Experimental Investigation on dry sliding wear behaviour of plasma sprayed TiO_2 -Inconel 718 coatings on Al6061 by using Taguchi technique

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Abstract

This paper deals with the study of dry sliding wear behaivour of plasma spray coatings on Al6061 composites. The TiO_2 and Inconel coating ranging from 30% and 40% is coated with Al6061 alloy. Pin-on-disc wear testing apparatus is used for studying the wear behaviour of un-coated and coated on Al 6061 composites. The effect of wear parameters considered for this study was applied load and sliding speed. Taguchi method is employed to optimize the process parameters. L16 orthogonal array is used for conducting the wear experiments. The results showed that the addition of wear coated specimen (30% Inconel) was very minimal and lesser volumetric wear rate compared to uncoated Al6061. With increase in load the volumetric wear rate increases, while with increase in sliding speed the volumetric wear rate is decreased. The applied load is considered as the most significant parameter.

Keywords: Keywords: Al6061, Plasma Spray, TiO_2-Inconel718, Wear.

I. INTRODUCTION

Metals such as aluminium and its alloys are widely used nowadays suitable to their low weight and energy saving. Because of its low ductility and tribological properties, aluminium tends to show low wear resistance. Plentiful researchers are studying to improve and vary the usage areas of aluminium. However, aluminium has to show better mechanical strength and resistance to high temperatures to be used in applications such as moving machine parts. Coating aluminium surface with hard ceramic is a way to increase these properties. Ceramic materials have high hardness and high resistance to thermal and corrosive conditions. Alumina, titania, chromia and silica have been extensively used as surface coating materials to get better resistance of Al to wear, erosion, cavitations, fretting and corrosion. Literature survey shows plenty of work has been conducted on wear behavior of dissimilar coatings on heterogeneity of substrates. Azzi M et al [1] in his study on wear behaviour of CrSiN coated 301 stainless steel under wet and dry conditions confirmed that the corrosion reactions at the electrode/electrolyte interface were the reasons for the decline the tribological properties, sliding wear resistance improves when coating with CrSiN. Cetinel H et al. [2] in their study on tribological properties of surface coated layers on stainless steel substrates for high ambient temperature applications have confirmed that the hardness values initially increase up to 275 mm and wear resistance increases with depth. In their study on tribological properties of plasma sprayed nano structured Zr coatings when interacting with stainless steel under distilled water environment, Huang Chen et al. [3] have reported that nano structured zirconia coatings against stainless steel possessed better tribological properties when compared with traditional zirconia coating. In Woong Lyo et al. [4] in their study on microstructure and wear properties of plasma-sprayed chromium oxide–molybdenum oxide composite coatings have shows that composite coatings of Cr_2O3–MoO_3 have lower friction coefficients for MoO_3-added coatings. Kai Yang et al [5] in their study on sliding wear performance of plasma sprayed Al_2O_3-Cr_2O_3 composite coatings against graphite under severe conditions inferred that 10wt%Al_2O_3-90wt%Cr_2O_3 (AC90) composite coating exhibited wear resistance which was attributed to its higher thermal conductivity. Hence, from the groundwork, we come to know that less work has been reported on TiO_2 – Inconel718 composite coatings, even though this system is very attractive and efficient to combat both friction & wear. So, the ongoing work focuses on tribological behavior of plasma sprayed TiO_2 – Inconel718 composite coatings on Al6061 substrates.

II. EXPERIMENTAL DETAILS

A. Materials:

i. Coating material: Inconel-718:

Inconel-718 is chosen as the coating material. It is nickel based super alloy having very good wear and corrosion resistance joined with high strength at savior temperature. Inconel718 possess excellent corrosion and creep resistance. This alloy finds variety of applications like gas turbines, jet engines, steam generators, fission and fusion reactor structures. Table 1 gives the chemical composition of Inconel-718 used in the present work. The size of the particles of Inconel-718 alloy powder used ranged between 20 to 50 µm.

Table 1: Chemical composition of Inconel -718

Element	Weight %
Carbon	0.08
Manganese	0.35
Silicon	0.35
Phosphorus	0.015
Sulfur	0.015
Nickel + Cobalt	55.0
Chromium	21.0
Cobalt	1.00
Aluminum	0.80
Molybdenum	3.30
Titanium	1.15
Boron	0.006
Copper	0.15
Cb + Ta	5.50
Iron	Balance

ii. Substrate material: Al6061 alloy:

Al6061 is selected as substrate material. Table 2 gives the chemical composition of Al6061 substrate used in the present work. Al 6061 which finds wide applications in automobile and aerospace industries by virtue of its light weight is used as substrate material. The wear specimen (pin) of diameter 10 mm and height 20 mm.

Table 2: Chemical composition of Al6061

Element	Weight %
Al	97.9
Si	0.60
Cu	0.28
Mg	1.0
Cr	0.20

B. Coating Procedure:

TiO_2-30%Inconel718, TiO_2-40%Inconel718, alloy powder was plasma sprayed on Al6061 substrate. Alumina particles of 20 mesh size were used for grit blasting the substrate before coating. Hydrogen and argon gases were used as inert gases during the coating process with constant standoff distance of 5”. Table 3 gives the plasma spray parameters adopted in the present work to develop coatings of thicknesses 100 µm.

Table 3: Plasma spray parameters

Voltage	40 volts
Current	800 amps
Primary Inert gas – Argon gas	40 LPM
Secondary Inert– hydrogen	0.4 LPM
Carrier gas – Argon gas	2 LPM
Power	32 Kw
INCONEL718 powder	100 gm/min
Powder feed rate	33 grams / min

C. Wear test:

According to ASTM G99 standard, the abrasive wear test was carried out as per on coated specimens. Table 4 shows the test parameters considered in carrying out abrasive wear test. The experimental setup for abrasive wear testing is as shown in Fig. 1. Wear tests have been conducted on these specimens under different operational conditions like normal loads are 5,10,15 & 20 N and sliding speeds are 3.33, 5, 6.66 & 8.33 m/s, on pin-on-disc machine manufactured by DUCOM at Bengalure in India, a disc of EN-32, HRC 62-65 at a room temperature of 32ºC . The abrasive disk was fixed to the spindle of the machine maintaining perpendicularity to the axis of rotation. Before the wear test, every pin specimen is polished by different grit sizes of abrasive papers with 320, 400, 600 and 1200, resulting in smooth surface roughness that, wear surface complete contact with the surface of the abrasive paper. Two end polished of the pin is used for wear test at normal loads and sliding speeds after the test cleaning with acetone. And Initial weight of the specimen before wear test and weight loss after the wear test was noted and estimated the volumetric wear rate by considering the density of the material. Weight losses of pin materials were recorded by using a micro-electronic balance with an accuracy of 10^{-7} Kg at different time interval has shown in Fig 2. The results of the wear test were systematically compiled as shown in data result tables 1-12, and plotted the graphs for this research work.

Table 4: Test parameters

SI. No	Load (N)	Sliding speed(m/s)	Time (min)
1	5	3.33	16
2	10	5	20
3	15	6.66	27
4	20	8.33	40

Fig 1: Pin on disc testing machine

Fig 2 : Micro- balance weighing machine

III. RESULTS & DISCUSSION

A. Plan of experiments:

The experiment specifies wear testing principles which including Material coating (A), applied load (B), and sliding speed (C), as the process parameters. The experiments were carried out to analyze the influence of above parameter on dry sliding wear of Al 6061 composites. Control factors and their levels are shown in Table 6. Table shows the L16 (4)3 orthogonal array. If the full factorial design were used, it would have 34 = 81 runs. The L16 array requires only 16 runs, a fraction of the full factorial design. The standard Taguchi experimental plan with notation L16 (4)3 was chosen based upon the degree of freedom. The degrees of freedom for the orthogonal array should be greater than or at least equal to those of the process parameters.

Table 5: Control factors and their levels

Code	Parameters	Level 1	Level 2	Level 3	Level 4
A	Material coating (µ)	Un- coated	TiO_2	TiO_2+30% Inconel	TiO_2+40 % Inconel
B	Load (N)	5	10	15	20
C	Sliding speed (m/s)	3.33	5	6.66	8.33

Table 6: Experimental design using L16 orthogonal array

Experiment Run	Material coating	Load (N)	sliding speed (m/s)	Volumetric wear rate ($mm^3/mx10^{-4}$)	S/N ratio (dB)
200	5	100	1.03	0.86201	0.16799
200	10	300	3.4	3.5535	0.1535
200	15	300	6.63	6.5745	0.0555
200	20	1150	12.06	12.2399	0.1799
300	5	150	12.37	12.3715	0.0015
300	10	800	12.75	12.7414	0.0086
300	15	1050	12.98	12.9199	0.0601
300	20	50	13.2	13.9737	0.7737
400	5	1350	15.1	14.9184	0.1816
400	10	650	17.3	17.3152	0.0152
400	15	400	18.4	18.3715	0.0285
400	20	700	18.93	18.7794	0.1506
500	5	200	20.7	20.7173	0.0173
500	10	1100	21.5	21.4831	0.0169
500	15	700	22.8	22.7981	0.0019
500	20	500	28.73	28.7795	0.0495

B. Signal-to Noise ratio :

The volumetric wear rate was considered as the quality characteristic with the concept of "the smaller-the-better" and calculated by using following equation. Table 3 shows S/N ratio values of wear

$$\text{S/N ratio} = -10Log_{10}\frac{1}{n}\sum y^2 \quad (1)$$

Here n is 1 (volumetric wear rate only) & y is response value (wear value).

Table 6 shows S/N ratio analysis. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. The control parameter with the strongest influence was determined by the difference between the maximum and minimum value of the mean of S/N ratios, response table for signal to noise ratio for smaller the better which is shown in Table 4 for volumetric wear rate. Higher the difference between the mean of S/N ratios, the more influential will be the control parameter. The main effects plot for SN ratio of volumetric wear rate was shown in fig 3. The optimal parameter for volumetric wear rate is $A_3B_4C_4$.

Table 7: Response Table for Signal to Noise Ratios
Smaller is better

Level	Material coating	Load	sliding speed
1	66.74	52.22	64.86
2	64.72	62.16	63.83
3	62.62	66.21	62.59
4	58.65	72.15	61.47
Delta	8.09	19.93	3.39
Rank	2	1	3

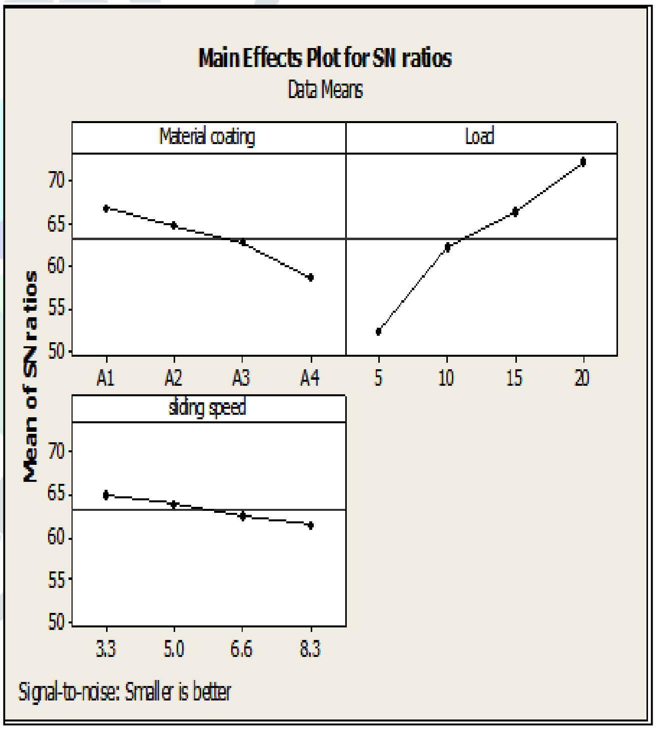

Fig 3: Main Effects Plot for SN ratios

C. ANOVA

Analysis of variance (ANOVA) was introduced by Sir Ronald Fisher. This analysis was carried out for a level of significance of 5%, i.e., for 95% level of confidence. The purpose of ANOVA is to investigate the percentage of contribution of variance over the response parameter and to find the influence of wear parameters. The ANOVA is also needed for estimating the error of variance and variance of the prediction error. The Table 5 shows analysis of variance for wear rate of the composite material. From the table 5, it is observed that the applied load, material coating and, sliding speed have the influence on wear of Al6061 composite material. The last column of the table 5 indicates the percentage contribution of each other on the total variation indicating their degree of influence on the result. It can be observed from the ANOVA table that the applied load (55.16) was the most significant parameter on the dry sliding wear of composites followed by material coating (14.95) and sliding speed (11.96). When the P-value for this model was less than 0.05, then the parameter can be considered as statistically significant. The applied load is considered as the most significant parameter. The pooled error associated in the ANOVA table was approximately about 17.93%. This approach gives the variation of means and variance to absolute values considered in the experiment and not the unit value of the variable. The fig 4 shows the residuals plots for volumetric wear rate.

Table 5: Analysis of Variance for Volumetric wear rate, using Adjusted SS for Tests

Source	DF	Seq SS(10^{-6})	Adj SS (10^{-6})	Adj MS	F	P	% of contribution
Material coating	3	5.5	5.5	1.8	1.67	0.272	14.95
Load	3	20.3	20.3	6.8	6.15	0.029	55.16
sliding speed	3	4.4	4.4	1.5	1.32	0.352	11.96
Error	6	6.6	6.6	1.1			17.93
Total	15	36.8					100

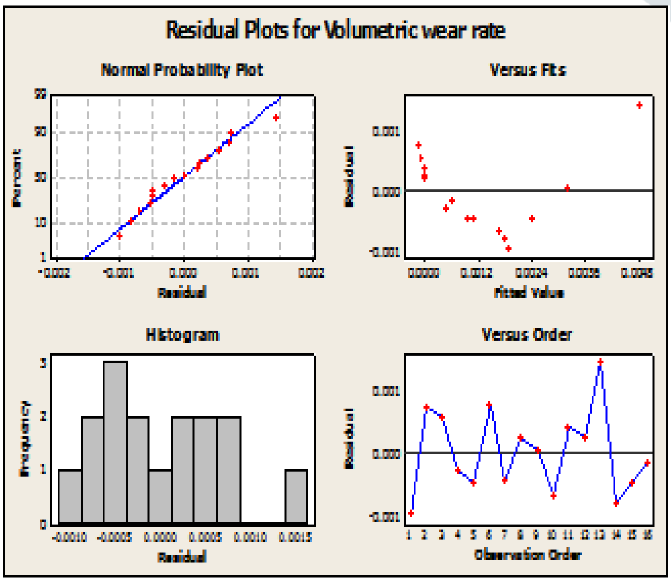

Fig 4. Residual Plots for Volumetric wear rate

3. Results and Discussions

3.1. SEM Photographs:

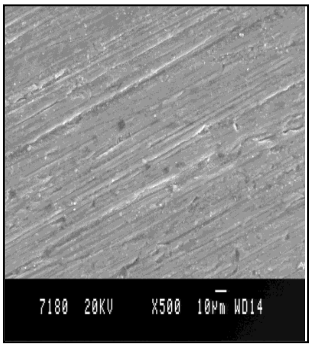

Fig 5: Inconel coating on Al6061 substrate

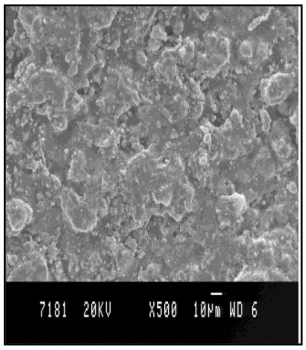

Fig 6: Weared Al6061 substrate

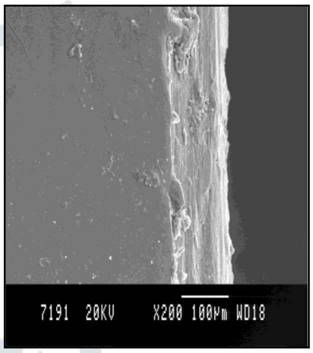

Fig. 7. SEM of cross sectional micrograph of Inconel-718 on Al6061 alloy

The SEM photograph of inconel coated Al6061 substrate in Fig.5 reveals the formation of even surface which lock in with the rubbing surfaces resulting in higher friction and wear resistance. Fig. 6 shows the SEM photograph of weard specimen exhibiting the formation of splats making the uneven surface of the substrates more uniform resulting in reduction of wear of the specimen. The coating thickness

IV. CONCLUSIONS

The following conclusions can be drawn based on the experimental investigations.

The volumetric wear rate of un-coated and coated on Al 6061 composites is primarily influence by applied load

1. Values of volumetric wear rate is almost constant in transition regime for all the normal pressures
2. The optimal process parameters for volumetric wear rate are $A_3B_4C_4$.
3. The applied load is considered as the most significant parameter
4. From ANOVA it is observed that applied load (55.16) was the most significant parameter on the dry sliding wear of composites followed by material coating (14.95) and sliding speed (11.96).

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