Effect of coating on erosion wear: An experimental investigation

K Vinod¹ and R K Porwal²

Faculty of Mechanical Engineering, Sri Ramswaroop Memorial University, Lucknow India

*Corresponding author: E-mail: vinodmpec@gmail.com

Abstract. Two stainless steels namely AISI 430 and AISI 204 have been investigated for their slurry erosion resistance. The erosion tests were carried out using a pot tester at the particle impact velocity of 10.7 m/s, slurry concentration of 10%, 20% and 30% by weight and the impingement angle of 30° and 90°. To improve the slurry erosion resistance of the stainless steel AISI 430 and AISI 204, Cr₃C₂-25NiCr coating was deposited on that, using HVOF (High Velocity Oxy Fuel) technique. Erosion results show that Cr₃C₂-25NiCr coating exhibits better slurry erosion resistance than the AISI 430 and AISI 204.

1. Introduction

During rainy seasons slurry erosion problems are very important in hydroelectric power plants because during this season the number of solid particles impacting the surfaces of bearing, blades, nozzles and guide vanes increase. Some other engineering systems, in which the slurry erosion is a problem, are pipelines, jet turbines, valves used in slurry transportation, steam turbines and fluidized bed combustion system. The slurry erosion is a deprivation of mass by a material open to a stream of slurry. Slurry erosion takes place when the material runs through the slurry or the slurry runs past the material. Erosion wear occurs due to the regular impacts of solid particles. There are two mechanisms of slurry erosion wear first deformation wear and second cutting wear. Deformation wear occurs at high impinging angles in ductile materials and cutting wear is prominent at low impinging angles which are associated with both the brittle and the ductile materials. High velocity oxy-fuel (HVOF) coating is a type of thermally sprayed coating which improve the resistance to erosion and abrasion. HVOF coating is widely used in engineering components. [1-3].

2. Literature review

Erosion wear of LSA-modified steels is investigated by Shivamurthy et al, to find out the impingement angle for maximum erosion rate. The tests are conducted at various impingement angles at two different sizes of particle whereas the slurry velocity and slurry concentration are fixed. Shivamurthy et al observed that the hardness of the Colmonoy 88 and Stellite 6 coatings increases two times and the slurry erosion resistance two to three times in comparison to the substrate 13Cr-4Ni steel. The hardness is improved because of uniformly distributed borides and carbides of W and Cr. A100 μm size of erodent has a brittle erosion behavior for LSA-modified steels. [4]
Desale et al investigate the particle size effect on slurry erosion of AA 6063. The 37.5–655µm sized particles are used to investigate the erosion at 90° and 30° impingling angles at a velocity of 3m/s for a slurry concentration of 20% weight of solid particles. They found that the slurry erosion wear due to small sized particles is higher than big sized particles [5].

Desale et al investigate the affecting parameters of slurry erosion wear of ductile materials using a slurry pot tester. Three different erodents and seven ductile materials were used to investigate the velocity effect, particle size effect and slurry concentration effect of solid particles. They found that the slurry erosion is a function of the ratio of the hardness of erodent to the hardness of target material under normal conditions. The worn out surfaces are observed through the surface roughness measurements and SEM micrographs that unwraps that the penetration by erodent particles at the substrate material surface is a function of the ratio of the hardness of erodent to the hardness of substrate material. At normal impingment impact angle, the slurry erosion has strong dependence on the size of particle and velocity but weak dependence on the concentration of slurry [6].

Gandhi and Borse determine the slurry erosion wear and the fine sized erodent particles (less than 75µm) effect on slurry erosion wear of grey cast iron using a pot tester. Fine sized erodent particles are added in the slurry of constant mass of big sized erodent particles mixture. The slurry erosion rate reduces when the fine sized erodent particles less than 75µm added in the slurries and increases with increasing the concentration of coarse size erodent [7].

Fang et al studies the slurry erosion wear performance of four ceramic materials by using a jet impingement test rig with sand water slurry to investigate the impingement angle effect, and sand concentration effect. They found that the 85% alumina has the most erosion rate while the PSZ zirconia has the lowest erosion rate. They are also observed that the REFEL F SiC has greater erosion rate than Sialon 101. Brittle fracture and plastic deformation are the erosion wears mechanisms for these materials [8].

Wood looks at alternative of plasma electrolytic oxide and high velocity oxy fuel coatings for components subject to corrosion and slurry erosion. Tests are being made to find out the relations between corrosion and erosion. Some comparisons with field experience and experimental are made and spotlight the present semi-empirical and theoretical erosion, corrosion and erosion–corrosion models and also identified some limitations for these models. The non-intrusive electrochemical noise technique is discussed as emerging electrochemical techniques [9].

Clark and Hartwich found that at the same impingement angle and impact velocity the effect of the size of the erodent should reflect in the change in the eroded volume when the same mass but different size and uniformly-shaped erodent impacts on the target surface. They also observed that the erodent size effect on erosion rate can only be understood if the erodent size effect on erodent impact conditions and on the slurry flow is known [10].

AISI 304 and AISI 420 stainless steels in acid slurry containing chloride ions are investigate by Lopez et al and observed the effect of impingement angle and impact velocity on the corrosion–erosion resistance. They also observed that the AISI 304 stainless steel is mainly degraded under corrosion–erosion conditions by the mechanical action of impacting erodent and the AISI 420 stainless steel is mainly degraded by chemical action, for high impact velocity regardless of the impingement angle. The surface damage increases with impact velocity for both steels [11].

3. Experimental Planning

| S. No. | Material | C | Mn | Si | Cr | Ni | P | S | Others |
|-------|----------|---|----|----|----|----|---|---|--------|
|       |          |   |    |    |    |    |   |   |        |

Table 1. Nominal chemical composition of AISI 430 & AISI 204 stainless steels.
In the present work, two stainless steels namely AISI 430 & AISI 204 and Cr$_3$C$_2$-25NiCr coatings on AISI 430 & AISI 204 are selected. The chemical composition of AISI 430 & AISI 204 stainless steels are given in table 1. A pot tester is used in the present investigation for erosion wear. Specimens of size 30 mm × 5 mm × 2 mm were cut and corners were chamfered. The experimental conditions used in the present study are shown in table 2.

Table 2. Experimental conditions.

|                               |   |
|-------------------------------|---|
| Impingement angle (degree)    | 30°, 90° |
| Impingement speed (m/s)       | 10.7 |
| Sand size (µm)                | (500-600) 550 |
| Room Temperature              | 40-45°C |
| Slurry Concentration          | 10, 20 and 30 wt% |
| Cycle time                    | 60 min |

In order to obtain identical condition for every experiment, the test specimens were polished before conducting the test. Before and after each test the test samples are cleaned with tap water. An electronic balance is used to measure the mass loss of the test specimen. The average mass loss of the test samples is used to calculate the erosion rate. A sand-water mixture is used as the slurry. Two successive sieves of 500 and 600 µm are used to sieve the sand to obtain mean size erodent of 550 µm.

4. Results and Discussions

Slurry erosion wear of AISI 430 & AISI 204 stainless steels & Cr$_3$C$_2$-25NiCr coatings have been evaluated using a pot tester. Figure 1 shows the Cumulative mass loss v/s Time in hour at 30° impact angle (a) and at 90° impact angle (b) at 30% wt concentration for AISI 430, AISI 204 and Chromium carbide coatings on it. When the erosion time increases the material removal increases. Results shows that the AISI 430 has the maximum erosion rate among all four materials and Chromium carbide coating on AISI 430 and AISI 204 have almost same erosion rate which are lowest erosion rate among all four materials.
Figure 1 (a). Cumulative mass loss v/s Time in hour at 30° impact angle and 30% wt concentration for AISI 430, AISI 204 and Chromium carbide coatings.

Slurry erosion rate of AISI 430, AISI 204 and Chromium carbide coating on AISI 430 and AISI 204 stainless steels are subjected to slurry erosion wear in a pot tester at the impact velocity of 10.7 m/s, impingement angle 30° (a), 90° (b) at slurry concentrations of 10%, 20% and 30% by weight.

Figure 1 (b). Cumulative mass loss v/s Time in hour at 90° impact angle and 30% wt concentration for AISI 430, AISI 204 and Chromium carbide coatings.
Figure 2 (a). Slurry erosion rate (mg/hr) v/s Slurry concentration (% wt) at 30° impact angle for AISI 430, AISI 204 and Chromium carbide coatings.

Figure 2 shows the Slurry erosion rate (mg/hr) v/s Slurry concentration (% wt) at 30° impact angle (a) and 90° impact angle (b) for AISI 430, AISI 204 and Chromium carbide coatings and Figure 3 shows the bar chart of the Slurry erosion rate (mg/hr) v/s Slurry concentration (% wt) at 30° impact angle (a) and at 90° impact angle (b) for AISI 430, AISI 204 and Chromium carbide coatings. It is clear that AISI 430 has higher slurry erosion rate than other materials used in experiments and both coatings have the almost same erosion rate which is minimum for all materials used in experiments. Figures also show that slurry erosion rate increases with increasing the slurry concentration.

Figure 2 (b). Slurry erosion rate (mg/hr) v/s Slurry concentration (% wt) at 90° impact angle for AISI 430, AISI 204 and Chromium carbide coatings.
Figure 3 (a). Slurry erosion rate (mg/hr) v/s Slurry concentration (% wt) at 30° impact angle for AISI 430, AISI 204 and Chromium carbide coatings.

Figure 3 (b). Slurry erosion rate (mg/hr) v/s Slurry concentration (% wt) at 90° impact angle for AISI 430, AISI 204 and Chromium carbide coatings.
**Figure 4 (a).** Slurry erosion rate (mg/g) v/s Slurry concentration (% wt) at 30° impact angle for AISI 430, AISI 204 and Chromium carbide coatings with 60 minute cycle time.

**Figure 4 (b).** Slurry erosion rate (mg/g) v/s Slurry concentration (% wt) at 90° impact angle for AISI 430, AISI 204 and Chromium carbide coatings with 60 minute cycle time.
Figure 5 (a). Slurry erosion rate (mg/g) v/s Slurry concentration (% wt) at 30° impact angle for AISI 430, AISI 204 and Chromium carbide coatings with 60 minute cycle time.

Figure 5 (b). Slurry erosion rate (mg/g) v/s Slurry concentration (% wt) at 90° impact angle for AISI 430, AISI 204 and Chromium carbide coatings with 60 minute cycle time.

Figure 4 shows the Slurry erosion rate (mg/gram of erodent) v/s Slurry concentration (% wt) at 30° impact angle (a) and 90° impact angle (b) for AISI 430, AISI 204 and Chromium carbide coatings with 60 minute cycle time and Figure 5 shows the bar chart of the Slurry erosion rate (mg/gram of erodent) v/s Slurry concentration (% wt) at 30° impact angle (a) and at 90° impact angle (b) for AISI 430, AISI 204 and Chromium carbide coatings with 60 minute cycle time. It is clear that AISI 430 has higher slurry erosion rate than other materials used in experiments and both coatings have the almost same erosion rate which is minimum for all materials used in experiments. Figures also show that slurry erosion rate decreases with increasing the slurry concentration.

5. Conclusions

An investigation of impingement angle and slurry concentration on slurry erosion behaviour for AISI 430, AISI 204 and Cr$_3$C$_2$-NiCr coating on AISI 430 and AISI 204 stainless steel has led to following conclusions:

- AISI 430 has higher slurry erosion rate (mg/hr) than AISI 204 and Cr$_3$C$_2$-NiCr coating on AISI 430 and AISI 204 stainless steel and both the coatings have the almost same erosion rate.
(mg/hr) which is minimum for all materials used in the experiments. Slurry erosion rate (mg/hr) increases with increasing the slurry concentration. Slurry erosion rate (mg/hr) is greater at 30° impingement angle than at 90° impingement angle.

- Slurry erosion rate, mg per gram of erodent (mg/g), decreases with increasing the slurry concentration. Slurry erosion rate (mg/g) is greater at 30° impingement angle than at 90° impingement angle. AISI 430 has higher slurry erosion rate (mg/g) than AISI 204 and Cr$_3$C$_2$-NiCr coating on AISI 430 and AISI 204 stainless steel and both the coatings have the almost same erosion rate (mg/g) which is minimum for all materials used in the experiments.

6. References

[1] Bukhaiti M A, Ahmed S M, Badran F M F and Emara K M 2007 Effect of impingement angle on slurry erosion behaviour and mechanisms of 1017 steel and high-chromium white cast iron, *Wear* 262, 1187–1198

[2] Wen D C 2010 Improvement of Slurry Erosion Resistance of Martensite/Ferrite Duplex Stainless Steel by Hot Rolling, *Met. Mater. Int.* 16, 13-19

[3] Wang H W and Stack M M 1999 The slurry erosive wear of physically vapour deposited TiN and CrN coatings under controlled corrosion, *Tribology Letters* 6, 23–36

[4] Shivamurthy R C Kamaraj M Nagarajan R Shariff S M and Padmanabham G 2009 Slurry Erosion Characteristics and Erosive Wear Mechanisms of Co-Based and Ni-Based Coatings Formed by Laser Surface Alloying, *Metallurgical and Materials Transactions A* 41A, 470-86

[5] Desale G R, Gandhi B K and Jain S C 2009. Particle size effects on the slurry erosion of aluminium alloy (AA 6063), *Wear* 266, 1066–1071

[6] Desale G R Gandhi B K and Jain S C 2008 Slurry erosion of ductile materials under normal impact condition, *Wear* 264, 322–30

[7] Gandhi B K and Borse S V 2004 Nominal particle size of multi-sized particulate slurries forevaluation of erosion wear and effect of fine particles, *Wear* 257, 73–79

[8] Fang Q Xu H Sidky P S and Hocking M G 2017 Erosion of ceramic materials by a sand water slurry jet, *Wear* 224, 183–19

[9] Wood R J K 2006 Erosion–corrosion interactions and their effect on marine and offshore materials, *Wear* 261, 1012–23

[10] Clark H M and Hartwich R B 2001 A re-examination of the ‘particle size effect’ in slurry erosion, *Wear* 248, 147–61

[11] Lopez D Congote J P Canob J R Torob A and Tschiptschin A P 2005 Effect of particle velocity and impact angle on the corrosion-erosion of AISI 304 & AISI 420 stainless steels, *Wear* 259, 118–24