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Slurry Erosion Behaviour of AlSiN Based HVOF Coatings: Effect of Impact Angle

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ABSTRACT

In this work AlSiN coating were deposited on AA 6082 in three different ratios of aluminium and silicon (%wt) by HVOF process and investigated the effect of different impingement angles under slurry erosion conditions as compared to uncoated AA6082. Jet-type slurry erosion test rig was used and effect of three parameters namely impact velocity, impact angle and slurry concentration on slurry erosion of uncoated AA6082 and AlSiN coated AA6082 was investigated. Micro-hardness was varied from (1875HV to 1471HV) by varying Al content from (90% to 60%). Dominant erosion mechanism found to be formation of crater and abrasion groves, ploughing in the removal of coating for all combination of AlSiN. Wear rate was found to be high at 30^0 (ductile mode (Si: 10%)), as the volume of Si content was increased to 40%, the mode of erosion mechanism was changed to mixed mode (ductile and brittle) at 60^0. Slurry rate was linearly varying with respect to impact velocity and slurry concentration.

Keywords: AlSiN, Slurry erosion, AA 6082, HVOF coating, Surface studies

1. Introduction

In hydraulic power plants erosion of turbine components due to sand particles present in water is a very serious problem around the world. The same problem face by hydraulic power plants in India, especially situated in Himalaya region [1]. Hydraulic power plants installed in Himalayan region of India contributed around 12% of electrical energy in India. In Himalayan region landslide is very common phenomena and it increases during monsoon. Due to this slurry particle concentration in water increases up to 10^4 ppm, and due to this increased concentration hydro turbine components undergoes for repair. This increased the maintains cost. When consider all power plants this is major economic loss, especially for a developing country like India. The hydraulic turbine components, which are mainly required maintains due to slurry erosion are guide vanes, top and bottom ring liners, labyrinths, runner blades, inlet valve seals, etc. various researches reported that wear of the target surface depends on hardness of the target material or hardness of the impacting solid particles or both [2–7]. Also it has been observed that the surface treatments of materials play a effective role in the erosion process [8]. In different parts of world researchers trying to find out solution on how to prevent hydraulic turbine blade from erosion and corrosion wear. Various metallic alloys are being developed to make different parts of hydraulic turbines. aluminum alloys are finding wide applications in the different fields like aerospace, automobile, defence, etc. due to Light weight, improved physical, mechanical and tribological properties. In this study analysis of the erosion wear on aluminum alloy for different parameter like variation in Slurry concentration, impinging angle, slurry impact velocity.

It has been understood from various experiments that thermal spray coatings are highly suitable to increase the hardness and slurry erosion resistance of the target surface economically. The chemical and mechanical properties of target material and coatings are deciding factor for good erosion resistance. Deposition conditions also played a good role [9].

Higher coatings thickness and very good mechanical properties can be achieved by High-velocity oxy-fuel (HVOF) spray process as compared to other thermal spray process. Due to very high kinetic energies and relatively low temperatures (about 700^0 C) a very good cohesive strength can be achieved between deposited feedstock powder particles. Also Adhesion between substrate interface and coating can be 10 times higher achieved by typical HVOF process as compare to other thermal spraying processes [10].

It has been learnt from the literature that wear performance of coatings are depending upon many parameters such as impact velocity, impingement angle and shape, size and flow rate of erodent. Wear performance also affected by ph value and coating thickness as well as the binding ability of coatings, etc. [11-12].

The slurry erosion wear performance of AA1050 & AA5083 has been investigated by Kiragi et al.[13] under both dry and slurry jet erosion. AA5083 showed higher erosion resistance compared to AA1050 in both the tests. Surface studies indicate that at lower impingement angle dominant factors are cutting and abrasion grooves for both the dry and slurry erosion tests. At the higher impingement angle, the material removal process was mainly by ploughing and formation of crater in dry erosion and cracking in slurry erosion.

A similar investigation on HVOF-sprayed TiAlN coatings on AA5083 and AA1050 aluminium alloy by Kiragi et al.[14] depicts mixed ductile and brittle mode of erosion model. At lower impact velocity the erosion mechanism affirms from SEM images was mixed ploughing and microcutting with platelet mechanism for both the alloys. Detachment of peaks and valleys, cracks, abrasion grooves and formation of crater are evident at higher impact velocity.

In the present work, HVOF-sprayed AlSiN coatings in three different ratios of Al & Si on AA6082 have been studied to understand their slurry erosion behaviour. The HVOF thermal spray process has been chosen for the deposition of coating powder (AlSiN) on the aluminium alloy 6082. The study shall provide useful information regarding the performance of the HVOF spray AlSiN coatings on AA6082. Also uncoated AA6082 has been tested and results compared to HVOF coated AA6082.

2. Materials and Methods

2.1 Base material

In this study Al alloy 6082 has been chosen as its property are high strength, good weldability and good corrosion resistance. Aluminium alloy 6082 is a medium strength alloy with excellent corrosion resistance. It has highest strength of 6000 series alloy. Alloy 6082 is commonly known as structural alloy. The addition of large amount of manganese controls the grain structure which in turn results in a stronger alloy. The chemical composition of this AA6082 is given in table 1.

Table 1. Nominal chemical composition of AA6082 (%wt)

Al	Mn	Fe	Mg	Si	Cu	Zn	Ti	Cr	other
Balance	0.4-1.0	0-0.5	0.6-1.2	0.7-1.30	0-0.1	0-0.2	0-0.1	0-0.25	0-0.15

2.2 Coating deposition

Commercially available Al and Si were mixed in three different ratios by weight as 90% Al & 10% Si, 75%Al & 25%Si and 60%Al & 40% Si and investigated their slurry erosion performances in the this study. These coating powders were deposited on the given aluminium samples at M/S Harsha Specialty welding Private Limited, panchkula (India), by using commercial HVOF thermal spray system(HIPOJET2700M). The compressed air jets used to cool down the specimens during and after spraying. the Al_2O_3 grit was used to grit blasted the specimens before coating deposition to the surface roughness so as there were good coating adhesion between coating podwer and target matarial. For convenience uncoated AA6082 and HVOF coated 6082 has given following designation in Table II.

Table II

Designation	**Composition**
6082UNC	Uncoated AA 6082
6082C-1	HVOF coated AA 6082 with 90%Al & 10%Si
6082C-2	HVOF coated AA 6082 with 75%Al & 25%Si
6082C-3	HVOF coated AA 6082 with 60%Al & 40%Si

2.3 **Slurry Jet Erosion Test**

The slurry jet erosion test was performed on slurry jet erosion tester (TR- 411) supplied by Ducom, India designed according to ASTM Standard as shown in Fig. 1. The slurry jet erosion tester consists of the following components, erodent tank, two motors for water & erodent feed, water tank, sample holder, water purification unit, control board etc. As shown in fig 1 sample kept on an adjustable sample holder which can be adjusted at various angles with respect to the direction of slurry. Slurry comes out of a nozzle of 4mm just above the sample holder. The square sample of 24 × 24 mm size was used for the slurry erosion test. The mass loss of each sample was calculated by the difference weight of sample before and after the slurry erosion test. After each cycle of erosion testing for 1o min duration, samples were washed and cleaned with acetone and then dried before measuring the weight change. Weight loss of specimens was measured by using an electronic microbalance balance with 0.1 mg resolution. Fresh slurry was used for every sample.

Fig. 1 slurry jet erosion tester

2.4. **Slurry** Silt required for experiments was procured from sand market, jaipur, Rajasthan. Silt was dried under sun and sieve analysis was done to classify particle size distribution. Predetermined amounts of silt particles of different size distributions were mixed in order to obtain silt samples of 100 mm and 300 mm average particle size.

2.5 **Experimental conditions**

Experiments were done under steady state condition at constant velocity and sand discharge to understand the effect of different impingement angle. Experiments were conducted in 2 setup. In first setup Impact velocity and sand discharge were kept constant at 10m/s and 160gm/min. to analysis the effect of impingement angle on slurry erosion different values of angle taken i.e. 15^0 , 30^0 , 45^0, 60^0 , 75^0 and 90^0. In other setup impact velocity were kept 40m/s and other parameter were the same as previous setup. Gap between nozzle and samples were 20mm that is fixed.

3. Results and discussion

3.1 Mechanical properties

3.1.1 Coating Thickness Measurement

Five readings were taken randomly on all coated sample of AA6082 samples by Posi Tector 6000 and the results are shown in Table IV

Table IV **coating thickness measurement**

S.No	6082C-1	6082C-2	6082C-3
1	145µm	138 µm	131µm
2	141µm	154 µm	149µm
3	135µm	161 µm	138µm
4	156µm	144 µm	152µm
5	149µm	169 µm	139µm
average	145µm	153 µm	141µm

3.1.2 Micro Hardness Test Analysis

Five readings were taken randomly on one coated sample of each AA6082, and AlSiN coated samples on INNOVA TEST NEXSUS 4303 micro Vickers hardness tester under a fixed load of 300gf for a fixed time period of 10 seconds. Average micro hardness was calculated and the results obtained during Vickers micro hardness test for all three types of samples are shown in Table V.

TABLE V: MICRO VICKERS HARDNESS TEST RESULTS

S.No	6082UNC	6082C-1	6082C-2	6082C-3
1	104HV	1493HV	1371HV	1258HV
2	95HV	1536HV	1346HV	1296HV
3	97HV	1510HV	1365HV	1289HV
4	101HV	1515HV	1349HV	1263HV
5	102HV	1541HV	1359HV	1249HV
Average	99HV	1519HV	1358HV	1271HV

Value of micro hardness varies with variation of Al and Si % in coating. As Al % increase, value of hardness increase. Similar trend proved by various researchers as Bozhko et al[15] , Lewin et al[16] and Musil et al[17].

3.2 Slurry erosion behaviour

To evaluate the performance of three HVOF spray coatings and uncoated AA6082 under slurry erosion conditions, the HVOF spray AlSiN coated and uncoated AA6082 specimens were subjected to slurry erosion tests under staedy state condition as described earlier. Results shown in fig. 2 and fig. 3. From the erosion results under all experimental conditions, it has been observed that the HVOF sprayed coatings showed comparatively higher erosion-resistance in comparison with uncoated AA6082. This may be attributed to the higher hardness of this coating in comparison with uncoated AA6082. From the results shown, it is obvious that as the impact velocity increases slurry erosion rate for coated and uncoated AA6082 specimens also increases. Slurry erosion rate is influenced by factors such as velocity of impacting particles, impingement angle and slurry concentration.

From the fig.2 and fig. 3, it can be seen clearly that under steady state erosion uncoated AA6082 show maximum erosion at 30^0 which indicate its ductile behavior. For all coated AA6082 erosion wear were maximum at 90^0 which indicate its brittle nature of coating. From the results it can understand that for coated AA6082 samples, erosion rate increase with increase in Si content. From the literature, it is also concluded that ductile materials are prone to wear more at oblique angles whereas brittle materials at normal angles and more [19, 20].

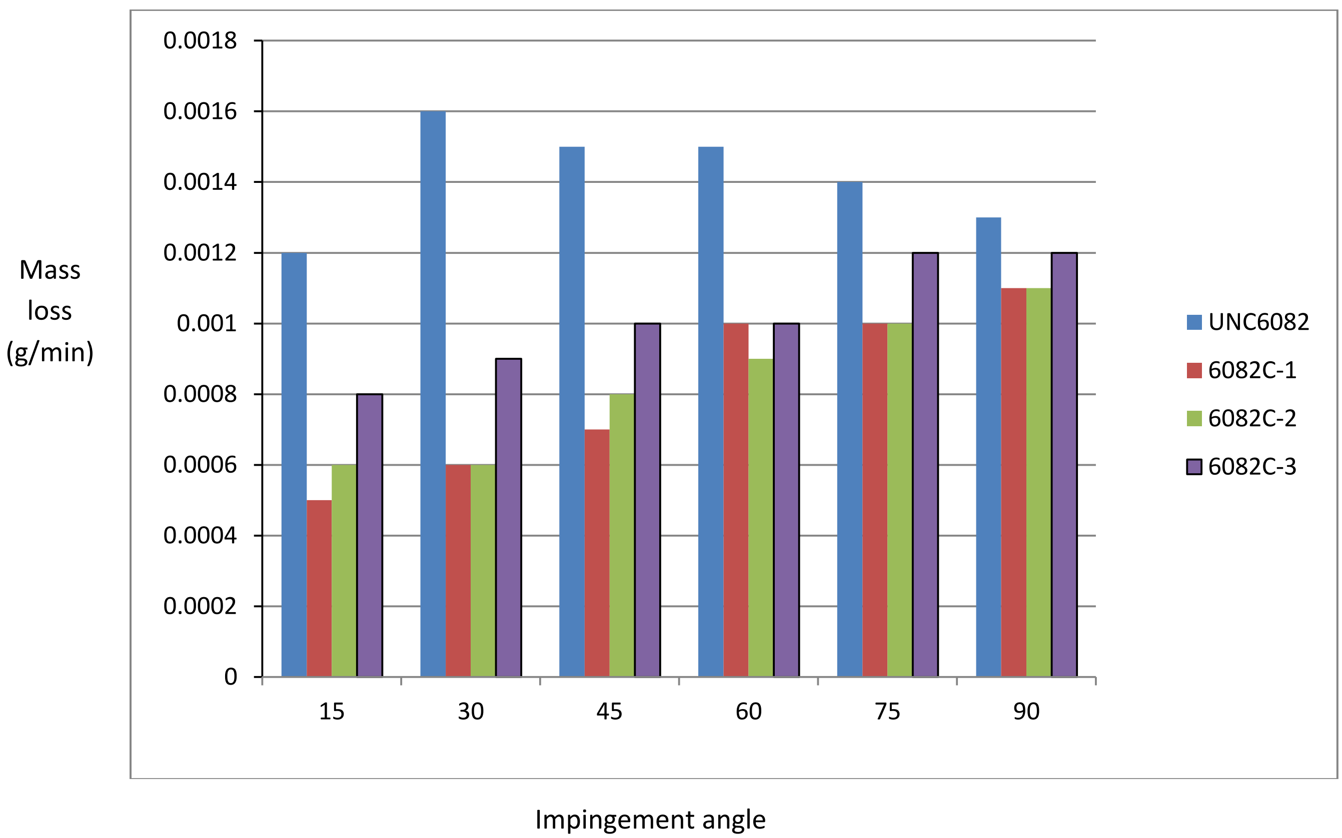

Fig. 2 slurry erosion wears variation with impingement angle at 10m/s

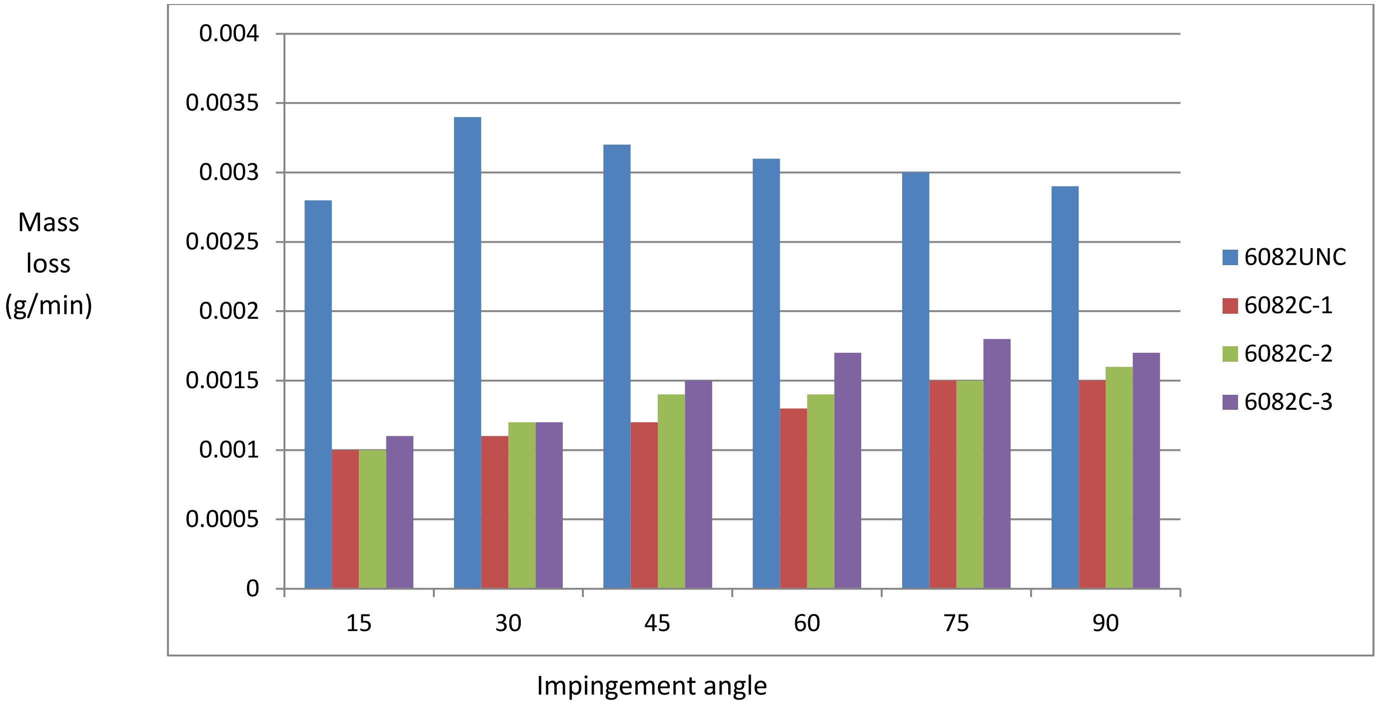

Fig. 3 slurry erosion wear variation with impingement at 40m/s

3.2 Examination of eroded surfaces.

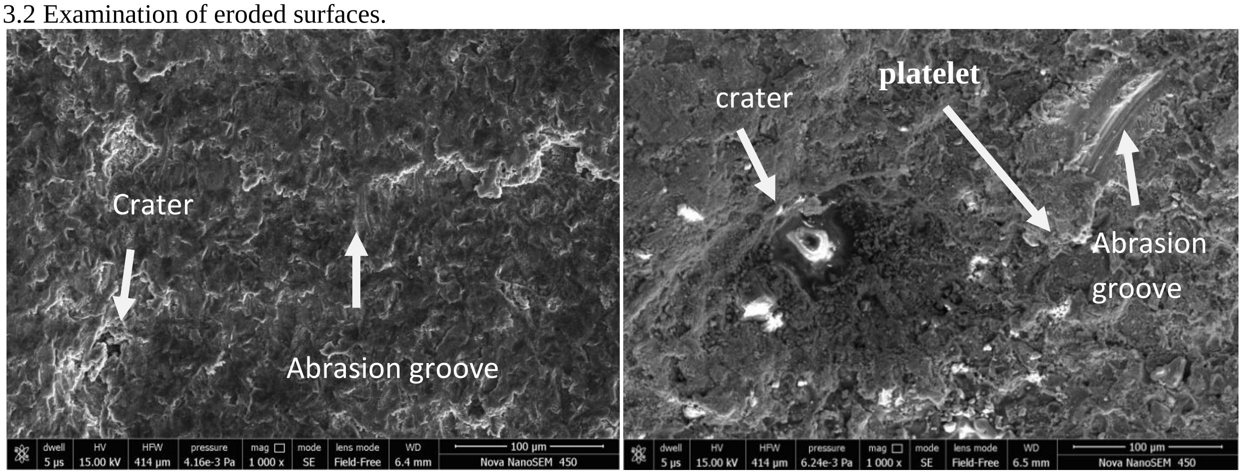

Fig 4 SEM image of 6082C-1

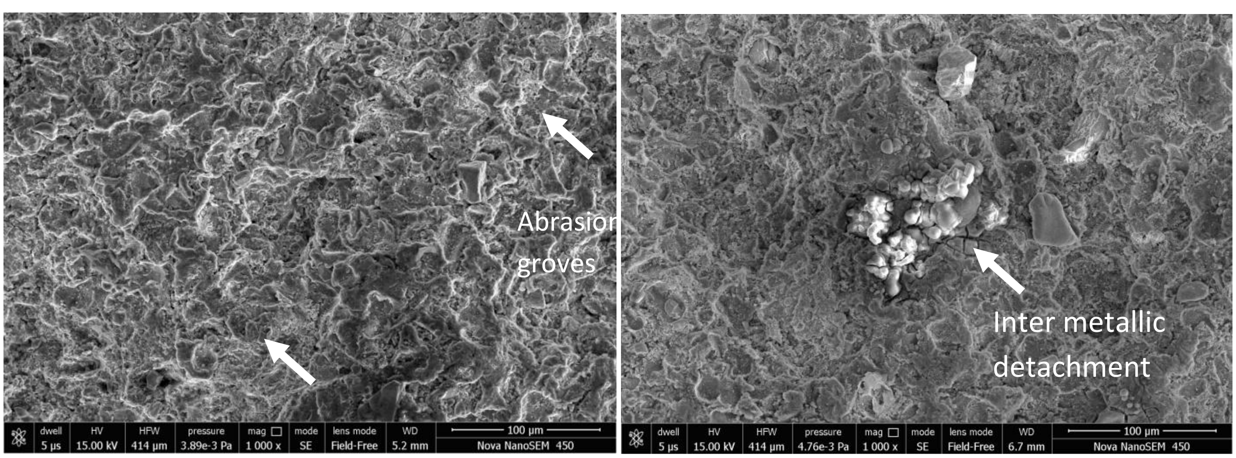

Fig. 5 SEM images of 6082C-2

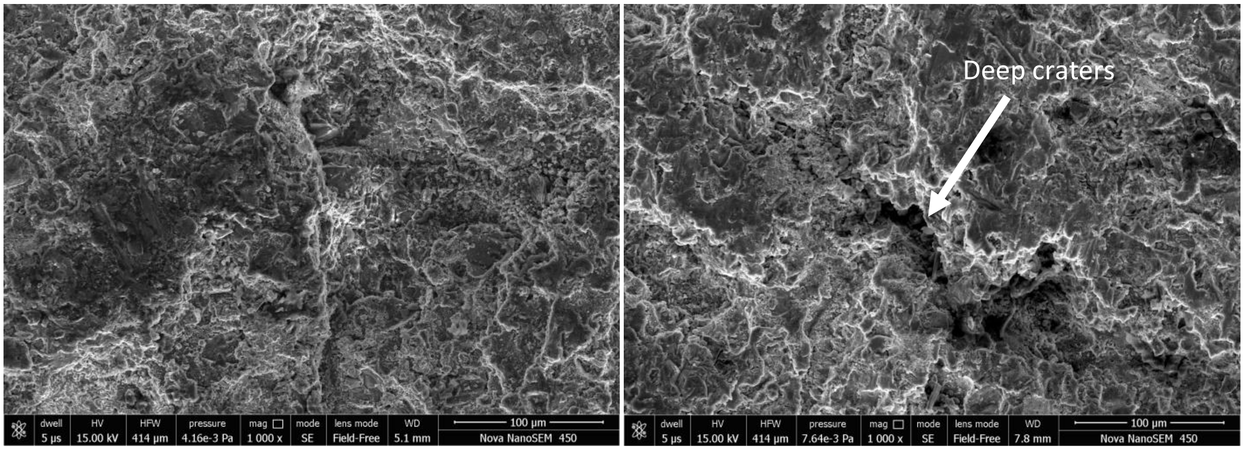

Fig. 6 SEM images of 6082C-3

From these SEM image erosion mechanism can be understand. Dominant erosion mechanism found to be formation of crater and abrasion groves, ploughing in the removal of coating for all combination of AlSiN There are micro ploughing and micro cutting was found for uncoated AA6082. For coated AA6082 samples micro-cutting, micro ploughing and plastic deformation take place resulting in fracture after continues strike of hard slurry particles on the coated surface.

4. **Conclusion**

The following results can be write down based on the present study on slurry erosion of uncoated AA6082, HVOF coated aluminum alloy at various impingement angle:

1. For uncoated AA6082 Slurry erosion wear was maximum at 30^0 impingement angle and it decreases when impingement angle increase.
2. For all coated samples erosion rate is maximum at 90^0. This indicates that as the AlSiN coatings showed brittle nature.
3. Slurry erosion rate is increased with increase in silicon content at all impingement angles.
4. Erosion mechanism as undestood from SEM images is found to be micro cutting and micro ploughing for uncoated AA6082. for coated AA6082 samples micro-cutting, micro ploughing and plastic deformation take place resulting in fracture after continues strike of hard slurry particles on the coated surface.

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