Evaluation of slurry erosion wear characteristic of plasma sprayed TiO$_2$ coated 410 steel

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Abstract: In the present study, slurry erosion performance of plasma sprayed Titanium oxide (TiO$_2$) coatings on AISI 410 steel has been investigated. Erosion studies were performed on uncoated and plasma sprayed TiO$_2$ coated steel using slurry erosion test rig at room temperature by varying the rotational speed (500, 750, 1000, and 1500), keeping sand concentration and time as constant. To know the erosion mechanism, SEM microphotographs were taken before and after the erosion test. EDX analysis confirms the presence of Titanium oxide particles. Vickers’s micro hardness test was performed on the surface of both coated and un-coated samples to access the hardness value. Plasma sprayed titanium oxide coated 410 grade steel showed superior slurry erosion resistance as compared to un coated steel. It may be due to higher hardness and less porosity of TiO$_2$ coated steel substrates.

Key words: Plasma Spray, Slurry Erosion, Micro Hardness.

1. Introduction

The mass loss that happens when small solid particles suspended in liquid medium hits steel surface is a important consideration in the design of components which are used in hydro applications like pump impellers, turbine blades, mining pipelines etc. AISI 410 SS find applications in turbine blades, pipelines, and pump impellers, bearings etc. slurry erosion rate is influenced by various liquid flow variables such as flow velocity, slurry concentration, abrasive particle size and property of material. slurry erosive behavior of plasma sprayed titania-30 wt% Inconel 718 coating on copper substrate with a coating thickness of 100 and 200 µm. Show that coated copper exhibited greater wear resistance than uncoated copper. [1]. The composite coating performance of CF8M turbine steel under slurry erosion condition concluded that composite coated substrate have better resistance for slurry erosion compared to uncoated steel. [2]. Tribology of thermal sprayed WC-Co based coatings on steel substrate was observed that by optimizing the deposition parameters of HVOF coating gives improved erosion resistance by 50% more than conventional detonation gun sprayed coating and also the maximum erosion will be observed at 90º jet angle while minimum erosion will be at 30º jet angle. [3]. Slurry erosion of Ni based alloy coating on commonly used hydro turbine steel concluded that all the coatings helps in improving the erosion resistance but with one sample containing 40 wt% Al$_2$O$_3$ shows maximum improvement to erosion. [4]. In slurry erosive wear study of Ni-P coated Si$_3$N$_4$ reinforced AL6061 composite, electroless process was used to coat Ni-P on silicon nitride particles and the developed composite were subjected to slurry test. The test results reveal that developed composite shows higher slurry erosion resistance compared with metal matrix alloy. [5]. Study on slurry erosion properties of ceramic coating and functionally gradient materials concluded that under oblique angle of impact Al$_2$O$_3$ coating shows better erosion resistance. [6]. A comparative study on
HVOF sprayed Fe-based amorphous metallic coating with 304 stainless steel under slurry impingement. Concludes that amorphous metallic coating exhibited higher erosion-corrosion resistance than 304 stainless steel. [7]. Slurry erosion behavior of Inconel-718 coated AL6061 alloy shows decreased slurry wear rates on coating substrate with Inconel-718. [8]. Erosion-wear behavior study of Al$_2$O$_3$-Cr$_2$O$_3$ composite coating on stainless steel substrate by plasma spraying method. Concludes that Al$_2$O$_3$-Cr$_2$O$_3$ composite coating exhibits better erosion resistance than pure Al$_2$O$_3$ coating. [9]. A comparative study on dry and slurry erosion behavior of HVOF sprayed Wc-CoCr coating on 410 stainless steel shows that dry erosion rate of coated samples is more when compared to slurry erosion and also cermet coating with fine Wc have higher erosion resistance than pure cermet coating. [10].

In the present study TiO$_2$ powder is thermally sprayed on 410 SS using APS technique and its slurry erosive wear behavior is investigated.

2. Experimental Details

2.1 Material selection

AISI 410 SS was selected as a substrate material it is a martensitic stainless steel with good hardness and strength, finds most of its application as turbine blade material in hydropower generation, pump impellers and pipe lines in mining industries etc. TiO$_2$ powder of particle size 50 µm was chosen as a coating material and it was thermally sprayed on 410 SS with the help of atmospheric plasma spray technique (APS).

2.2 coating procedure

Initially the substrate material was grit blasted and before the actual spray process begins a thin layer of Ni-Cr bond coat was applied on substrate to provide good bonding between the coating and the substrate. TiO$_2$ powder particles of size 50 µm were thermally sprayed on 410 SS using atmospheric plasma spray technique, and a coating thickness of 200 µm was achieved with minimum porosity. Plasma spray set up consists of two electrodes as anode and cathode which ionizes the working gas flowing between the electrodes. Argon and hydrogen were used as primary and secondary working gases during the coating process. The parameters adopted during the plasma spraying are kept constant until the completion of coating.

2.3 Micro hardness

Hardness of coatings and substrate material is an important consideration for slurry erosion behavior. In the present work Vickers micro hardness test was conducted on both TiO$_2$ coated and uncoated samples with a load of 100 gm and a dwell time of 10 s. Hardness values are measured at three different surface areas on the specimen and the average of three readings were considered as a micro hardness value of the material. For base material micro hardness value will be 211Hv0.1 and for TiO$_2$ coated specimen micro hardness value is 344Hv0.1

2.4 slurry erosion test

Test samples of TiO$_2$ coated and uncoated material of dimension 25×25×8 mm were subjected to slurry erosion test. Initial Weight of all the samples was noted before and after the test in order to determine the mass loss. Initially the uncoated areas of the coated specimens were masked with the masking tape in order to avoid the mass loss of uncoated areas. The same method is even followed for the uncoated samples also where only one surface area was exposed to slurry erosion while the
remaining surfaces are masked with the masking tape. Figure 1 Shows the Erosion pot tester which is used as a test equipment to conduct the slurry erosion test and it consist of six stainless steel slurry cups (capacity 2 lts) along with six vertical spindles at the centre of each slurry cups. The spindles were connected to the electric motor through belt drive for a maximum run of 1500 rpm. Slurry was prepared by mixing 3.5 % NaCl and silica sand particles of size 312 µm having concentration 150 gms/ltr in distilled water. The test specimens were fixed in to the spindles with the help of screws, all the fixed samples were dipped in to the slurry cups and the spindle was made to rotate at the required rpm. In the present work slurry rotation was varied from 500-1500 rpm in a step of 500, 750, 1000 and 1500 rpm with test duration of 10 hrs. After the test all the samples were cleaned with acetone and they were weighed to know the mass loss.

![Figure 1](image)

**Figure 1.** Photograph of slurry erosive wear tester. (1) Non-corrosive spindle unit (2) slurry unit, (3) Precision guides, (4) Powder coated tubular structure, (5) Thermocouple, (6) Water cooling unit and (7) Motor drive for slurry unit.

3. Result and Discussion

3.1 Microstructure

Microstructure analysis was carried out on TiO$_2$ coated and uncoated samples before the slurry erosion test. Figure 2 and 3 shows the SEM photographs of uncoated material and TiO$_2$ coated material, SEM of TiO$_2$ coated sample reveals the fair and uniform distribution of TiO$_2$ powder particles on substrate with minimum porosity.
3.2 Slurry Erosion Test

3.2.1 Effect of Slurry Rotation Speed

The effect of rotational speed on slurry erosive wear of developed coatings of thickness 200 µm and uncoated material is shown in Figure 4(a). It is observed that with increased in the slurry rotational speed results in higher mass loss. This is due to reality that with increasing the slurry rotational speed impact velocity of silica particles increases their by causes a severe damage on the exposed surfaces. Further the 200 µm thick coating exhibited good wear resistance to slurry erosion compared to uncoated material. Figure 4 (b) represents the EDX analysis at the interface between the coated and substrate material which confirms the presence of elements like Cr, Ti and Ni.

![Figure 4](https://via.placeholder.com/150)

(a) Shows (a) Effect of Coatings v/s Un-coated material (b) EDX analysis at the interface between coating and substrate.
3.2.2 Erosion Corrosion Mechanism

SEM images of slurry eroded uncoated and TiO$_2$ coated samples are shown in fig (5) and (6). Mass loss from the surface of both samples involves erosion and corrosion mechanism. Major mass loss is observed from the uncoated samples because of its less corrosion resistance capability and hardness as compared to coated steel. Fig (5) shows the indications of dark white patches of corrosion mechanism on uncoated sample. It is also observed that in fig (6) it shows the presence of some micro pits and micro cracks on the eroded surface of TiO$_2$ coated sample which are the main sources for mass loss from the coated surface.

Figure 5. (a) Uncoated steel at 500 rpm

Figure 6. (a) TiO$_2$ coated steel at 500 rpm

Figure 5. (b) Uncoated steel at 750 rpm

Figure 6. (b) TiO$_2$ coated steel at 750 rpm

Figure 5. (c) Uncoated steel at 1000 rpm

Figure 6. (c) TiO$_2$ coated steel at 1000 rpm
4. Conclusion

An investigation in effect of rotational speed on slurry erosive behavior of thermally sprayed TiO$_2$ coating on 410 SS has leads to the following conclusion.

- Rotational speed is the factor which has the highest influence on the slurry erosive wear.
- Plasma sprayed TiO$_2$ coatings shows higher micro hardness compared to uncoated substrate.
- Slurry erosion rates of both uncoated and TiO$_2$ coated samples increases with increasing the speed.
- The 200 µm thick TiO$_2$ coating exhibited good slurry erosion resistance compared to uncoated 410 SS.

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