Combined slurry and cavitation erosion resistance of surface modified SS410 stainless steel

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Abstract. Slurry erosion and combined slurry and cavitation erosion resistance of thermal spray coatings are studied and compared with the as-received martensitic stainless steel material. 70Ni-Cr coatings are deposited on SS 410 material through plasma thermal spray process. The synergy effect of the combined slurry and cavitation erosion resistance of plasma thermal spray coatings were investigated in a slurry pot tester in the presence of bluff bodies known as Cavitation Inducers. Results showed the combined slurry and cavitation erosion resistance of martensitic stainless steel - 410 can be improved by plasma thermal spray coating. It is observed that the plasma spray coated specimens are better erosion resistant than the as-received material, subjected to erosion test under similar conditions. As-received and the surface modified steels are mechanically characterized for its hardness, bending. Morphological studies are conducted through scanning electron microscope.

1. Introduction

Slurry erosion is the result of the interaction of solid particles present in liquid on the surface of any materials. Slurry erosion is a tedious and serious problem in fluid handling and processing industries [1, 2]. Slurry erosion also plays a key role in deteriorating the hydraulic machine components. Silt in water acts as erodent, consisting of hard quartz (70-98 %), which causes severe damage to the machine components [3]. Erosion caused by slurry is a complex process, as the factors viz., operating conditions, characteristics of erodent, various properties of the material, impingement angle, concentration, fluid flow conditions acts simultaneously [4].

Martensitic stainless steels such as 13Cr-1Ni, 13Cr-4Ni, etc. are generally used as the hydraulic machine material. It possesses excellent mechanical and functional properties, which can resist corrosion. But the martensitic stainless steels are prone to erosive wear, hence gets damaged due to excessive silt present in the water, along with the cavitation. Composite materials are also evaluated for tribological studies to suit for the required applications [5]. Surface modification techniques like mechanical processing [6, 7], coating [8-10], microwave processing [11-12], laser deposition [13-17] and friction stir processing [18] are employed to improve the erosion resistance of the hydro turbine materials.

Surface modification is the most viable technique to increase the life of the Hydro-turbine materials as found from the literature. Composite coatings WC/Co by Oxy fuel powder process and Al₂O₃ by Wire arc spray process are deposited on to the AISI 304 steel for slurry erosion resistance of hydro turbine materials. It was observed that WC/Co coating showed better erosion resistance than all other materials evaluated, resulted may be due to the hard carbides existence [19]. CF8M steel a hydro turbine material was surface modified by High velocity oxy fuel spray process by WC-10Co-Cr and Al₂O₃ with TiO₂ coating for slurry erosion evaluation. It is observed that WC-10Co-Cr exhibited better slurry erosion resistance than the other coating and CF8M steel due to its high hardness. Al₂O₃ with TiO₂ eroded more than the CF8M steel due to its low hardness and lesser adherence to the substrate.
[20]. CA6NM turbine steel was surface modified by the HVOF spray process by Cr3C2–NiCr coating for slurry erosion evaluation. Surface modified steel showed better erosion resistance than the unmodified CA6NM steel for all the test conditions [21]. Investigation on well known 13Cr-1Ni material, surface modified by HVOF spray technique for slurry erosion investigation has been carried and found the better erosion resistance of the coating material than the as-received material [22, 23]. 13Cr-4Ni and 16Cr-5Ni were surface modified through detonation gun spray process by WC-Co-Cr coatings and observed the improvement in erosion response of the coated material than the as-received material [24]. WC-12Co clad developed through microwave energy on the austenitic stainless steel were subjected to erosive wear investigation and observed the improvement in erosive wear behaviour of the clad material [25].

Literature available was very less for the combined effect of slurry erosive wear and cavitation using a slurry pot tester. Therefore in the present work, martensitic stainless steel SS410 is used as a candidate material and is surface modified through plasma thermal spray process by 70Ni-Cr. The surface modified and as-received steel are investigated for slurry erosion individually and the combined effect of slurry erosion and cavitation using slurry pot tester for erosion resistance is studied. The cavitation is incepted by using the prismatic bluff bodies known as Cavitation Inducers (CIs) in the slurry pot tester.

2. Experimental section

2.1. Test setup

![Figure 1: Slurry pot test setup](image)

Slurry erosion and cavitation effect in the present work is created in slurry pot erosion tester (figure 1). It consists of a pot, and a specimen holder. The pot contains four baffle plates which are welded as shown in the figure 1. Measured quantity of water and sand is used as slurry (10% wt) for the evaluation of the material. The specimen holder is fastened to the spindle driven by 3 kW motor at constant speed of 625 rpm. The holder used for mounting the specimens contains two circular plates; between which the specimens are placed and fastened by bolts and nuts. The erosion test is conducted for 20 h and the weight loss of the specimens is measured at 5 h intervals by electronic balance (Make: Anamed) having an accuracy of 1 mg. The erosion test is conducted with sand particle having the average size in the range of 200 to 300 microns. The size range of the erodent is selected based on the literature that the erosive particles greater than 300 µm diameter couldn’t pass through the filters of the hydropower plants [26].

2.2. Test materials and cavitation inducers

The nominal chemical composition of the SS410 material in percentage is shown in table 1. The dimensions of the as-received and surface modified specimens for the slurry erosion test are of (10 x25x6) mm width, height and thickness. Triangular prismatic bodies, known as Cavitation Inducers (CI) are of 316L stainless steel having 10 mm base and 25 mm height are used to induce cavitation in the slurry pot. It is found from the literature that CIs with 30° apex angles produced more erosion of materials than the CIs with 15°, 45° and 60° apex angles. Therefore in the present investigation, CIs
3. Results and discussions

3.1. Hardness characterization

Microhardness test was conducted using Vickers micro-hardness measuring instrument (HWMMT-X7) by applying 0.1 kg load with dwell time of 15 s with a pyramid indenter. The comparison of hardness values are shown in table 2. The surface hardness of the plasma spray coated specimen is compared with the as-received specimen under similar loading conditions. Result shows that the plasma spray coated specimen possess higher hardness compared to that of as-received specimen.

| Grade | C     | Si  | Mg  | P   | S   | Cr  | Ni  |
|-------|-------|-----|-----|-----|-----|-----|-----|
| SS410 | 0.08/0.15 | 1.00 | 1.50 | 0.040 | 0.030 | 11.5/13.5 | 0.75 |

3.2. Bending test

(a) Specimen before bending test  (b) Specimen after bending test

Figure 3: Surface modified specimen for bending test
Bending test is conducted for both the as received and the surface modified material. Table 3 shows the results of the bending test. Figure 3(a) shows the specimen before bending test and figure 3(b) shows specimen after bending test. Table 3 shows the results of the bending test, which confirms that coated specimen possess better bending characteristics than the as received material.

| Specimen type         | Load at Peak, kN | Tensile Strength, MPa | Load at Break, kN |
|-----------------------|------------------|------------------------|-------------------|
| Specimen without Coating | 8.26             | 54.78                  | 40.42             |
| Coated specimen       | 9.75             | 64.44                  | 6.45              |

3.3. Peel-off test

Peel off test was conducted according to the ASTMC 633 test method for cohesion or adhesion strength of Thermal Spray Coatings. A test Strip of 25 mm wide and 175 mm length is adhered to 25×100×6mm plasma spray coated steel specimen with the exertion of pressure by a 2 kg roller. The sample is detached at an angle 90°, at a constant speed of 300 mm/min. Peel off test confirms the good adhering strength of the coating done on the base material and confirms that the coating has passed the peel off test.

3.4. Slurry erosion test

Figure 4: Weight loss of the surface modified and the as-received specimens for slurry erosion (Without CI) and combined slurry and cavitation erosion test (With CI). (a) 200 µm sand and (b) 300 µm sand.

Weight loss comparison plots of the plasma spray coated and as-received specimens subjected to erosion test individually and synergy of slurry erosion and cavitation test with and without cavitation inducers are shown in figure 4. The comparison plot of the erosion test conducted with 200 µm sand is shown in figure 4(a). It is observed from the plot that, the surface modified material is better erosion resistant than the as-received material for both slurry erosion and combined slurry and cavitation erosion test. The results obtained with 300 µm sand are shown in figure 4(b). Similar results as compared with the 200 µm sand are obtained for erosion test with 300 µm sand that, the coated material is better erosion resistant than the as-received material under similar conditions. Erosion of as received material is more compared to 70Ni-Cr coated material, due to increase in hardness which confirms with the results found from literature. Results of the slurry erosion test with 300 µm sand size has also resulted in increased weight loss as compared with erosion test with 200 µm sand size, which also confirms that the increase in sand size also results in increased erosion. The effect of the
sand size on the erosion of both 70Ni-Cr plasma spray coated SS410 material and as-received falls well within the error limit.

3.5. SEM characterization

![Figure 5: SEM micrographs. (a) As received specimen, (b) Surface modified specimen, (c) Coating thickness specimen, (d) Erodent (e) & (f) Best and Worst erosion resistance for 200 µm sand and (g) & (h) Best and Worst erosion resistance for 300 µm sand.](image-url)
Surface morphology of the specimens before test, erodent, and specimen showing best and worst erosion resistance after test are carried by SEM and their micrographs are shown in figure 5.

Erosion of the materials is caused due to the erodent in the water for slurry erosion and by locating the cavitation inducers for combined slurry and cavitation erosion test. Figure 5(a) shows morphology of the surface of as received specimen in which martensitic phases are identified. Figure 5(b) represents the micrograph of the surface of coated specimen, the pores are observed from its micrograph. Figure 5(c) shows the coating thickness of the specimen and its thickness is about 67 µm on the substrate surface. Figure 5(d) gives the surface morphology of the erodent, in which sharp edges and irregularity of the erodent are visualized. Figure 5(e) & 5(f) shows the surface morphology of the specimens subjected to slurry erosion test conducted with 200 µm sand with and without CIs, where as figure 5(g) and figure 5(h) for 300 µm sand. It is known from the literature that erosion takes place either by cutting (micro cracks) or by ploughing action (deformation) of the material. The erosion is enhanced by the cavitation induced by the CIs in the erosion chamber. Micrographs show the scratches, pits, deep craters, protrusions formed on the surface after erosion making the surface rough. These sharper craters are formed by the erosion effect of sand particles contained in the water and also due to low pressure region that causes cavitation due to the presence of CIs. The repetitive nature of the solid particle in striking the specimen and implosion of the cavities on the surface, accelerating the solid particles due to implosions leads to removal of the material from the surface. These contribute to the weight loss of the material, which also confirms through the micrographs for slurry erosion test alone and combined slurry and cavitation erosion test.

4. Conclusions

i. Slurry erosion and combined slurry and cavitation erosion test were performed on the as-received and the 70Ni-Cr plasma spray coated SS410 stainless steel material.
ii. Cavitation Inducers are placed to induce cavitation in the slurry pot for creating synergy of slurry and cavitation erosion in the test.
iii. 70Ni-Cr plasma spray coated SS410 material has shown better erosion resistance than the as-received material for the sand particle having the average size in the range of 200 to 300 µm.
iv. The effect of the sand particle size has direct relation with the weight loss; with increase in the sand particle size, erosion rate increases.
v. Increase in the hardness of the coated material than the as received material has increased the erosion resistance for both slurry erosion and combined slurry and cavitation erosion test.

5. References

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