forming and becoming attached to the disk surface [14]

In this study, the material transfer from SiC ball to disk (the MZ and the YZ coatings) was occurred. Fig. 6d and Fig. 7d shows that EDX spot analyses at the smooth regions of the worn surfaces detected the present Si and C elements beside Zr, Y, Mg and oxygen elements. The friction heat delivered into the coating layer is expected to be limited to the near surface region owing to low thermal conductivity of zirconia, and this may lead to a high temperature in the surface region, which also facilitates the formation of the smoonth layer . The SiO_2 may be formed under these conditions. Since the oxidized transferred layer was strongly adheren to the coating surface, the wear rate was reduced [3,9]. The smooth area of the MZ worn surface is larger than that of the YZ worn surface. The smooth regions adhered to the worn surfaces of the MZ coating is larger than those adhered to the worn surface of the YZ coating (Fig. 6 and 7). When the contacting surfaces are smooth, the contact forces are distributed over wider areas, and stress are distributed and therefore, less intense.

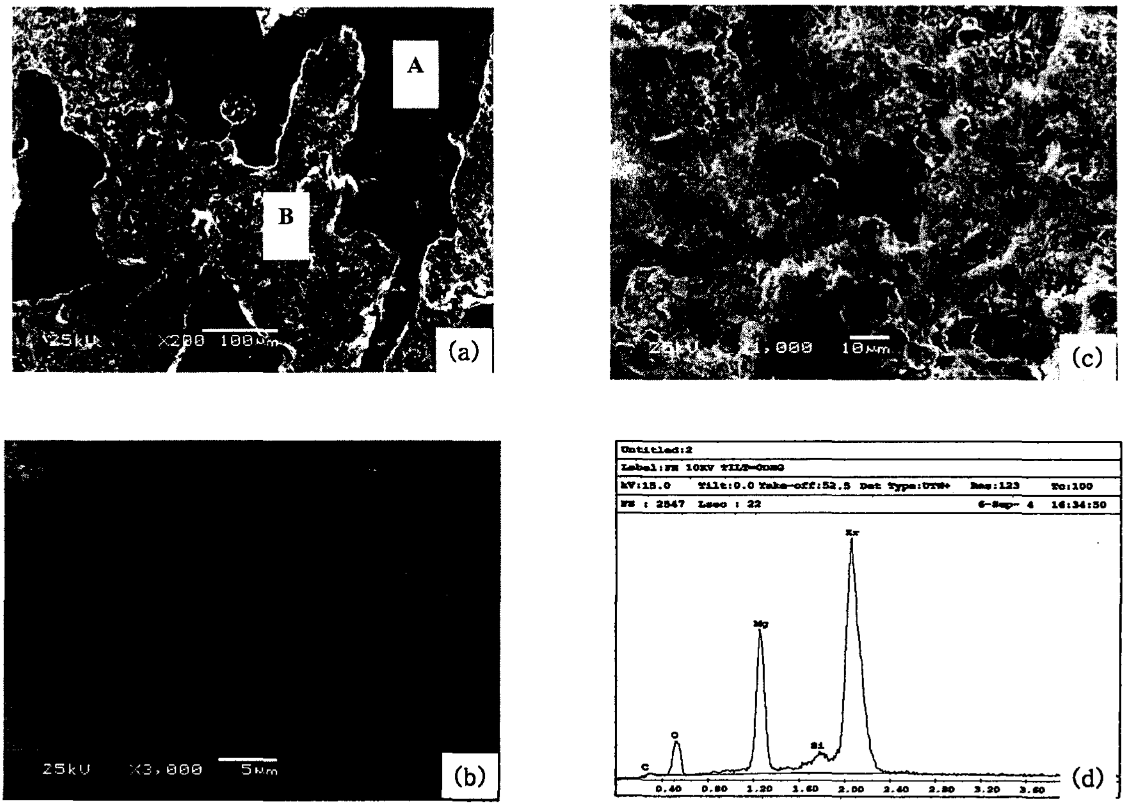

Figure 6. Worn surface of MZ after sliding under 50N

a) Region A: Material transfer; region B: pull-out; b) Higher magnification of region A;

c) Higher magnification of region B; d) EDX analysis of smooth region A (fig. 6b)

It is suggested that the material transfer on the worn surfaces played an important role for wear resistance these coatings. The wear mechanisms, such as those described above have already been previously observed in the similar ceramic wear test [15] at room temperature and the material transfer from ceramic counter face was occurred during the testing condition, which is similar to some test [4,8,15]. At higher temperature test conditon such as 200^{0}C, the material transfer seemed to affect the wear behavior [2]. The main wear mechanism of zirconia ceramic also changed under different fracture toughness. Wear occurred predominantly by fracture in the brittle ziconium oxides and plastic depformation was observed in the toughner ziconium oxides [4]. The wear rate of ceramic was improved with increase fracture toughness [3,4,11]. As the results, it was shown that fracture toughness of the MZ coating is higher than that of the YZ coating (Tab. 2) and it also can be seen in Fig. 7b with evidence of striation marks on the worn surfaces, but not in Fig 6b and the SEM images (Fig. 6b and 7b) confirmed the influence of fracture toughness on the wear process. For these studied coatings, the fracture toughness had a significant influence on the wear performance of these coatings.

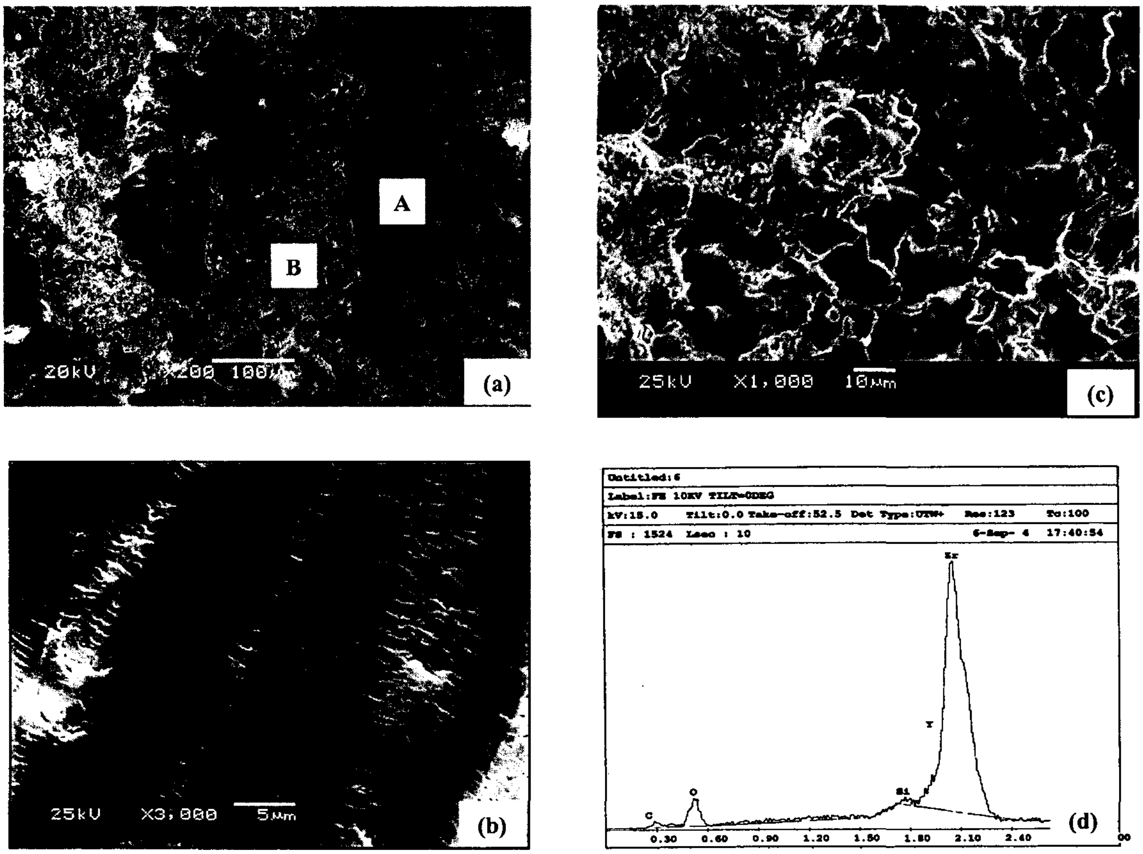

Figure 7. Worn surface of YZ after sliding under 50N
a) Region A: Material transfer; region B: pull-out; b) Higher magnification of region A;
c) Higher magnification of region B; d) EDX analysis of smooth region A (Fig. 7b)

The wear resistance of the MZ coating is better than that of the YZ coating. The conclusion also agrees with Y.M.Chen [1] which tested at high speed and the phase transformation was occurred on the worn surfaces and rapid wear of MgPSZ and YTZP was found in a special range of sliding speed, wear resistance of MgPSZ, however, remain better than that of YTZP.

5. Conclusions

(1) The friction coefficients of MZ and YZ were almost the same under these test conditions. With the increase of load from 30N to 80N, coating exhibited a decrease trend in friction coefficients slightly from 0.6 to 0.45 for these coatings

(2) The wear mechanism of these coatings were almost the same under the different load conditions. The material transfer and pull-out were involved in the wear process of studied coatings in all cases.

(3) The fracture toughness had great influence on the wear resistance of these coatings. The toughner material and the better wear resistance.

(4) The material transfer played an important role in wear performance. The wear resistance of the MZ coatings was better than that of the YZ coatings under the same testing condition.

Acknowledgement

This research was supported by the Program for the Training of Graduate Students in Regional Innovation which was conducted by the Ministry of Commerce, Industry and Energy of the Korean Government. and BK21 program of Kyungpook National University

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