KSTLE International Journal, Vol. 6, No. 2, December 2005, pp. 45-50

Sliding Wear Characteristics of Plasma Sprayed $8\%Y_2O_3$-ZrO_2 Coating for Post-spray Heat Treatment

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Abstract: Plasma ceramic spray that is applied on a machine part under severe work conditions has been investigated for tribological behavior. The application of ceramic coatings by plasma spray has become essential in tribosystems to produce wear resistance and long life in severe conditions. The purpose of this study was to investigate the wear characteristics of $8\%Y_2O_3$-ZrO_2 coating, in view of the effect of post-spay heat treatment. The plasma-sprayed $8\%Y_2O_3$- ZrO_2 coating was studied to know the relationship between phase transformations and wear behavior related to post-spray heat treatment. Wear test was carried out with ball on disk type on normal loads of 50N, 70N and 90N under room temperature. The phase transformation of phase and the value of residual stress were measured by X-ray diffraction method(XRD). Tribological characteristics and wear mechanisms of coatings were observed by SEM. The tribological wear performance was discussed in the focusing of residual stress. Consequently, post-spray heat treatment plays an important role in decreasing residual stress. Residual stress in the coating system has a significant influence on the wear mechanism of coating.

Keywords: Friction, wear, plasma spray coating, XRD

1. Introduction

The application of ceramic coatings by plasma spray has become essential in tribosystems to produce wear resistance and long life in severe conditions [1]. Ceramic coating such as Al_2O_3, Cr_2O_3, Al_2O_3-TiO_2, Y_2O_3-ZrO_2, and ZrO_2 are an attractive material because they can be used under severe operating conditions; whereas conventional tribomaterials exhibit performance difficulties at larger loads, higher speeds and higher temperatures [2].

It was reported that PSZ (Partially Stabilize Zirconia) coating have better wear resistance than its sliding against a metallic substrate [7-9]. The wear mechanism of plasma sprayed $8\%Y_2O_3$-ZrO_2 coatings, carried out in a reciprocating sliding tester at a temperature of 200°C, was affected by plastic deformation and material transfer [7]. In a similar test conducted at higher temperatures up to 800°C, phase transformation from monoclinic to tetragonal considerably affected the wear behavior of $8\%Y_2O_3$-ZrO_2 coatings [9]. It was also reported in this paper [9] that an increase in the amount of phase transformation from non-transfromable tetragonal(t') to metastable tetragonal occurred on the wear surface and wear debris with an increase in the temperature to 800°C, and this was related to the lower wear losss with increasing temperature [9]. Various plasma-sprayed ceramic coatings have been studied in a roller-on-block tester at 450°C and the wear mechanisms for all of these coatings were reported to be fatigue spalling, plastic deformation as well as material transfer, as in metal [10]. Furthermore, the wear mechanism of plasma-sprayed coating was dominated by a value of residual stress owing to the mismatch of the TEC (Thermal Expansion Coefficient) of the coating system [4,11].

Many papers on plasma ceramic sprayed coatings have reported on coating failure as the mismatch of the TEC and the elastic modulus between the coating and the substrate [3-5]. The defaults include cohesive failure, spallation in the coating, weak adhesive strength of the interface and high residual stress of coating; all of which influence the wear resistance characteristics of coating [3-6].

Residual stresses are inevitably generated in most coatings during the deposition process. They would be often improved tribological performance of coating. However, it is difficult to control a residual stress of coating in manufacturing process [12]. In order to reduce residual stress of the coating, the tribological coatings have been carefully applied the post-spray process. It is important to improve tribological characteristics of the coating with post-spray treatment.

For a better understanding of the post-spray heat treatment, which can evaluate wear behavior of plasma-sprayed coating and the relationship between residual stress and temperature of post-spray heat treatment from a new perspective. Therefore, the purpose of this study is to evaluate the wear behavior of a plasma-sprayed $8\%Y_2O_3$-ZrO_2 coating on a casting iron and understand the correlation between wear performance and temperature of post-spray heat treatment. We identify their phase transformations due to post-spray heat treatment. Also, the effect of residual stress as post-spay heat treatment temperature will be discussed.

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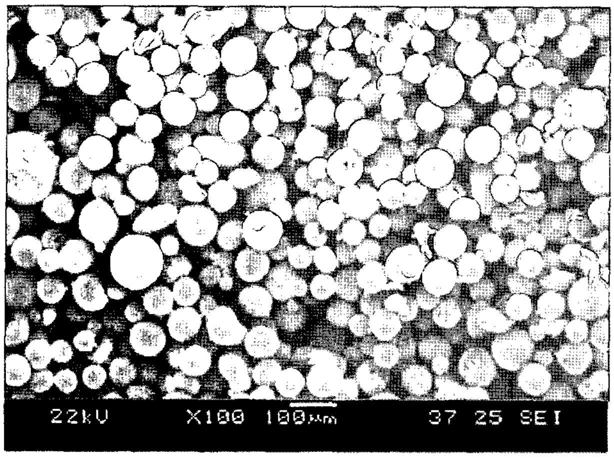
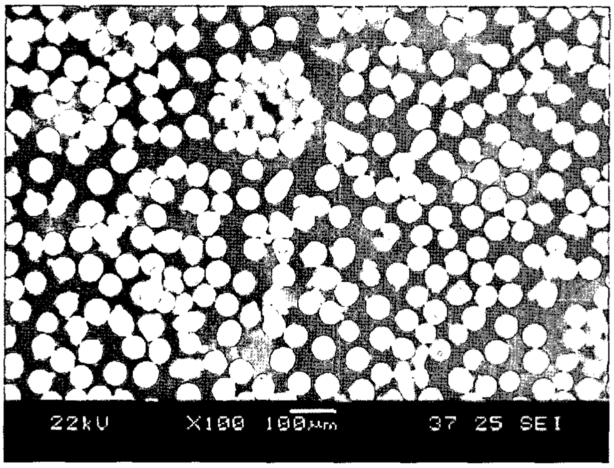


(a)



(b)

Fig. 1. SEM photograph of 8%Y_2O_3-ZrO_2 (a) and NiCrAlY (b) for coating power.

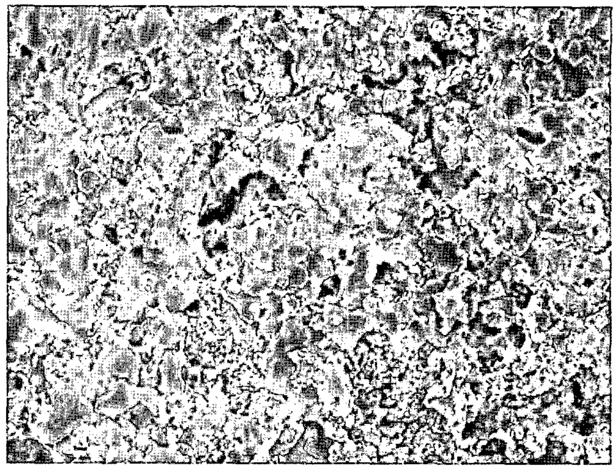


Fig. 2. SEM photograph of surface 8%Y_2O_3-ZrO_2 coating.

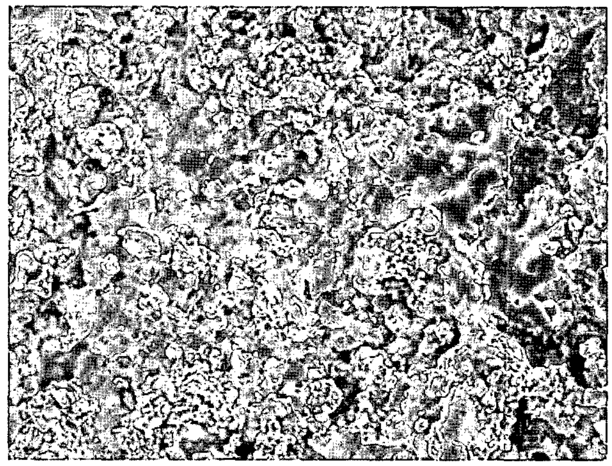


Fig. 3. SEM photograph of surface for post-spray heat treatment at 200°C.

2. Experimental Procedure

2.1. Specimen preparation

The casting iron (GC200) was provided by a commercial supplier. The casting iron was machined to make disk specimens with a 20 mm diameter and 5 mm thickness. The uniform thickness of all specimens was ensured by grinding less than 0.1 mm of tolerance from both sides of the disc surfaces. One side of the disc was then polished and finished to remove the grinding damage and any surface irregularities.

The materials used in the coating process were commercial powders, 8%Y_2O_3-ZrO_2 (Metco 204B-NS) and NiCrAlY. They consisted of small particles in spheres and had regular grain shapes, as shown in Fig. 1. Also, the grain sizes ranged between 55~100 μm. The top coating thickness is 250 μm and bond coating is 60 μm thickness. The roughness of the substrate was reduced to less than 20 μmR_{max} by sand blasting. The contact surfaces were prepared by polishing to 0.4 μmR_{max}.

The microstructures of the coatings are shown in Fig. 2. It is also observed the lamellar structure of the 8%Y_2O_3-ZrO_2 coating aggregated on the layer plane. In order to obtain specimens of post-spray heat treatment, they are kept at 200, 400, 600 and 800°C, during 1hour in furnace, and then furnace cooling. Fig. 3 shows a surface of post-spray heat treatment at 200°C. It is found that surface of coating is covered oxidation film and more aggregated the splats.

2.2. Wear test and analysis

A wear test was carried out between a disc-type coated and ball-type SiC specimen. The details of the wear test method and specimen configurations are shown in Fig. 4. The friction and wear tests were carried out at room temperature under dry conditions. Each specimen was cleaned in an ultrasonic bath with acetone for 10 min before and after testing. The wear volume was calculated from the surface profile by using a profilometer (Mitutoyo Surftest 500). The hardness of the coating layer was measured by a Micro-Vickers hardness tester (Shimadzu, HMV-200). The loads used in this experiment were 50, 70, and 90 N, Also, the sliding velocity of the wear test was kept a constant of 0.1 m/sec.

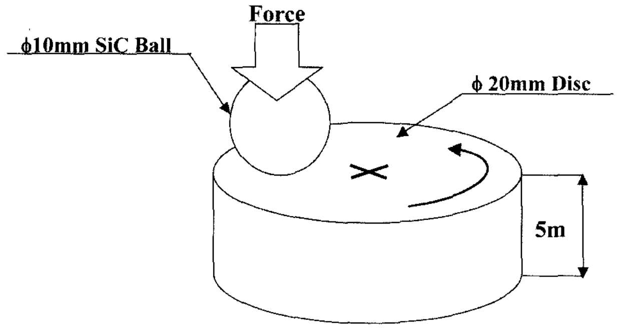


Fig. 4. Schematic illustration of ball-on-disk type wear test.

3. The Results

3.1. The Phase Transformation by post-spray heat treatment

Fig. 5 shows the X-ray diffraction pattern in between the range of 2θ= 25-150° as-spray and post-spray heat treatment at 600°C. It is observed the monoclinic crystal, tetragonal system and a few cubic systems in XRD patterns of coating, as shown in Fig. 5.

We can find enlarged X-ray diffraction pattern with the range of 2θ= 28-33 in Fig. 6. As temperatures of post-spray heat treatment, the peaks of 2θ= 28-35° were changed with an increased transformation ratio of the monoclinic structure(m). The change of peak (2θ= 30degree) indicate the transformation of the tetragonal structure state(t). The phase of coating at 200 and 400°C was transferred from tetragonal to monoclinic. As shown in Fig. 6, the phase of tetragonal structure is transferred from the monoclinic with an increase temperature of post-spray heat treatment, At 200 and 400°C, the phase transfer from t-phase to m-phase are shown as relatively increasing with as-spray coating. On the other hand, on post-spray heat treatment at 600, 800°C, we can observe the increasing t-phase in comparison to the as-spray coating.

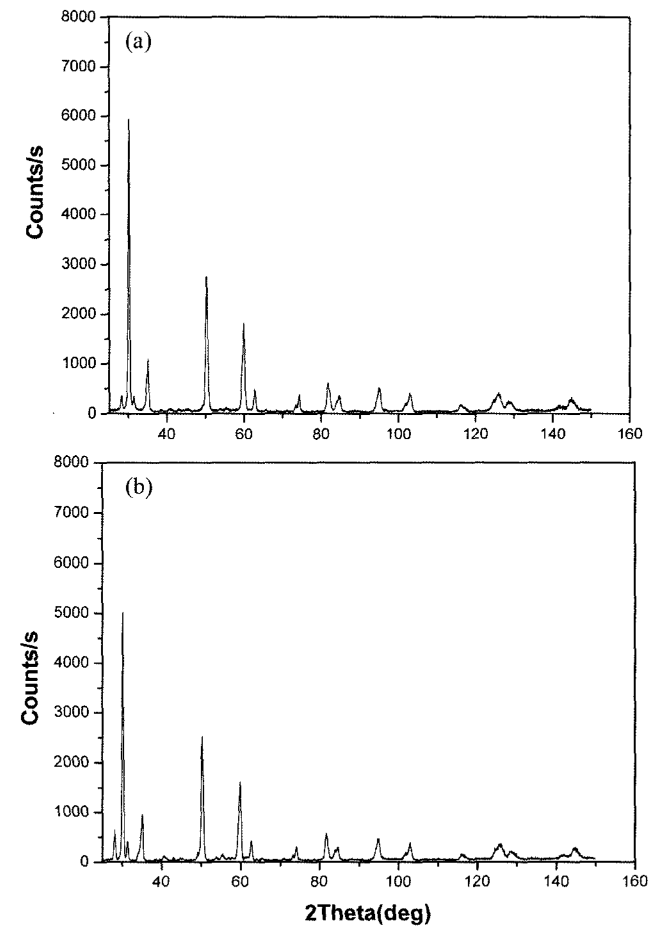


Fig. 5. XRD patterns 8%Y_2O_3-ZrO_2 coating for as-spray (a) and post-spray heat treatment at 600°C (b) in range 2θ= 25-150°.

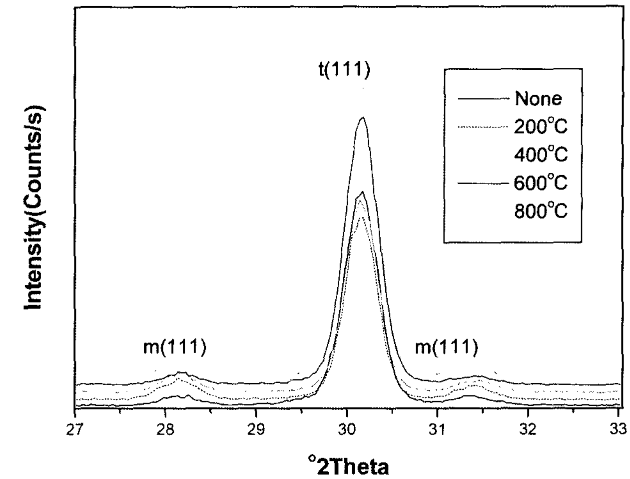


Fig. 6. X-ray pattern change depending on various temperature of post-spray heat treatment in 2θ= 27-33°.

3.2. X-ray diffraction analysis by post-spray heat treatment

In this work, for the X-ray diffraction angle a peak of 94.97° was selected because of the stronger intensity. Fig. 7 shows the XRD diffraction pattern to temperature of post-spray heat treatment in 2θ= 94.97°. It shows the change of the peak of the diffraction intensity's distribution transfer as incident angle (Ψ). At this point, this peak indicated the change of d-spacing on the *hkl* plane at 2θ. From this we can identify the existence of the residual stress, which is the tensile residual stress in coating. As the heat treatment temperature of post-spray is increasing, the tensile residual stress of the coating is decreasing.

3.3. Specific wear rate of coating for post-spray heat treatment

Fig. 8 shows the specific wear rate as a function of the temperature of the post-spray heat-treatment. It is observed that coating of post-spray heat treatment at 600 and 800°C have better wear resistance than that of as-spray, post-spray heat treatment at 200 and 400°C.

Fig. 9 shows the specific wear rate as a function of sliding distance under normal load of 50N at various temperatures of post-spray heat treatment. It is found that the specific wear rate for post-spray heat treatment at 200°C is higher, and post-spray heat treatment at 400°C is independent of the normal load. Especially, the specific wear rate for post-spray temperature at

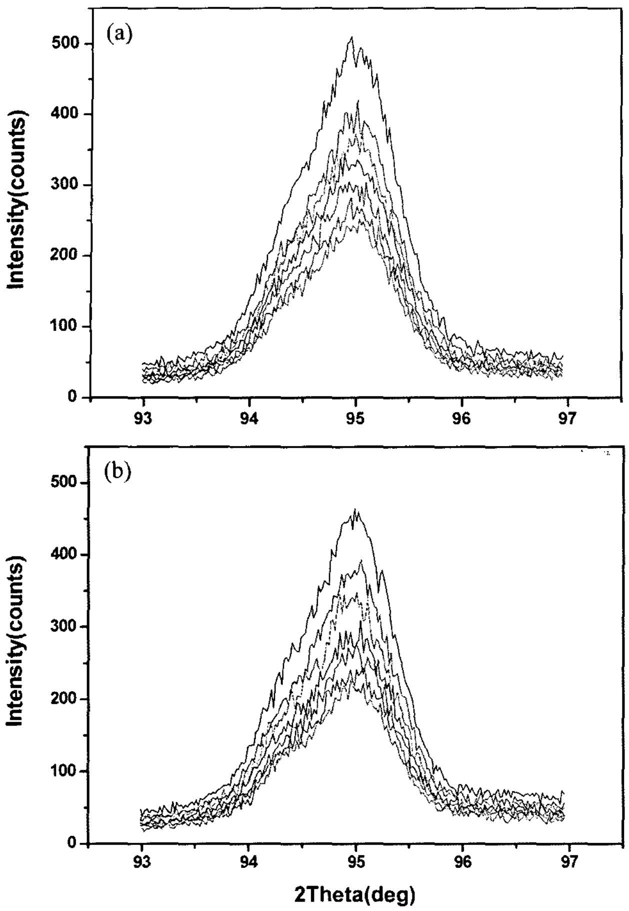


Fig. 7. XRD patterns 8%Y_2O_3-ZrO_2 coating for as-spray (a) and post-spray heat treatment at 600°C (b) in range 2θ= 93-97°.

600°C is indicated higher wear resistance among wear test. Therefore, it was identified that the wear behavior was dependent on the temperature of post-spray heat treatment. We will discuss this reason in chapter 4.

3.4. Observation of worn surface

To examine the wear mechanism of coating, we observed the worn surface using SEM. Fig. 10 shows SEM photograph of the worn surface under normal load 70 N, heat treatment temperature at 200°C. It is observed that abrasive wear is generated by the concentration stress on the defect of coating, such as the hole's pattern during the process of wear on Fig. 10(a). As shown in Fig. 10(b), the worn surfaces have severe pull-out of wear debris and tribo-film due to material transfer during the wear process.

The SEM photograph of the worn surface for heat treatment temperature at 400°C under normal load 70 N, as shown in Fig. 11. It shows the brittle fracture of the coating, which are the typical wear properties of zirconia coating. Also, it observe severe plastic deformation of the coating and surface crack owing to the normal load.

We can see the worn surface of coating have a homogeneous abrasive wear, as shown in Fig. 12. It finds wear mechanism for heat treatment temperature at 600°C of is plastic deformation in worn surface.

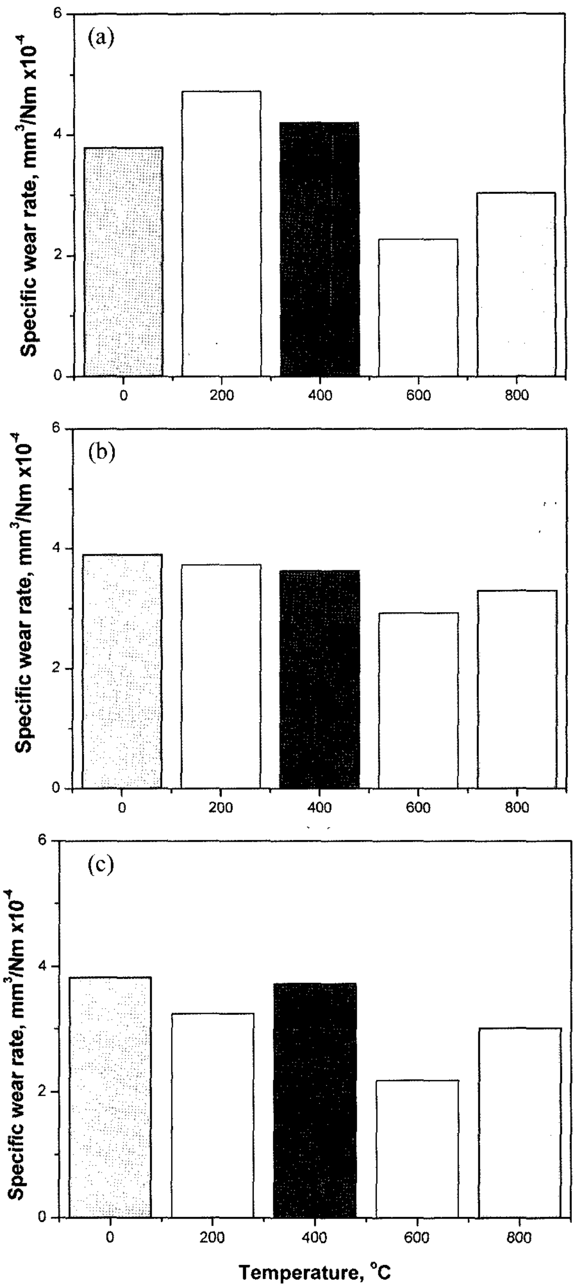


Fig. 8. Specific wear rate vs. temperature of post-spray heat treatment under normal load of 50 N (a), 70 N (b) and 90 N (c).

4. Discussion

The results showed the wear behavior of 8%Y_2O_3-ZrO_2 coating with post-spray heat treatment during sliding. It shows that temperatures of post-spray heat treatment have influence on the wear characteristics of coating (Fig. 9). It is convinced that the phase transformation of the coating is due to the temperature of post-spray heat treatment (Fig. 7). Also, We can find the result of X-ray diffraction pattern for temperatures of post-spray heat treatment (Fig. 6).

In 8%Y_2O_3-ZrO_2 coating, which had post-spray heat treatment at 600 and 800°C, the phase of tetragonal are more stabilized than that of 200 and 400°C (Fig. 6). These results are

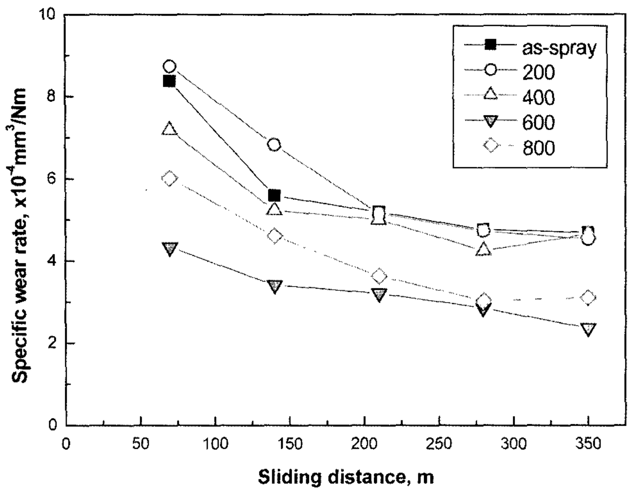
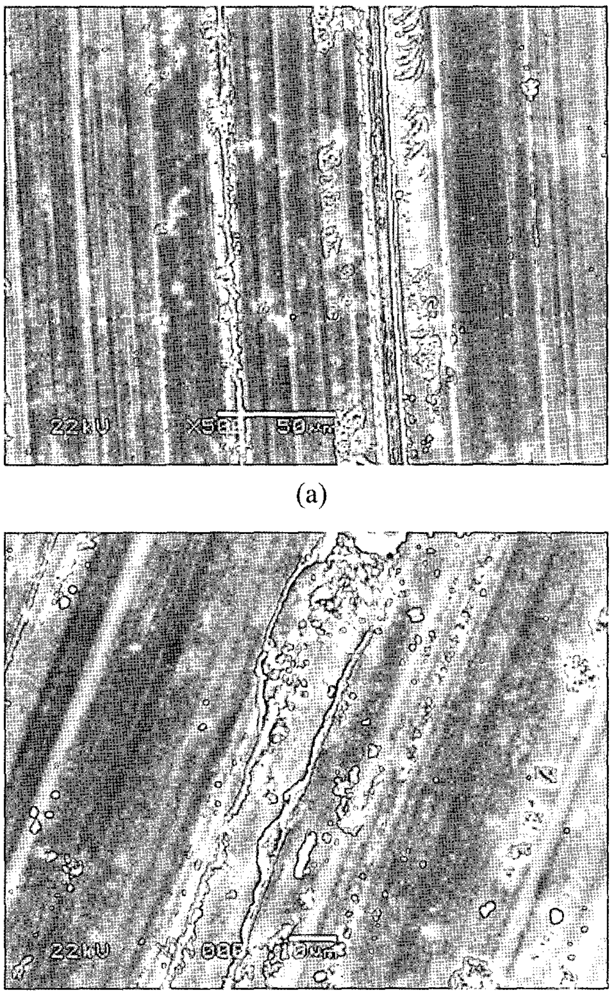


Fig. 9. Variation of specific wear rate vs. sliding distance under normal load of 50 N.



(a)

(b)

Fig. 10. SEM photograph of worn surface for post-spray heat treatment at 200°C.

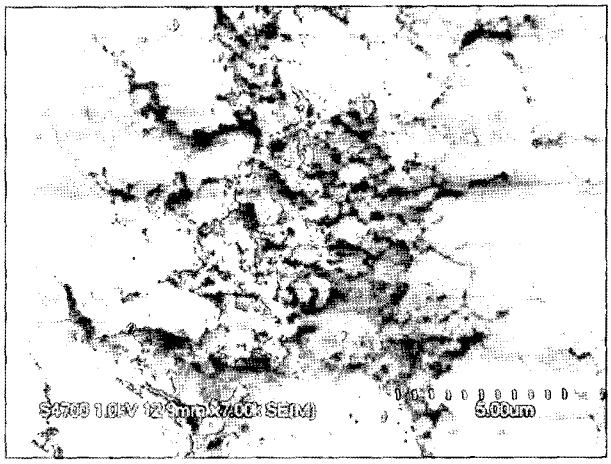


Fig. 11. SEM photograph of worn surface for post-spray heat treatment at 400°C.

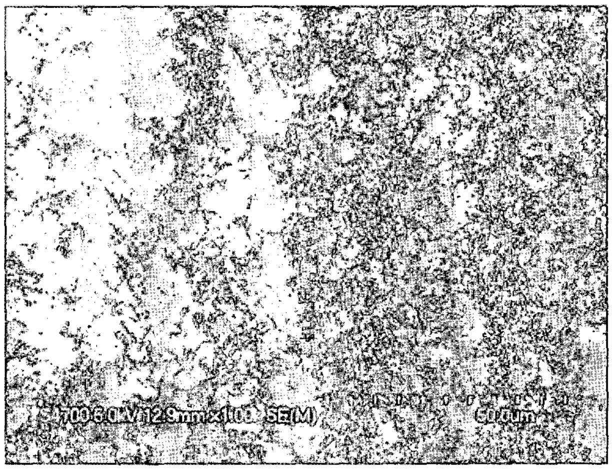


Fig. 12. SEM photograph of worn surface for post-spray heat treatment at 600°C.

contrary to those possible phase changes from the tetragonal system to monoclinic system or cubic system if the heat is treated at higher than 1400°C. However, the result of this work agrees with Sato's [13] report, which states that the phase transfers are also occurring at about 300~400°C under humidity condition.

We are concerned with the wear characteristics of 8%Y_2O_3-ZrO_2 coating as a function of the effect of post-spray heat treatment. Many papers on thermal spraying coating have reported to solve the problem of the mismatch of the TEC and thereby improve the cohesive strength between the coating and the substrate [5-11]. It has been identified that compatible bond coating has advantages in its mechanical and tribological characteristics [11]. Improved plasma-sprayed coatings require certain tribological characteristics including the wear resistance of the coatings. However, generally speaking, the trouble of plasma spray can be solved by the residual stress in

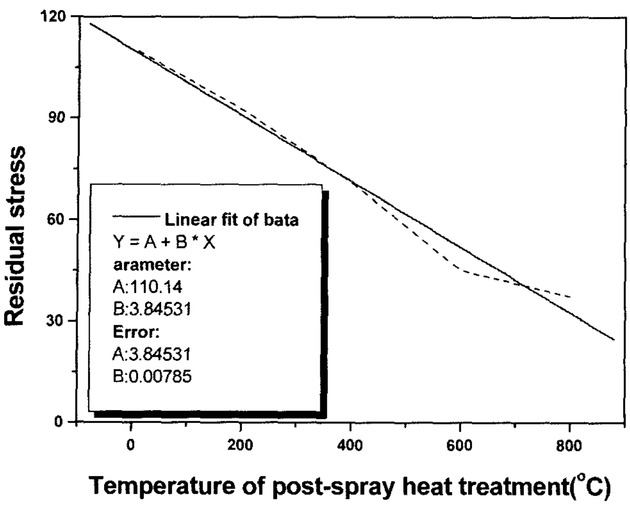


Fig. 13. Relationship between the residual stress of coating and the temperature of post-spray heat.

the coating system. Therefore, it will discuss the tribological wear performance as a magnitude of residual stress in detail.

Residual stress, a problem in thermal-spray coatings, influences the adhesive or cohesive strength of the coating, leading to coating failure, through spalling or cracking of the coating, or debonding it from the substrate [7-11]. The wear performace of the coating is thus correlated to the residual stress [6]. The value of tensile residual stress in coating is decreased as elevated temperature of post-spray heat treatment, as shown in Fig. 13. The result of XRD indicated decreasing residual stress of coating according to elevated temperature of post-spray heat treatment.

Fig. 13 shows the linear fit curve of residual stress as a function of the temperature of post-spray heat treatment. According to calculation from the XRD analysis, there is a tensile residual stress of 110.7 Mpa in as-sprayed coating. The residual stress in coating is decreased by 92.5 Mpa, 71.0 Mpa, 45.1 Mpa, and 37.4 Mpa as increasing temperature of post-spray heat treatment. It was found that the wear mechanism of coating, which has a high level of residual stress, is abrasive wear and micro-fractures (Fig. 10-12). The wear performance relate to the value of residual stress in coating. Therefore, it is important to control the residual stress of coating within an optimal range. Consequently, post-spray heat treatment plays an important role in decreasing residual stress. Residual stress in coating systems has a significant influence on the wear mechanism of coating.

4. Conclusions

To gain a better understanding wear behavior of a plasma-sprayed 8%Y_2O_3-ZrO_2 coating of the post-spray heat treatment, experimental tests were performed and an analysis of XRD and worn surface was conducted. As a result, the following conclusions can be drawn.

The specific wear rate of coating strongly influenced temperatures of post-spray heat treatment.

Phase transformation from the tetragonal to monoclinic structure was observed to influence the wear behavior of 8%Y_2O_3-ZrO_2 coating.

Post-spray heat treatment plays an important role in decreasing residual stress. Residual stress in coating system has a significant influence on the wear mechanism of coating.

Acknowledgment

This work was supported by Korea Research Foundation Grant (KRF-2004-041-D00079).

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