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Abrasive Wear Behaviour of Plasma Sprayed Al_2O_3 / TiO_2 Coatings

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Abstract*: *Premature failure due to abrasive wear is observed in high powered engine in recent decades, despite of stringent maintenance procedures comparative to older engine. Plasma spray coatings are recurrently used to circumvent the abrasive wear in aerospace, defense and certain automotive applications like piston pump, cylinder bore etc. This work is to identify the most influencing wear parameters namely sliding speed (S_S), applied load (A_L) and sliding distance (S_D) of the composite coated steel. Initially the surface morphology and elemental analysis was carried out to analyze the surface roughness and homogeneous distribution of the composites. Furthermore wear analyzes results indicates that the composite coating has high wear resistance and specific wear rates are ranging from 0.52346 × 10^{-5} m^3 / N-m to 3.25711× 10^{-5} m^3 / N-m.

Keywords* : *Plasma spray coating, specific wear rate, cylinder bore, Taguchi.

I. INTRODUCTION

In industrial application like automobile, aircraft, agricultural and marine vehicles the usage of piston pumps are inevitable [1]. The abrasive wear is major problem in the cylinder bore due to continuous sliding of surfaces, which leads to the premature failure of the engine [2]. In addition wear rates are associated with fluctuating critical processing temperature, high pressure and relative velocity [3]. Abrasive wear accounts for almost 44% premature engine failure as well as failure of cylinder bore [4]. This implies high adherent and smooth surface coating is to improve the engine life against wear rate. Plasma spray coating is widely used to prevent degradation of various parts like turbine blade, cylinder bore under severe conditions. Plasma spray coating method offers various thickness ranges 10 µm to 1 mm with high deposition rate and good adherence to the substrate. [5]. Furthermore this method extensively ropes the ceramic material coating to improve the life span of numerous components in industrial equipment's [6]. Plasma sprayed Aluminium Oxide (Al_2O_3) and Titanium Oxide (TiO_2) coatings are recurrently used for wear resistance in various applications [7], [8].

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Al_2O_3 coating has predominated wear resistant property but it is used in limited application due to poor brittle nature [9], [10]. In addition of TiO_2 with Al_2O_3 leads the wear resistance due to very strong adhesion and low porosity [11]. The accumulation of 3-40 wt% TiO_2 with alumina has become very common in plasma spraying method to improve the mechanical properties. In this study, specified combination of Al_2O_3 + 13% TiO_2 was deliberated from established literature [12]. The work is focus on identifying the most influencing wear parameters (by pin on disk method) of the plasma sprayed composite (Al_2O_3 + 13% TiO_2) coating.

II. MATERIALS AND METHODS

Mild steel rod (ASTM A36 - Ø12 mm) used as substrates, which is roughened by blasting quartz sands of 16-20 mesh. All the samples were cleaned carefully with acetone then surface were grit blasted using aluminium oxide blasting media. Herein, Ni + 5%wt Al powder and Al_2O_3 + 13%wt TiO_2 were used as top and bond coating respectively [13]. The Ni + 5%wt Al and Al_2O_3 + 13% TiO_2 composites were prepared separately by ball mill (SPEX 8000D, UKRAINE) for 5 hours with constant speed of 300 rpm and 12 ZrO_2 ball in the milling jar. The bond and top coating has done on mild steel substarte by Praxair plasma spray system with SG-100 gun. Prior to applying composites on the substrate, three trial were executed to optimize the powder flow rate and other conditions to obtain desired coating thickness (120 ± 25 µm). The surface morphology and quantitative elemental analyses of coated samples (Figure 1) were obtained using scanning electron microscope (ZEISS SUPRA 55) and EDAX (OXFORD measurements) as per ASTM D 4541 [14]-[17]. In order to determine surface roughness of the coating [18], the areas of 10 × 10 µm were scanned with 512 × 512 data points using AFM NTEGRA PRIMA – NTMDT, Ireland. After confirming the presence of composite on the substrate, dry sliding wear analysis has been carried out by pin on disc tester (DUCOM TR-20LE-PHM-400) as per ASTM G99 [19]. Three trails were carried out to ensure its repeatability for the samples. The test was done under the room temperature 25 ^{O}C, ambient humidity, varying process parameter like sliding velocity (1.308 m/s 1.962 m/s, 2.610 m/s), load (30 N, 40 N, 50 N) and sliding distance (1200 m, 1800 m, 2400 m). The volume loss has been calculated from mass loss value which obtains from before and after the test by weighing machine. Finally the specific wear rate has been calculated by Equation 1. An orthogonal array and S/N ratio were employed to identify the wear influencing parameter. Considering all 3 parameters and 3 levels, the L_9 orthogonal array has chosen for this study.

To identifying process parameter for this case, “smaller is the better” quality characteristic was chosen and calculated S/N ratio from Equation 2.

$$\text{Specific wear rate (Wsp)} = \frac{\text{Volume loss } (m^3)}{\text{Load (N)} \times \text{sliding distance(m)}} \quad (1)$$

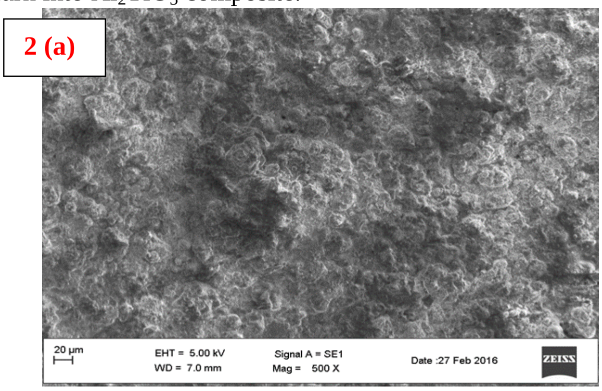
$$\frac{S}{N} \text{ ratio} = -10 \log_{10} y^2 \quad (2)$$

Figure 1. Plasma sparyed composite (Al_2O_3 + 13% TiO_2) samples

III. RESULTS AND DISCUSSION

A. Morphological Studies

The surface homogeneity of Al_2O_3, +13% TiO_2 composite is shown in Figure 2. Owing to good agglomeration of the composite coating (Figure 2a), the surface roughness was less and it can be reduces the wear rate. Figure 2b shows the equiaxed polygonal shape of composite embedded with few partially melted particles, which is due to the few TiO_2 particles were partially melted under the plasma spraying condition. However there is no porosity in the coating surface, which means Al_2O_3 +13% TiO_2 composites being uniformly distributed in the entire surface. Figure 3 shows that the quantitative analysis of Al_2O_3 +13% TiO_2 composite coatings, which reveals alumina and titanium dioxide were uniformly blended and distributed on the whole surface and turn into Al_2TiO_5 composite.



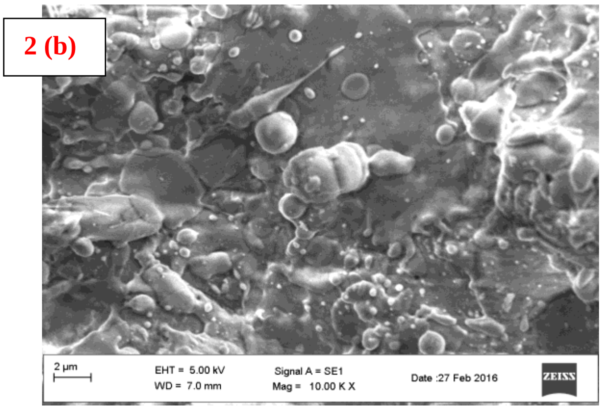


Figure 2.(a) Surface morphology of Al2O3, +13% TiO2 composite; (b) Melted region of the Al2TiO5 composite

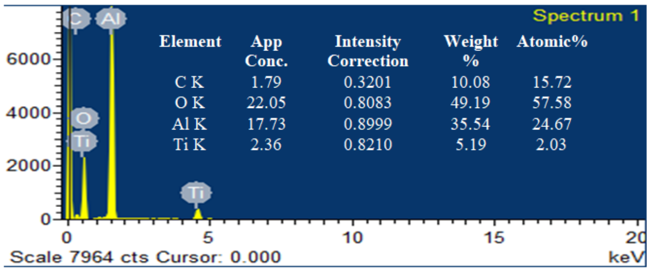
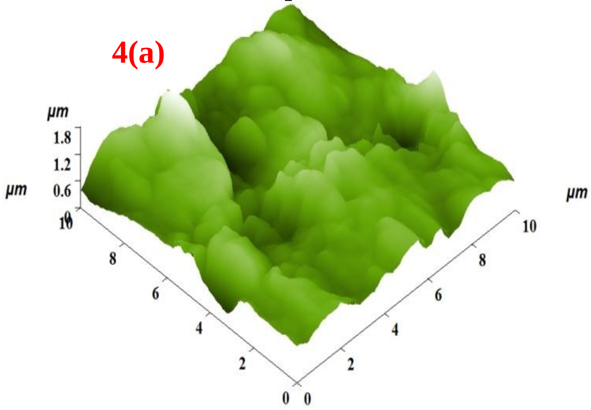


Figure 3. Quantitative analysis of Al_2O_3 +13% TiO_2 composite



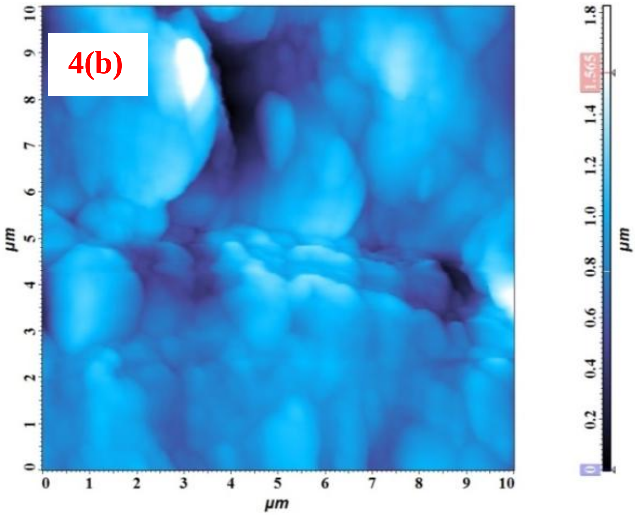


Figure 4. Al_2O_3 +13% TiO_2 composite (a) Three Dimensional topography (b) Surface Structure by AFM

The atomic force microscope image shows (Figure. 4) the 3-dimensional topography of the Al_2O_3 + 13% TiO_2 composite coated surfaces. It describes the Peak-to-peak (Sy) is 1824.61 nm, Ten Point height (Sz) is 912.966 nm, Surface Skewness (Ssk) of -0.128403, Coefficient of Kurtosis (Ska) of 1.47615, Entropy is 12.9892, Redundance is -0.199084 and average surface roughness is 167.63. From these results it has been concluded that the degree of discontinuity is very less which means composite has less porosity, good surface finish and perfectly clustered.

B. Wear Analysis

The dry sliding wear test was conducted by varying process parameter and calculated mass loss with the help of weighing machine.

From mass loss, volume loss has been calculated and found the specific wear rate (W_{sp}) by equation 1 and shown in Fig. 5. It has clear that specific wear rate is increased when the load is increased which means the specific wear rate is directly proportional to the normal applied load (as per Archard's law). Likewise, when sliding distance increase wear also increased due to temperature rise and causes the delamination of coating surface. However specific wear rate is decreased when sliding a velocity increase which is due to high boding strength of the coating interface. From specific wear rate values S/N ratio and mean values was calculated using Equation 2 and mentioned in table 1.

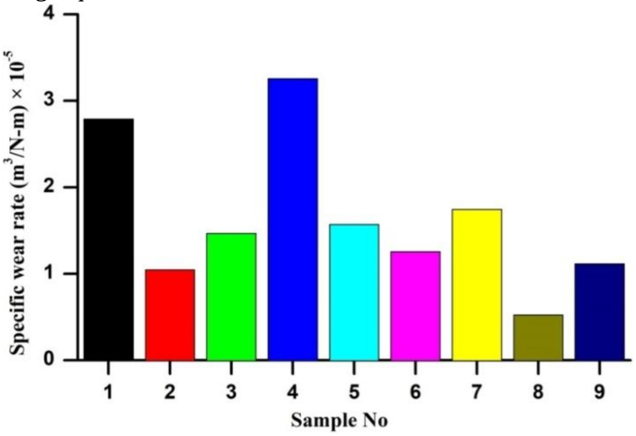


Figure 5 Specific wear rate of samples

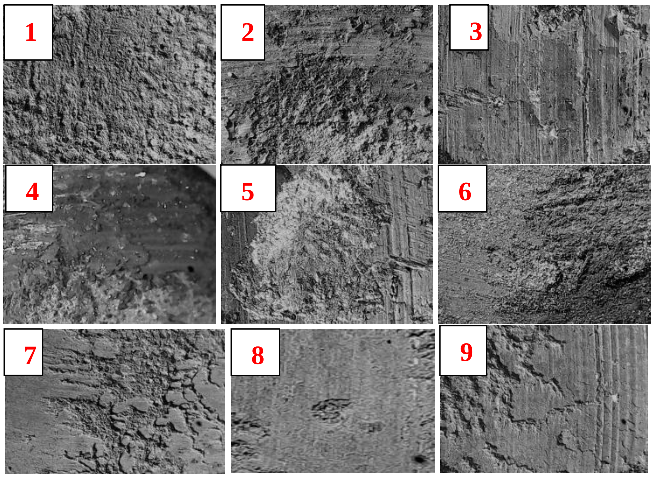


Figure 6. Worn tracks of the composite with effect of the various wear parameters

Table 1 Specific wear rate, SN ratio and mean values based on varying parameter

Sample No.	S_S (m/s)	A_L (N)	S_D (m)	Specific wear rate (m^3/N-m) $\times10^{-5}$	S/N ratio	Mean
1	1.308	30	1200	2.79181	-8.9177	2.79181
2	1.308	40	1800	1.04693	-0.3983	1.04693
3	1.308	50	2400	1.4657	-3.3209	1.4657
4	1.962	30	1800	3.25711	-10.256	3.25711
5	1.962	40	2400	1.57039	-3.9202	1.57039
6	1.962	50	1200	1.25631	-1.982	1.25631
7	2.61	30	2400	1.74488	-4.8353	1.74488
8	2.61	40	1200	0.52346	5.6223	0.52346
9	2.61	50	1800	1.11672	-0.9589	1.11672

The effect of the various wear parameter of the Al_2O_3 +13% TiO_2 composite on steel are shown in Fig. 6 (1-9). The worn tracks of fourth sample (Fig. 6.4) were much rougher than other samples. On the other hand eighth sample has very less worn tracks which mean it has high wear resistance than other samples. From table 2 it was clearly understand that the most influencing parameter of specific wear rate is A_L followed by S_S and S_D respectively. From figure 7 it can be noted that the best combination for obtaining least specific wear rate is 2.610 m/s of sliding speed (Level 3), 40 N load (Level 2), and sliding distance of 1200m (Level 1). The lowest specific wear rate of eighth sample is 0.52346×10^{-5} m^3/N-m which is under tried combination.

Table 2 Response table for SN Ratios

Level	S_S (m/s)	A_L (N)	S_D (m)
1	-4.21231	-8.00322	-1.75913
2	-5.38625	0.43459	-3.87129
3	-0.05732	-2.08725	-4.02545
Delta	5.32894	8.43781	2.26632
Rank	2	1	3

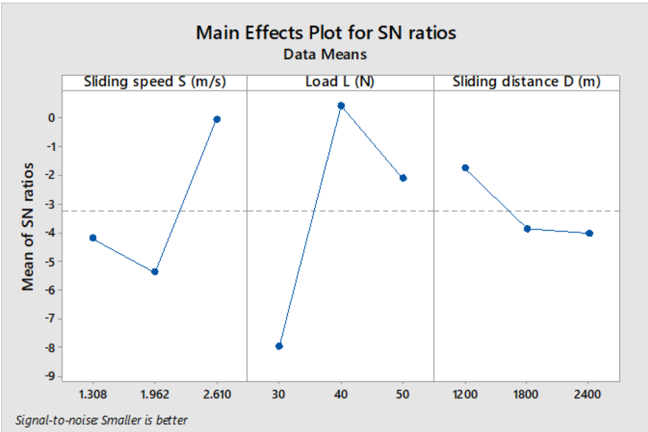


Figure 7. Main effect plot for SN ratios of Al_2O_3 +13% TiO_2 composite

IV. CONCLUSION

The purpose of this work is to identify the influence of wear parameters like S_S, A_L and S_D of the (Al_2O_3 + 13 % TiO_2 composite) coated steel. Initially quantitative analysis and surface morphology of composite coating has been analysed EDAX and SEM analysis, which has confirmed that the composite coating material presence and uniform deposition on the substrate. Also surface roughness of the composite is very less which decrease the specific wear rate. The design of experiment approach has been engaged and acquired data in controlled way using Taguchi method. From the results it has noted that the less specific wear rate is 8th combination (S_S - 2.610 m/s, A_L - 40 N and S_D - 1200m). Taguchi analysis revealed that the most influencing parameter is applied load followed by sliding speed and sliding distance. As sum up the Al_2O_3 + 13 % TiO_2 composite coating has high wear resistance due to adherence to the substrate. Therefore it can be used to reduce the wear loss due to abrasion which will increase the performance of the cylinder bore as well as engine life.

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