Combined slurry and cavitation erosion resistance of HVOF spray coated SS 410 steel

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Abstract. The hydro turbine materials surface is degraded due to the slurry erosion and cavitation. The solid particles carried by water impacting the material results in slurry erosion. The damage occurred due to slurry erosion is the concern, when considered individually. The erosion damage is observed to be severe when slurry erosion and cavitation are combined. The hydro turbine material, martensitic stainless (SS 410) is surface modified with 80Ni-Cr by High Velocity Oxy Fuel spray process. The coated material subjected to post thermal treatment at a temperature of 950 °C, soaked at 1 h, 2 h and 3 h are subjected to combined slurry and cavitation erosion test. The cavitation is created by using Cavitation Inducers. The tests are conducted by using silica sand as the erodent with three different sizes of 150, 200 and 300 µm. The results are compared with the as-received specimen. The results confirmed the effect of heat treatment on the end results, as the coated thermal treated specimens showed better erosion resistance against the as-received specimen. The eroded specimens are characterized by Scanning Electron Microscope. The thermal treated HVOF coated specimens shown the better erosion resistance.

1. Introduction
The material’s surface degradation is profound to be the most common problem in fluid handling industries. The degradation rate increases due to the presence of solid particles in the fluid medium. In power plants, the major components runners, blades, turbine buckets will erode due to the continuous interaction with water carrying abrasive particles such as ash, grit, sand etc. The mixture of abrasive particles with water forms the slurry. The degradation of turbine materials due to the influence of slurry is known as slurry erosion. The erosion rate of these hydro turbine materials gets accelerated during the monsoon season, due to higher amount of solid particles carried by the water [1].

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problem of slurry erosion is a concern for much hydro power producing nations and suffering financial losses of several million dollars per annum [2].

To assess the problem, the research is carried to evaluate the erosion of materials by the development of test methods, and test rigs and by the surface modification of materials [2-7]. The evaluation of slurry erosion got complicated due to number of associated parameters [8]. The erosion of materials by slurry erosion, cavitation, and corrosion is evaluated individually [9-10]. The combined mode of slurry and cavitation erosion study is also carried out [11]. The results from the combined mode, confirms the erosion of materials due to combined effect is more than with the individual effects. The surface modification of materials is done by number of techniques, but the thermal spray coating is widely accepted and used.

Titanium Aluminum Nitrogen was coated on the steel specimens by ion-plasma sputtering for wear resistance [12]. Ni-based super alloys are thermal sprayed by Yttria stabilized zirconia for solid particle erosion investigation for gas turbine application [13]. The WC-12Co coatings are deposited on the mild steel substrate by using the detonation spray process for slurry erosion evaluation [14]. Carbon fiber reinforced polymers were surface coated by Ti-AI-Cr and multilayered Ti/TiN through magnetron sputtering technique for erosion investigation [15]. The mild steel specimens were thermally sprayed with Inconel 718 powder air plasma spray technique to investigate the slurry erosive characteristics [16]. Ni based thermal spray coating was deposited by high velocity flame spray on the hydro turbine material 13-4 stainless steel with Aluminium oxide varied in different proportions, is evaluated for its erosion characteristics by slurry erosion test rig [17]. The combined slurry and cavitation erosion resistance of 70Ni30Cr HVOF thermal spray coating were studied and compared to that of an uncoated martensitic stainless steel (SS 410) [18].

In the present work, the martensitic stainless steel of SS410 type is used as the substrate material, on which 80Ni-Cr has been thermally sprayed by High Velocity Oxygen Fuel (HVOF) spray process to investigate the combined slurry and cavitation erosion behavior. The synergy of slurry and cavitation erosion test method is a non ASTM standard test method. Cavitation Inducers (CIs) are used to induce cavities leads to the synergy effect in the slurry pot [11].

2. Experimental

2.1 Material

The Martensitic stainless steel (SS 410), is used as the substrate material, its chemical composition is described in Table 1. The substrate material is surface modified by HVOF thermal spray process with 80Ni-Cr. The coated material was subjected to heat treatment. The specimens were subjected to thermal treatment with muffle furnace set at a constant temperature of 950°C and soaked at different periods of 1 h, 2 h, 3 h and are water quenched. The specimens used for the slurry erosion test is of the dimensions of $25 \times 10 \times 6$ mm$^3$.

Table 1: Chemical composition of SS 410 material

| Grade | C    | S    | P    | Si  | Mn  | Cr     | Ni   |
|-------|------|------|------|-----|-----|--------|------|
| 410   | 0.08/0.15 | 0.03 | 0.04 | 1   | 1.5 | 11.5/13.5 | 0.75 |

2.2 Test setup

The combined slurry and cavitation erosion test is conducted in the conventional slurry pot erosion tester; its schematic diagram is shown in figure 1 which is similar to the method reported by Amarendra et al [11]. The tester consists of a container (pot) of 320 mm diameter and 285 mm height and is attached with four baffle plates of 30 mm width placed mutually perpendicular to each other. The baffle plates are used to avoid the settling of sand at the bottom of the pot. The specimen holder contains two circular plates with 200 mm diameter in between which specimen and the CIs are placed with polymer material to provide necessary gripping between the specimen
and the plates, held securely by bolts and nuts. The specimen holder is attached to the spindle driven by a variable speed gear drive maintained at a constant speed of 625 rpm.

![Schematic of the test setup](image1.png)

**Figure 1: Schematic of the test setup**

### 2.3 Test conditions and parameters

- Test duration: 20 h
- Erodent type: Silica sand
- Erodent size: 150, 200 and 300 µm.
- Slurry concentration: 10 wt. %
- Slurry medium: Tap water

![Specimens and CIs arrangement on the plate](image2.png)

**Figure 2: Specimens and CIs arrangement on the plate**

The cavitation is inceptivized by using the CIs. The CIs were of triangular prismatic bluff bodies with 30° apex angle with 10 mm base and 25 mm height placed in between the slurry and the specimen creating a low pressure region resulting in the cavitation. Figure 2 shows the arrangement of specimens and the CIs for erosion test. Specimens were exposed to slurry with the cavitation inducers.
for combined slurry and cavitation erosion investigation. The specimens and CIs are placed at a distance of 0.8 times the base of the triangle of the CI [11].

3. Results and discussions

3.1 Slurry erosion tests with CIs

AR - As received specimen  
C - Coated specimen  
C HT 1 - Coated specimen heat treated at 950°C and soaked for 1 h.  
C HT 2 - Coated specimen heat treated at 950°C and soaked for 2 h.  
C HT 3 - Coated specimen heat treated at 950°C and soaked for 3 h.

Figure 3 shows the comparison plots of the slurry erosion test conducted with CIs. The erosion test was conducted on the as received specimen, HVOF coated specimen, and the HVOF coated thermal treated specimens. The weight losses of the specimens are measured at an interval of 5 h with an electronic balance (Amada make with 0.001 g least count) during the 20 h erosion test. The result confirms the effect of heat treatment on the weight loss of the specimens. Figure 3(a) is the result of the slurry erosion test conducted with 150 µm sand. The coated untreated specimen is eroded much more than other specimens. CHT1 specimen showed better erosion resistance, then the coated specimen without post thermal treatment. Figure 3(b) and figure 3(c) are the result of the slurry erosion test conducted with 200 and 300 µm sand respectively. For the sand size of 200 µm, the C HT 2 specimen eroded more when compared with the other specimens. C HT 3 specimen showed better erosion resistance. With 300 µm sand, the C HT 1 specimen eroded more while C HT 2 specimen showed the better erosion resistance. From the test results, the effect of combined cavitation and slurry erosion is observed [11]. The thermal treated coated specimens have shown better erosion resistance to the synergy effect [18]. This may be because of increase in hardness of the coating and formation of...
carbides due to thermal treatment. The observed test results confirm that the 80Ni-Cr coated specimens are better erosion resistant than the as-received specimens irrespective of the test sand size.

3.2 SEM Examination

The Figure 4 shows the micrographs of specimens showed best and worst erosion resistant specimen surface morphology by Scanning Electron Microscope. Figure 4 (a) and (b) are the SEM Micrographs of the specimens subjected to slurry erosion test with CIs for 150 µm sand. Figure 4 (a) is the micrograph of C HT 1 specimen showed the better resistance to erosion with 150 µm sand. The detaching of the coated surface and the damage at different locations are observed. Figure 4 (b) is the SEM micrograph of the C specimen, showing the deep damage to the coating surface and the most damage is occurred at the nearby places of the specimens. Figure 4 (c) and (d) are the SEM Micrographs of the specimens subjected to slurry erosion test with CIs for 200 µm sand. Figure 4 (c) is the eroded surface of the C HT 3 specimen, the surface is uneven after the test and very minute damage on the coated material is observed. Figure 4 (d) is the eroded surface of the C HT 2 specimen showing the damage to the coating material at various locations. Figure 4 (e) and (f) are the SEM Micrographs of the specimens subjected to slurry erosion test with CIs for 300 µm sand. Figure 4 (e) is the micrograph of the C HT 2 specimen, with the increase in the sand size, the damage occurred to the surface seems more and the detachment of the coating material is observed. Figure 4 (f) is the micrograph of C HT 1 specimen showed the least resistance to erosion with 300 µm sand. The deep crater and the damages at various locations are observed. Figure 4 (g) is the magnified image of figure 4 (b), confirms the nearby damages to the specimen.
Figure 4: SEM micrographs of the specimens with better and least erosion resistance for each sand.
(a) C HT 1 specimen with 150 µm sand, (b) C specimen with 150 µm sand (c) C HT 3 specimen with 200 µm sand, (d) C HT 2 specimen with 200 µm sand, (e) C HT 2 specimen with 300 µm sand, (f) C HT 1 specimen with 300 µm sand, and (g) C specimen of higher magnification with 150 µm sand.

4. Conclusions
1. The combined slurry and cavitation erosion test was conducted for the as-received, the HVOF coated, and the post thermal treated coated specimen.
2. The 80Ni-Cr HVOF coated specimens are better erosion resistant then the as-received specimens irrespective of the sand size.
3. The 80Ni-Cr HVOF coated-post thermal treated specimens are found to be better erosion resistant than the coated untreated and the as-received specimens.

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