Friction and Wear Assessment of Yttria Stabilised Zirconia Thermal Barrier Coatings Produced by Plasma Spraying Method

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ABSTRACT:

Wear and friction behaviour of yttria stabilised zirconia coatings are very sensitive to the structure of the material and test parameters such as temperature, applied load, sliding speed, and environment. The present study describes the friction, and sliding wear behaviours of plasma sprayed yttria stabilized zirconia coating (ZrO_2-8wt.%Y_2O_3 (YSZ) deposited on a stainless steel substrate with NiAl bond coat. Tribological properties of the coating were assessed under lubrication condition at loads of 4N and 8N. The frictional behaviour of coating was assessed at a constant temperature of 50°C, while wear characteristics of the coating were investigated at 50°C and 100°C. The experimental results of this study showed a slight decrease in frictional coefficient with increasing load. However, the coating wear rate was slightly increased with increasing load and temperature. The coating wear mainly involved materials transferred from the counter body and pulling-out from the coating material.

Keywords: Thermal barrier coatings; plasma spraying; wear resistance; friction; yttria stabilised zirconia.

1. Introduction

Zirconia based ceramic coatings have great potential for tribological applications because of their unique set of properties such as high hardness, refractoriness, low density, strength and stiffness. Thermal spraying is a well-established coating technique in industries where large components are required for wear and corrosion resistance applications. Among the thermal spraying processes plasma spraying is used widely for spraying ceramic coatings. A high plasma temperature makes it possible to spray refractory materials such as oxides. Plasma spraying involves the injection of particles, usually in the range 20-90µm into a plasma jet with temperatures of up to 15000K which causes a high degree of particle melting, and velocities of up to 800m/s which leads to improved deposition densities and bond strength. The thickness of individual splats is typically in the range of 1-20µm. The porosity of the air plasma spraying (APS) coatings is usually in the range 1-7% and the thickness of the deposit varies between 300-1500µm[2]. Traditionally plasma spraying has been used for corrosion and wear protection, thermal insulation or repair applications.

Plasma sprayed yttria stabilised zirconia (YSA) have been used as a thermal barrier coatings in engines and gas turbines. Previous studies of the friction and wear behaviours of yttria stabilised zirconia coatings have been reported[3,4,5,6]. The results of these studies suggested that these coatings are sensitive to structure of the material and test parameters (temperature, applied load, sliding speed etc.).

The goal of this work is to assess the friction and wear behaviour of yttria stabilized zirconia coating under lubricating condition at different loads and temperatures.

2. Experimental Procedures

2.1. *Substrate preparation*

Stainless steel substrate with nominal chemical composition (wt%) 0.08% Carbon, 2% Manganese, 18.45% Chromium, 8.30% Nickel, 1.09% Silicon, 0.045% Phosphorous and 0.03% Sulphur was used to deposit the coating.

The stainless steel substrates were shot blasted using steel blasting media (# 29) prior to coating application. A surface roughness of 9µm was achieved. The surface roughness of grit blasted samples was measured using a roughness profiler (Surfcorder 1700a). Stainless steel substrates of circular discs shaped were used for coating's friction and wear assessment tests.

2.2. *Coating deposition*

Sulzar Metco Air Plasma Spray (APS) coating system was used to deposit coating on a stainless steel substrate. Before coating the powders were heated at 105ºC in an oven for about 30 minutes to remove the moisture. A double layer coating that consisted of a Ni-5%Al bond coat and YSZ (ZrO_2-8wt.%Y_2O_3) yttria stabilised zirconia top coat was produced for friction and wear tests. APS (Air Plasma Spraying) parameters for coatings produced are shown in table 1.

Table 1. Air plasma spraying parameters.

Parameters	Values
Current (A)	500
Ar flow rate(schf)	90
Ar pressure(psi)	60
H_2 pressure (psi)	50
H_2 flow rate(schf)	15
Powder feed rate (lb/hr)	6
Spray distance (inch) and angle (º)	6 and 90

Surfcorder 1700a was used to evaluate the surface roughness of the as-sprayed coating using diamond stylus. A length of 2.50mm was scanned for this purpose. The radius of diamond tip was 2µm and the scanning speed was kept at 0.5mm/sec.

Coating thickness was measured using an optical microscope. Coating's cross-sectional samples were studied using SEM (Hitachi S3700N) and Leica Image Analyser. The micro-hardness of the coating surface was measured (ASTM E384 standard) using Vickers's hardness tester at 500g.

2.3. *Friction and wear testing:*

CSM Pin on Disc Tribometer was used to evaluate the friction and wear properties of the coating. Circular tracks of 13mm radius were produced using 100Cr6 steel ball as a counter body at normal loads of 4N and 8N. At each load, three tests were performed at a temperature of 50°C and 100°C under lubricating condition (using 50µl machine oil). Each test was performed for 3000 laps at a speed of 0.5m/s. The frictional movements were continuously recorded by a computer and the samples were cleaned by ethanol after each test, the coating's wear was assessed from the depth of the wear track by using a profiler/surface texture measuring perthometer (Surfcoder 1700a) with a diamond stylus. A length of 2.50mm was scanned for this purpose. The radius of the diamond tip was 2µm and scanning speed was kept 0.5mm/s. The wear tracks produced by Tribometer, were analysed using an Image analyser advanced microscope, a zoom microscope and a scanning electron microscope. The wear pattern developed at counter body (steel balls) were also analysed using an Image Analyser System.

3. Results and Discussion

3.1. *Coating characterisation*

Characterization of the coating has been reported previously[7].

Figure 1 shows the optical microscopic image of the coating's cross-section deposited by APS(air plasma sparing) method with Ni-5%Al bond coat and yttria stabilised zirconia (ZrO_2-8%wt.Y_2O_3) top coat on a grit blasted stainless substrate. The dark area with visible voids is yttria stabilised zirconia thermal barrier coating (topcoat), while the light area is Ni-5%Al coating (undercoat). The reason for applying a Ni-5%Al undercoat is to enable good adhesion of the ceramic coating with the substrate and to protect the substrate from high temperature oxidation. Optical micrograph (fig.1) of as-sprayed coating confirms a good level of bond coat adhesion with the substrate. A large amount of porosity can be seen inside the TBC topcoat. Porosity seems to be more or less often scattered throughout the topcoat.

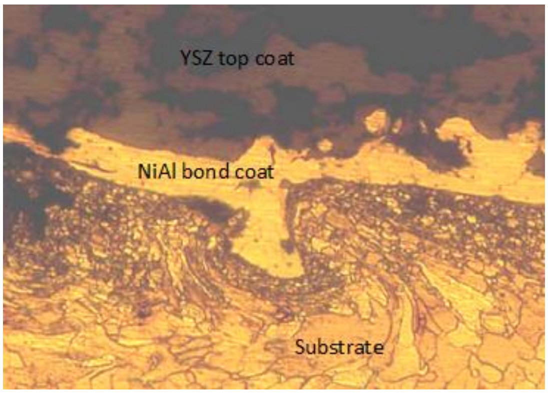

Fig. 1 Optical micrograph of coating cross-section (200X).

The average thickness of TBC (thermal barrier coating) was about 600µm, whereas the average thickness of NiAl bond coat was about 20µm. The SEM surface topography of TBC with marked intra-splat micro cracks and debris particles is shown in Figure 2.

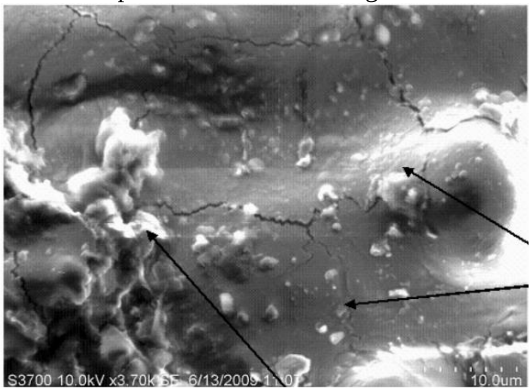

Fig. 2 SEM micrograph of as-sprayed coating.

It also confirms that particles were in a fully molten state when they transferred to the substrate, as no powder particle features were observed on the coating surface. The splashes of fine debris particles are due to the impact of the molten particles. The intra-splat micro cracks most likely resulted from the residual shrinkage or thermal stresses, due to the difference of thermal expansion coefficient of various phases present in the coating. The presence of intra-splat micro cracks and fine debris particles is also reported by Salman et.al in their study on plasma sprayed and HVOF coatings[8,9]. The average micro hardness of the YSZ coating was HV425.

3.2. *Friction and wear assessment*

Figure 3 shows friction coefficient values of TBC under lubrication condition at a load of 4N and temperature of 50°C. The values of friction coefficient using 100Cr6 steel ball varies between 0.117 - 0.129 for a sliding distance of about 59m. The average value of friction coefficient of coated sample is 0.126 and no coating failure was observed until a sliding distance of about 59m was reached. The value of friction coefficient (COF) initially increases for a short period from 0.117 to 0.124 due to high surface roughness of the coating. After a run-in period, the surface become smoother and lubricating oil film also becomes stable and this results in slight fluctuations in COF. Thuong et al.[3] also reported the friction coefficient of yttria stabilised zirconia coating (YZ) at room temperature under lubrication condition in the range of 0.10-0.15.

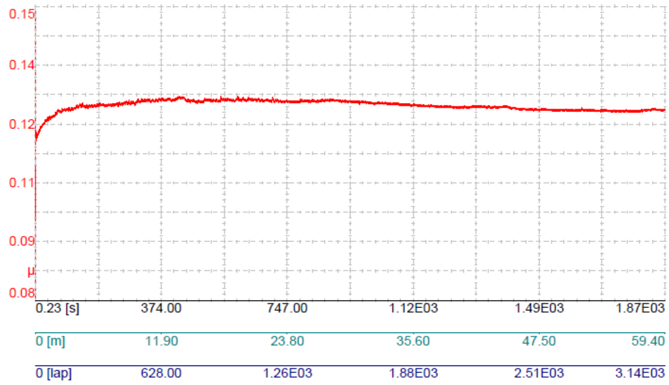

Fig. 3 Friction co-efficient with varying time, sliding distance and no. of laps at 50°C and load of 4N.

Figure 4 shows the friction coefficient of coating sample at a load of 8N and temperature of 50°C under lubrication condition. The friction coefficient of the coating at of 8N load is 0.088-0.108 and no coating failure was observed until a sliding distance of about 57m. With an increasing load from 4N to 8N the friction coefficient of the coating deceased slightly. A slight decrease in friction coefficient with increasing load is also reported by Thong et al.[3] in their study on sliding behaviour of plasma sprayed zirconia ceramic coatings.

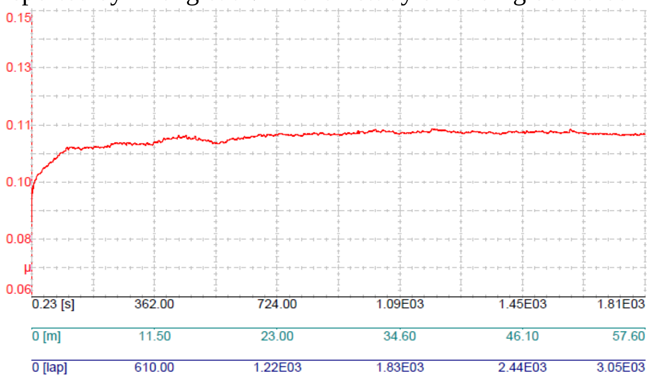

Fig. 4 Friction co-efficient with varying time, sliding distance and no. of laps at 50°C and 8N load.

Figure 5 shows the wear tracks morphology of the coated samples at different temperatures and loads, under lubrication condition and it suggests that there is no appreciable coating failure/wear.

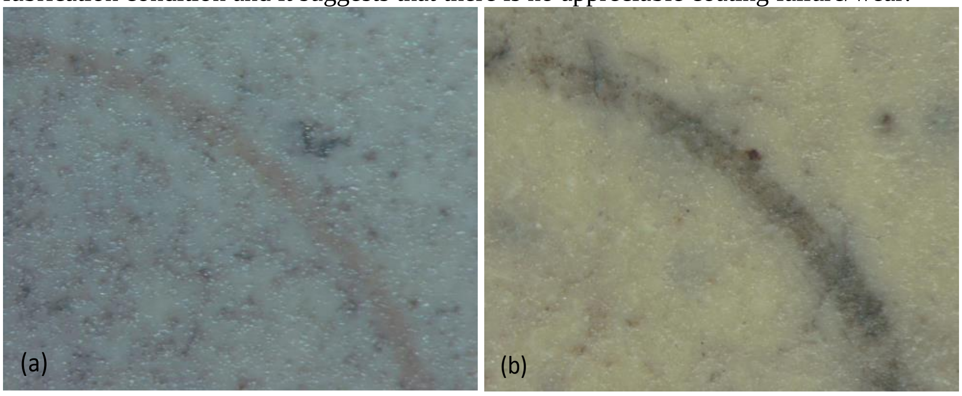

Fig. 5 Wear track morphology of coated samples (a) at 50°C and 4N load; (b) at 100°C and 8N load.

The ploughing pattern formed at the counter steel ball in figure 6 clearly shows its excessive wear/damage. It also suggests the possibility of material transfer from counter steel ball material on to the wear tracks of the coated samples.

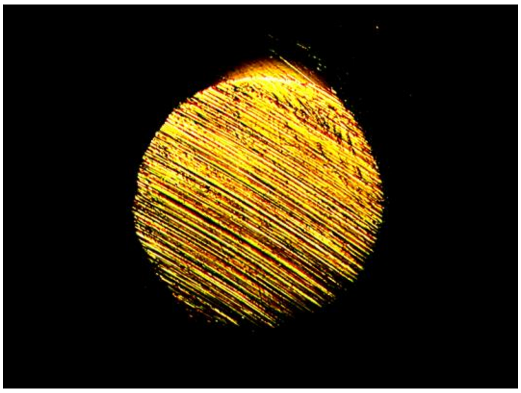

Fig. 6 Micrograph of counter body (steel ball) at 50°C and load of 4N.

SEM image and EDS analysis of the wear track of the coated sample further confirmed the presence of metallic materials (Fe, Cr) and coating material pull out on the wear track. The transfer of metallic material during sliding test by using a metallic counter face is also reported by other studies[5,10].

Surface profiles of the wear track cross-sections (figure 7) of coated sample under lubrication condition at a load of 8N and temperature of 50°C and 100°C after 3000 laps further confirms the substantially lower amount of wear in coated sample. The average values of Ra of the wear tracks at temperature of 50°C and 100°C after 3000 laps under lubrication were Ra 0.7430 and 0.7894 respectively. Coating shows a slight increase in wear rate with increasing load and temperature.

Fig. 7 Surface profile of wear tracks at 8N load and temperature of (a) 50°C and (b) 100°C.

4. Conclusions

Yttria stabilised zirconia coating showed low friction coefficient under applied testing conditions. The friction coefficients of the coating decreased slightly with increasing load.

No coating failure was observed for all tested sliding distances.

Coating showed good wear resistance for applied loads and temperatures.

With increasing load and temperature, coating showed slightly increased wear rate.

Coating wear process mainly involved materials transfer from the counter body and pull out under all testing conditions.

Acknowledgments

The authors would like to thanks the Pakistan Institute of Technology for Minerals and Advanced Engineering Materials (PITMAEM), PCSIR Labs Research Complex, Lahore, Pakistan for their valuable assistant to carry out this work at their place.

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