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Experimental investigation on erosive wear behaviour of plasma spray coated stainless steel

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Abstract. Slurry erosion is an implicit problem in many engineering industrial components such as ore carrying pipelines, slurry pumps and extruders. Even the water turbine blades are subjected to erosive wear when the water contains considerable amount of silt. In the present study, Al_2O_3-40%TiO_2 powder particles of average particle size of 50 micrometer were deposited on EN56B martenistic stainless steel by atmospheric plasma spray technique. Ni/Cr was pre coated to work as bond coat for good adhesion between coating and the substrate material. A coating thickness of 200 micrometer was achieved. Coated and un-coated substrates were subjected to slurry erosion test as per ASTM G-119 standard. Slurry erosion test rig was used to evaluate the erosion properties at room temperature condition by varying the spindle speed. Scanning electron microphotographs were taken before and after the slurry erosion test. Microstructures reveal uniform distribution of coating materials. Eroded surface shows lip, groove, and crater formation and dense coating resulting in less porosity. Micro hardness test was evaluated and reported. EDX analysis confirms the presence of Al, Ti and O_2 particles. It was observed that, Al_2O_3-40%TiO_2 coated substrates exhibit superior erosion resistance as compared to un-coated substrates due to higher hardness and less coating porosity.

1. Introduction

Martenistic stainless steel are general purpose steels which are used in the fabrication of engineering components that require high mechanical properties and decent resistance to corrosion, such as valve parts, fasteners, cutting tools, hydroelectric turbine blades etc. [1]. Martenistic steels have good shock resistance and high plasticity, but due to less hardness and poor wear resistance they are sometimes not preferred for industrial application [2]. Thermal spraying is frequently considered as alternative prospective to the conventional coating processes for obtaining of wear and corrosion resistant coatings [3].Thermal spraying process is one of the largely used method of coating, which includes many processes and materials. Alumina-Titania composite ceramic coatings were extensively coated by the atmosphere plasma spray process for the components very much needed in wear, corrosion, erosion resistant environment [4]. Thus, plasma spraying is most versatile process used to produce coating of ceramic materials like Al_2O_3, Cr_2O_3, TiO_2 particles. They have properties like high hardness because of their pure ceramic nature. So, they were unconcerned to may erosion and corrosion environments [5]. Sanjeev Bhandari et.al have developed the Al_2O_3-13%TiO_2 and Al_2O_3 coatings on CF8M steels using D-gun spraying, and evaluated slurry erosion behavior with different process

parameters. They conclude that, Al_2O_3-13%TiO_2 shows superior resistance as compared to Al_2O_3 coated steel [6]. KVS Rao et al have studied the slurry erosion behaviour of plasma sprayed TiO_2 coatings on 410 steel substrate by varying the slurry rotational speed and reported that TiO_2 coated substrates possess more erosion resistance as compared to uncoated substrates [7].
In the light of the above, the objective of the present study is to evaluate the slurry erosion behavior of the plasma sprayed Al_2O_3-40%TiO_2 composite coating on the EN56B martenistic stainless steel by varying the slurry rotational speed at room temperature. These studies could help in increasing the performance of the components which operate in slurry erosive environment.

2. Experimentation details

2.1. Selection of substrate material and feed stock material

Martenistic stainless steels are general purpose steels which are used in the manufacturing of many engineering components, specifically in the hydro electric power generation sectors. During rainy season in India, the Himalayan region power generation units are facing erosion problems. In the present work EN56B martenistic steel substrates were selected as base material to develop the coatings for studying the erosion behavior.The substrate material was cut into standard dimension of 25x25x8mm from the steel sheet and subjected to grit blasting using alumina grit of size 60 micrometer. In the present study, Al_2O_3-40%TiO_2composite powder particles of average particle size 50 micrometer has been selected as feed stock materials. Fusing, blending and crushing operations have been done using ball mill to obtain this composition of powder particles. Ni/Cr powder particles in the ratio 80:20 are used as bond coat between the substrate and coating materials.

2.2. Coating method

Atmospheric plasma spray technique was used to develop the composite coating on the steel substrate. The plasma spray system is well known versatile process for ceramic coatings in which the plasma system consists of a house of power supply, control unit, heat exchangers, water supply unit for supplying the purified water to cool the sprayed gun. The System also has two electrodes(anode and cathode) in which high voltage current is capable of generating the arc between these and allow the primary and secondary(Ar and H2) gases into the arc chamber, which cause the ionization of the gases that leads to high temperature(about 150000K) plasma flame. Al_2O_3-40%TiO_2powders were introduced into the high temperature plasma flame through feeder. Flame from the tip of the nozzle melts the particles and impact on the target substrate with high velocity. Coating thickness of 200 micrometer was achieved successfully. The process parameters were kept constant throughout the operation. Ni/Cr particles of ratio 80:20 were made to deposit primarily on grit blasted substrates of average thickness 50 micrometer which acts as bond coat. Above this bond coat the surface coating of Al_2O_3-40%$TiO_2$was made using the same process.

2.3. Microstructure, micro hardness, porosity

One of the drawbacks of the plasma spray coating is formation of micro cracks and small pores on the surface of the substrates. In the present study scanning electron microscope was used to examine surface morphology of the coated and un coated surfaces before and after test. Microphotographs reveal the consistent scattering of the powder particles. EDX analysis was carried out for coated substrates and confirms the presence of Al and Ti particles. Porosity of the coated substrates was examined using optical microscope with image analysis software. In the present study micro hardness of the coated and uncoated substrates were examined using Vickers micro hardness tester.The micro hardness of the uncoated samples shows hardness of 259 HV0.1 and Al_2O_3-40%TiO_2coating shows hardness of 606 HV0.1.

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2.4. Slurry erosion test

Slurry erosion test for the coated and un coated steel substrates were conducted using high speed slurry erosion test rig as per ASTM G119 standard. Test rig consists of six rotating spindles(500-1500 rpm) and stainless steel slurry cups of capacity 2 litres. These cups are kept inside the test rig containing flat surface which is driven by electric motor for moving upward and downward. Test samples of standard size 25x25x8mm were fixed to the rotating spindles by means of screws and dipped into the slurry cup which contains 3.5% of NaCl powder and a required concentration of silica sand particles in one litre of distilled water. Before subjecting the samples to slurry test, one face of the sample was covered with masking tape to avoid erosion of the other face. In the present work slurry erosion study was carried out by varying the speed of the spindle in rpm(500,1000,1500) keeping silica sand particle size 312 micrometer and concentration 200gms/litre as constant throughout the test.

3. Result and discussion

3.1. Micro structure

Figure 1 and Figure 2 shows the scanning electron microphotographs of the uncoated and plasma coated Al_2O_3-TiO_2 steel substrates. They show the uniform distribution and dense deposition of coating material with good bonding with the substrate. Some deformed (partially melted) particles and lamellar structure was also observed.The optical microscopy analysis with image analysis software reveals a porosity of about 3.5% which describes that the coating obtained is very dense. Porosity is a function of powder particle size and effectiveness of the coating technique. Coarse powder particles are not desirable for obtaining dense coating. Fine particle size also yields good surface finish. Proper fusing of the powder coating also leads to less porosity and dense coating. Denser coatings give rise to higher hardness and obviously greater wear resistance. Composite coatings with a combination of various grades of powder particles were also found to yield good compaction and better hardness values. Figure 3 shows the Al_2O_3-40%TiO_2coating's EDX pattern that reveals the presence of Al, Ti, O_2 elements.

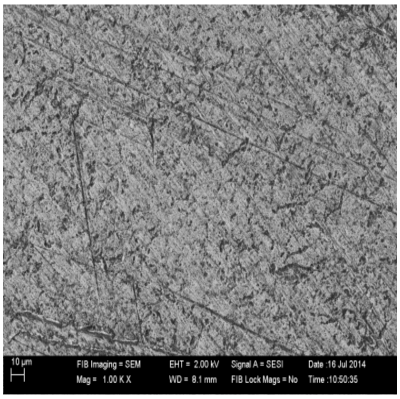

Figure 1. SEM image of base material before test

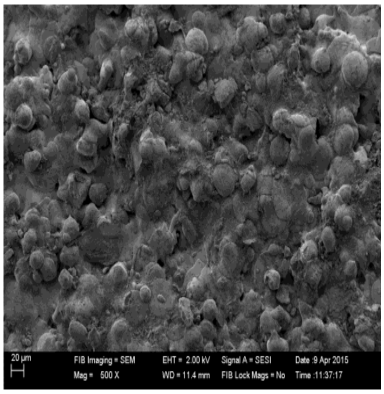

Figure 2. SEM image of Al_2O_3-40%TiO_2 coated substrate

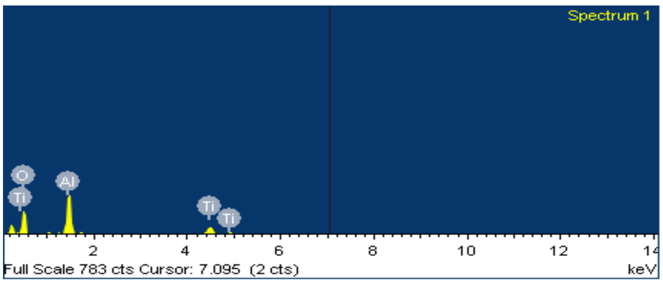

Figure 3. EDX spectrum of Al_2O_3-40%TiO_2coating

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3.2. Slurry erosion test

The coated samples were subjected to slurry erosion test using slurry erosion test rig. The test rig consists of a double walled water cooled stainless steel container with an internal diameter of 120 mm. The container houses six stainless steel spindles for mounting the test specimens. The spindle speed can be varied from 100 to 1500 rpm. The silica sand slurry was prepared by using distilled water with 3.5% NaCl and 20% silica sand. The Al_2O_3-40%TiO_2 coated test specimens were mounted on the stainless spindle. The erosion test was conducted for three different spindle speeds of 500rpm, 1000rpm and 1500rpm by keeping time as 5 hour. Slurry erosion rate was measured using weight loss technique. SEM images of the worn surface of uncoated and Al_2O_3-40%TiO_2coated steel are shown in Figure 4-7. Figure 8 shows the effect of spindle rotational speed on the erosion rate of the test surface. It is observed that, the mass loss for both uncoated and coated substrates increases with increase in the slurry rotational speed. Anyhow, coated substrates shows improved resistance to erosion as compared to uncoated surface. Al_2O_3-40%TiO_2 coated substrates shows better erosion resistance due to higher crack propagation resistance and toughness [3, 4]. From the experiment it was confirmed that, maximum mass loss occurs at higher speed (1500rpm). Because, at this speed impinging speed of the silica sand particles on to the substrates will increase that leads to irregular impingement causing more weight loss as compared at lower speeds. More plastic deformation was found to occur on both the uncoated and coated substrates causing the formation of grooves, lips and crater at higher rotational speeds as evidenced by the surface morphology of the test surface. Comparatively the plastic deformation on the Al_2O_3-40%TiO_2coated surface is much less than on the uncoated base material. This is attributed to better intersplat adhesion of Al_2O_3 and TiO_2 particles on the substrate which increases the hardness of the surface that resists wear loss.

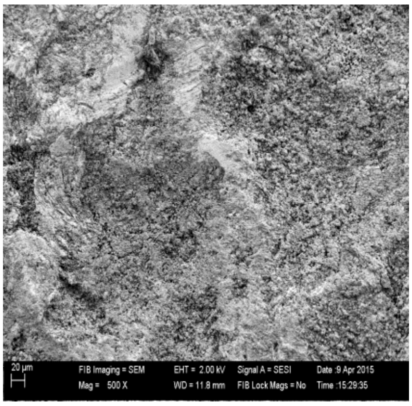

Figure 4. Un coated EN56B Steel at lower speed

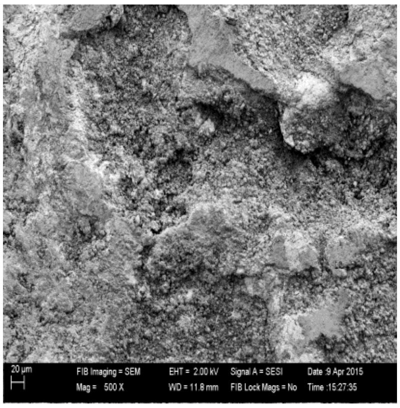

Figure 5. Un coated EN56B Steel at Higher speed

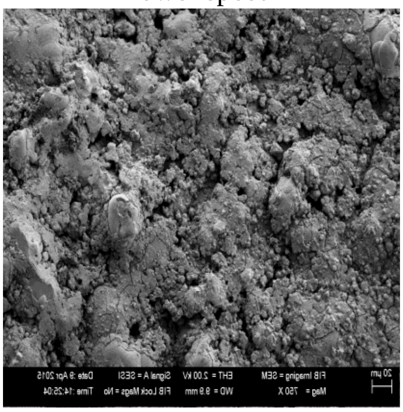

Figure 6. Al_2O_3-40%TiO_2coated steel at lower speeds

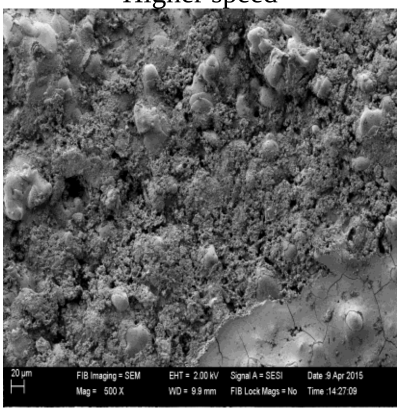

Figure 7. Al_2O_3-40%TiO_2coated steel at higher speeds

4. Conclusion

The conclusions composed from the present experiment are as follows:

- Al_2O_3-40%TiO_2powder particles were successfully deposited by plasma spray process on target material with dense coating and less porosity. EDX analysis confirms the presence of feedstock materials.
- Slurry Erosion Rate can be measured by varying different erosion parameters like Time, slurry concentration and particle size of the silica sand.
- Plasma spray coated steel substrates shows superior erosion resistance as compared to uncoated samples due high hardness of the surface.
- With increasing the speed of the slurry rotation, material loss of the exposed surface also increases for both uncoated and coated surface.

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