

Investigation of Tribological Properties of Plasma Sprayed Ceramic Coating AISI-1020 Stainless Steel

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Abstract

Objective: This work highlights on the effect of surface treatment on stainless steel in order to increase corrosion resistance. **Methods:** Tribological tests were conducted for 1020 graded stainless steels with plasma spray coating on it at a temperature of 80°C-120°C. ASTM G99 steel specimens with Cu-Al as a top coat and Ni-Cr as a bond coat were considered for dry sliding wear characteristics by using a pin-on-disc wear test rig. Weight loss was determined by considering three parameters. L_8 orthogonal array and ANOVA was conducted for various combinations. **Findings:** Surface treatment like coating helps in building corrosion resistance for steels. **Applications:** As the surface treatment is a fundamental part in manufacturing system this particular process can be implemented in several of parts in automobiles.

Keywords: ANOVA, Pin-on-disc, Plasma Spray Coating, Surface Treatment

1. Introduction

Few environment factors like temperature, pressure, moisture, infestation, contamination will result in change of material properties of any metals. Also contact between two surfaces may leads to friction, wear and progressive loss of the material. In order to overcome these factors some technology has to be adopted. So that it will helps in saving the material properties. In accordance to this coating is the one method that plays very important role in order to control damage from surrounding medium. Protective coating is excessively used in several major applications like in nuclear power plants, turbine buildings, aviation, aerospace materials and chemical technology and in many other modern technologies. Ceramic coatings will provide ideal protection for steel structures and reduces the defects from being failed. Coating provides extended life for the components under extreme conditions of thermal, corrosion wear and oxidation environments.

Ceramic coating helps in improving the properties of alloys and construction materials by increasing wear resistant property. Also it develops anticorrosion, anti wear and high temperature resistant properties. Most of the applications for mechanical components have to deal in the critical conditions with respect to load, speed or temperature and unfriendly chemical environments. All these demands of the present day technology can be fulfilled to the extent possible by the surface modification, which will protect the materials against various types of degradations. The surface modification includes mainly the coating and heat treatment. After the surface modification properties of the surface engineered materials will change. The major parameter which will get affected by the surface modification process is the wear.

In view of this, a literature survey has been made on the properties surface engineered materials, with particular attention on tribological properties of the ceramic coated materials.¹ Has carried out experimental analysis on plasma sprayed ceramic coatings. The authors

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have suggested that the plasma spray process is the most efficient technique on ceramic coatings. The wear characteristics of the multilayered ceramic coated materials were evaluated. The authors have concluded that the wear characteristics have maximum dependency on thickness of coated layers.² Worked on tribological characteristics particularly on wear rate and its properties on coated aluminum. Many other researcher^{3,4} and⁵ have carried out an experimental study on the tribological aspects of the ceramic coated materials. The results have shown that the thickness and the type of bond coat will influence the wear behavior and the nature of failure to a considerable extent.⁶ Have studied experimentally the bonding strength of the multilayer ceramic coated materials. The main attention was given to the materials of bond coat and top coat. Also the bonding strength of pre and post treated materials has been evaluated. It was stated that the pre and post heat treatments will influenced strength of material to a considerable extent.⁷ and ⁸ resulted that tribological characteristic for Al_2O_3 coating differs when the type contact is changed (conformal to linear).⁹ In this study, Al coating on metallic substrates by thermal spraying techniques was tested on a pin on disc wear testing apparatus. And it resulted that as the Al_2O_3 coating density increases the wear resistance also increases. Al_2O_3 coating done by detonation gun process is having a property of higher wear resistance on comparison with plasma spray coating process.¹⁰ The study is on tribological characteristic for a combination of plasma sprayed Al_2O_3 , TiO_2 with various proportions with CaF_2 , which is considered as a solid lubricant. Two body wear test was done using a pin-on-disc apparatus and this test helps in finding the wear resistance and the coefficient of friction.¹¹ In this work the tribological characteristics of plasma sprayed coating of Al with 40% ZrO_2 were studied at different temperature (200 degree and 300 degree centigrade) and coefficient of friction were marked and a study on wear behavior of Al coating by varying Cu percentage on AISI1020 stainless steel.¹² Have carried an extensive study on selected testing parameters on the tribological behavior of variety of steels. Here the wear test was conducted on pin on disc under different situations.¹³ Conducted a tribological study on polymer composites in which glass epoxy was filled with SiC, graphites and then using pin on disc apparatus under different conditions. The experiments were based on the techniques of Taguchi, orthogonal array and Analysis of Variance (ANOVA) was applied to know the tribological properties of these composites.¹⁴ Study

proves good improvement towards wear resistance when the combination of Al-Si is made.¹⁵ Studied the varying load and sliding distance based on pin on disc apparatus with oil hardened steel also they considered wear measurement in terms of weight loss.

2. Materials and Methods

The experimentations were conducted on pin on disc apparatus. The wear loss on the coated material has been determined. The wear behavior of the stainless steel has been identified under different conditions of the materials. The detailed information regarding the materials used and the experimental methods is discussed in the following section. Experimentation were carried out on the stainless steel (AISI 1020), which is widely used as structural steel in automobiles, used for Hydraulic rams. AISI 1020 stainless steel contains carbon 0.189%, silicon less than 0.02%, nickel lesser than 0.02%, Sulphur lesser than 0.005%, Manganese 0.498% and Phosphor lesser than 0.010%. And mechanical properties such as Poisson's Ratio 0.27-0.30, tensile Strength 394.7 Mpa, Elastic Modulus 190-210 Gpa, density 7.79-8.03($\times 1000$ kg/m³), elongation 36.5%, Yield Strength 294.8 Mpa, reduction in Area 66.0%, Hardness 111 HB, Impact Strength 123.4 J. Specimens are now made ready for wear test with two layers of coating. The top coat is mixture of aluminum and copper of thickness 200 μ m and Nickel Chromium as a bond coat of thickness 50 μ m. In this work the copper percentage varied for 10%, 20% and 30%. The bond coat of Nickel Chromium is used, because of its high bonding capacity. The plasma spray technique is used for the coat-

Table 1. Operating parameters of plasma spraying

Parameters			Range
Plasma system gun			ALT-F 3MB
Plasma gases	Pressure (Psi)		100-120
	Flow rate (Scfm)	Argon	80-90
		Hydrogen	20-25
Power	Current (A)		470-480
	Voltage (V)		62
Powder feed rate (gms/min)			40-50
Spraying conditions	Nozzle Dia (mm)		8
	Distance (inches)		4

ing purpose. The pre cleaned specimens were coated with Nickel-Chromium bond coat and then the mixture of Al_2O_3 and copper is sprayed with plasma spray technique. The process parameters used in the plasma spraying technique used in the present investigation are as given in the Table 1.

2.1 Material Conditions

2.1.1 Normal Condition

The specimens of AISI 1020 stainless steel are tested in the procured condition.

2.1.2 Al_2O_3 Coated

The AISI stainless steel is plasma sprayed with Nickel Chromium as a bond coat and on that only the Al_2O_3 coating is done for a thickness of 200 μm .

2.1.3 Al_2O_3+Cu Coated

The desired numbers of specimens are plasma sprayed with Al_2O_3 coating with required percentage of copper.

The wear test specimens were prepared as per the ASTM G99 standard. Wear test specimen of size 10X25 mm was prepared by lathe. Then the specimen is rubbed using SiC paper of grade 1000 to ensure the surface finish. The prepared specimens are coated with pure alumina as a top coating of thickness 200 μm with and nickel chrome as a bonding material of thickness 50 μm by using plasma spray coating technique is done under the temperature of about 80-120°C. The experimentations were conducted to know the effect of Cu on the wear behavior of the stainless steel. The required number of specimens is as given in the Table 2.

Table 2. The test matrix

Material Condition	Total number of specimens
Al_2O_3	30
Al_2O_3 + 10% copper	30
Al_2O_3 + 20% copper	30
Al_2O_3 + 30% copper	30

2.2 Experimental Procedure

Dry sliding wear characteristics of all specimens were conducted on ASTM standard pin on disc. The initial weight of the specimen before the test was taken in an

electronic weighing machine which is having least count of 0.0001 gm. The tests were conducted by having sliding time, load applied and sliding velocity as the parameters. After the test again the specimen is weighed to know the difference in weight. This difference between the initial and final weights gives the slide wear loss. Parameters such as the applied load, sliding distance and sliding velocity are considered for the experiment and the values for the same employed was varied from 15-75 N, 400 m to 2000 m and 1.047-5.236 m/s respectively. These values are based on literature survey. The process parameter and their levels are shown in Table 3.

$$\text{Wear Rate (Ws)} = \frac{\text{Volume Loss}}{\text{Load X Dis tan ce}} \text{mm}^3 / \text{N - m}$$

Table 3. Parameters with their values at three levels

Levels	Sliding Velocity, V in m/s	Applied Load L in N	Sliding Distance, D in m
1	1.047	15	400
2	2.094	30	800
3	3.142	45	1200
4	4.189	60	1600
5	5.236	75	2000

3. Results and Discussions

The study was made to know the interactions between all three factors such as sliding speed, load applied and sliding distance. L8 orthogonal array and ANOVA were used to conduct the experiments. On the other hand significant factor affecting the wear can be identified. ANOVA helps in finding optimal combination parameters which are predicted. Based on results, the contribution of individual parameters and their influence on the wear characteristics are plotted on the graph.

3.1 Effect of Sliding Velocity on the Wear Behavior

Figure 1 is the graph, plotted sliding velocity against the weight loss. Here load applied and sliding distance is kept constant. From the graph it is observed that as the weight loss of the specimen increases with increase in sliding distance. But as the percentage of copper increases the weight loss is decreasing. The more temperature generated at

greater sliding velocity will lead to the thermal softening of the coating, which in turn reduces the under surface shear strength and its hardness. Due to this phenomenon of thermal tribo-friction the weight loss is increased in sliding velocity.

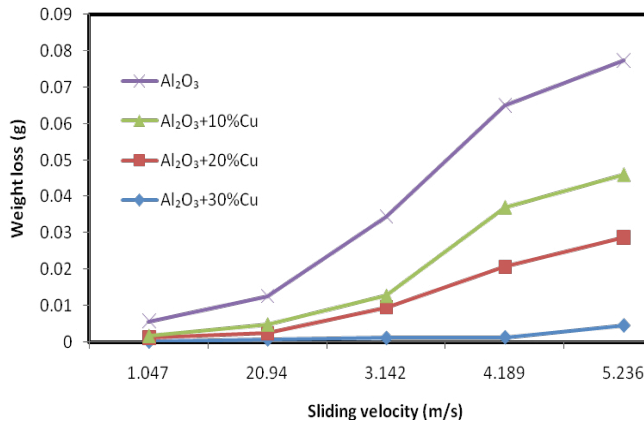


Figure 1. Effect of sliding velocity on wear.

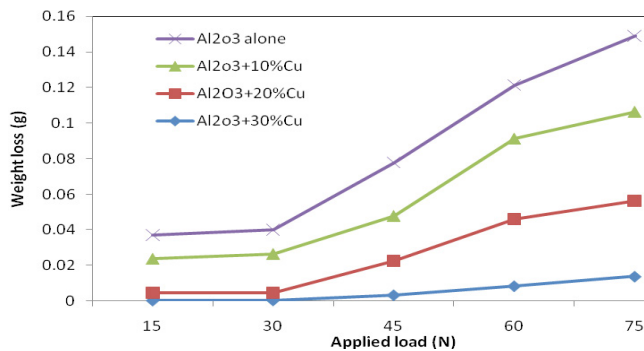


Figure 2. Effect of applied load on weight loss.

3.1.1 Effect of Load Applied on Weight Loss

From the experiment and the graph from the Figure 2, it is observed that the coated samples are having lesser weight loss. The weight loss increases in the coated specimens as the application of load increases. Adhesion wear was the mechanism that occurred during lower speeds. And at greater speeds and higher load conditions ploughing occurred. The trend of the curve is same for all varieties of the coated specimens. Percentage of copper plays important role on wear characteristics. As the copper percentage increases the wear rate decreases. When higher loads are acting that leads to higher plastic deformation with more shear stress in action. In fact the high load may induce de-cohesion of interlinked particle and their detachment from the coating. The increase in the weight percentage of Cu has softened the superficial layer

and also it has been a major cause for the formation of the greasy layer on the worn out surface. This will reduce the wear drastically. One more significant factor to be noted is that the addition of the copper has increased the bonding strength of the coated layer. Also during the abrasive action between the specimen and the disc, to some extent, the copper will act as the lubricant and hence reduces the wear. Obviously, the debris in the wear track plays an important role.

3.1.2 Effect of Sliding Distance on Weight Loss

In Figure 3 sliding distance is varied from 400 to 2000 m in steps of 400 m. During experimentation sliding velocity and load applied were kept constant. Weight loss increases with increase in sliding distance. For the coated specimen the weight loss is increases with increases in sliding distance. The prime cause for material removal is high temperature generated during the process. Due to high friction coefficient the Al₂O₃+Cu matrix suffered severe deformation and micro cracking and pullout of Al₂O₃+Cu particles occurred since the support of matrix were lost, which future leads to the formation of wear debris.

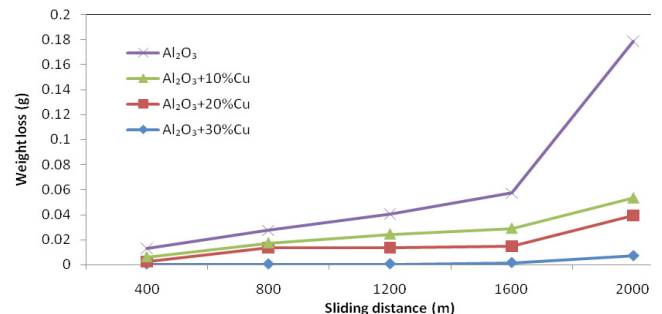


Figure 3. Effect of sliding distance on wear.

3.2 Design of Experiments and Statistical Analysis

Experiments were conducted in order to find the interactions between the factors. L₈ orthogonal array was conducted for various combinations. (2³ factorial designs of experiments). The experiments are planned for 2^k factorial design. In present investigation 2³ factorial designs was opted.

The experiments were conducted on all varieties of the materials based the chosen parameters as per the L₈ array. The result of the experiment is mentioned below in the Tables 4 and 5.

From the Tables 4 and 5, it can be inferred that, as Cu amount increases the wear loss decreases. This behavior of the material is found in all varieties of coatings. But, from the experimental results presented in these tables will not reveal any information regarding the severity of the process parameters. Due to this reason the ANOVA has been made for this experimental study.

Table 4. Experimental results of weight loss for AISI Steel with Al_2O_3 coating

Test	LOAD (N)	SLIDING VELOCITY (m/s)	SLIDING DISTANCE (m)	Wt. LOSS, gm Al_2O_3 alone
1	15	200	400	0.3
2	60	200	400	1.2
3	15	1000	400	0.8
4	60	1000	400	2.0
5	15	200	2000	3.3
6	60	200	2000	4.3
7	15	1000	2000	4.4
8	60	1000	2000	4.8

Table 5. Experimental results of weight loss for AISI steel with varied percentage of copper

Test	Wt. LOSS, gm Al_2O_3 +30%Cu	Wt. LOSS, gm Al_2O_3 +20%Cu	Wt. LOSS, gm Al_2O_3 +10%Cu
1	0.10	0.35	0.50
2	0.4	0.55	0.8
3	0.7	1.4	1.2
4	0.9	1.6	1.4
5	1.0	1.8	1.75
6	1.4	2.0	1.9
7	1.3	2.0	2.0
8	2	2.8	4.6

3.3 Results of ANOVA for the Ceramic Coated Materials

From the ANOVA results, the Sliding velocity (48.1%), sliding distance (32.6%) and the Load (20.3%) are the factors proving their influence on wear loss. It is proved that sliding velocity is the important parameter on comparison with sliding distance and the load with respect to wear. The Tables 6, 7 and 8 depict the variation of the wear with reference to the influencing parameters. From the Table 8, it can be observed that the contribution of

the sliding velocity (52.6%), is maximum as in case of the only Al_2O_3 coating. But one interesting feature which can be considered is the contribution of the sliding distance (36.4%), which is showing slight increment and influence of the load (12.4%) has reduced. From the Table 8, increase in percentage of copper reduces sliding velocity 46.4%. Meanwhile the percentage contribution of the load has been increased to 20.4%. Also it is found that the influence of the sliding distance has reduced to 34.1%. This is mainly because of the too ductile nature of the copper and also the copper will act as the self lubricant during wear. From the Table 9, the increase in the percentage of copper to 30% has decreased the influence of the sliding velocity to 40.8% and the influence of the sliding distance to 29.6%. At the same time the influence of the loads has been increased to the level of 31.5%.

Table 6. ANOVA results for ceramic coating Al_2O_3 alone

Parameters	SS	MS	F	P
A	4.961	4.961	1.16	0.203
B	0.031	0.031	0.01	0.481
C	0.151	0.151	0.04	0.326
Total				1.00

Table 7. ANOVA results for ceramic coating Al_2O_3 +10% Cu

Parameters	SS	MS	F	P
A	2.88	2.88	1.14	0.124
B	0.500	0.500	0.20	0.526
C	0.605	0.605	0.24	0.364
Total				1.00

Table 8. ANOVA results for ceramic coating Al_2O_3 +20% Cu

Parameters	SS	MS	F	P
A	0.7013	0.7013	1.15	0.204
B	0.1512	0.1512	0.22	0.464
C	0.3612	0.3612	0.53	0.341
Total				1.00

Table 9. ANOVA results for ceramic coating Al_2O_3 +30% Cu

Parameters	SS	MS	F	P
A	0.2813	0.2813	0.75	0.315

B	0.0313	0.3013	0.60	0.408
C	0.1512	0.1512	0.40	0.296
Total				100

4. Conclusion

- The coated specimen has lower weight loss compare to the normal specimen because of increased hardness of the coating.
- Sliding velocity, sliding distance and load applied are the important factors which play major influence on wear behavior.
- Variation in all the three parameters is directly proportional to weight loss of the specimens and Al₂O₃ coated specimens shows higher wear resistance compare to others.
- Sliding velocity is the main factor and causes higher weight loss compare to load and distance.
- From ANOVA it is found that the parameter sliding velocity plays important role on the wear loss.

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