A comparative study on solid particle erosion behavior of plasma sprayed Cr$_2$O$_3$ coatings on 410 grade steel

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Abstract: In the present investigation chromium oxide (Cr$_2$O$_3$) powder particles were used to deposit on 410 martensitic steel. Ni-Cr was used as bond coat. Erosion studies were directed on uncoated and also plasma sprayed steel examples at room temperature. The Erosion analyses were done utilizing an air-jet erosion test rig at a speed of 30 m/s by varying stand-off distance as per ASTM G-76. The stand-off distance considered were 10mm, 20mm, 30mm & 40mm. Silica sand particles of size 312µm was used as erodent. The surface morphologies were characterized using Scanning electron microscope (SEM) and presence of coating material was confirmed using energy dispersive X-ray analyzer (EDS). Vickers micro harness test was performed on surface of coated and un-coated substrates. It was observed that Cr$_2$O$_3$ Coated specimen exhibits better Erosion resistance when contrasted with uncoated substrates because of its enhanced property like micro hardness.

1. Introduction

Solid particle erosion is the dynamic loss of unique material from a strong surface because of mechanical collaboration between the surface and solid particles. Erosion is a significant issue in numerous designing frameworks, including steam and fly turbines, pipelines and valves [1]. Corruption of the metals and alloys is basic in high temperature antagonistic environment applications, for example, boilers, gas turbines, and territory of exchange of liquid. Power plants stand on the significant commercial ventures in misery from the debasement procedure, for example, consumption and disintegration [2]. Upkeep costs for replacing broken and corrupted tubes are high. There are a few methodologies that have been utilized to avoid the material corruption process, in that warm splashing procedures have pulled in huge consideration because of their versatility to spray almost any sort of covering powder (fired, metallic, polymeric, or composite)onto any substrate material [3]. The reason for this sort of coatings is to protect or shield the part from forceful situations and consequently improving the administration life of the substrate/base material [4]. Diverse sorts of thermal spraying procedures are accessible, for example, flame splashing, air plasma spraying, circular segment showering, high velocity oxy-fuel splashing, etc [5]. Among these, plasma spray (PS) is a standout amongst the most normally utilized thermal shower forms. Different strategies have limitations on the material that can be sprayed and on the substrate highlights like material, size, and shape. In plasma spraying, the covering material in the form of powder is brought into a high temperature plasma jet. The molecule gets liquefied and is made to imping towards the substrate. Upon effect, the liquid molecule is flattened and extinguished on the substrate severities [6]. This outcomes in a layered microstructure which may contain average surrenders, for example, pores, splat limits and micro-cracks. Plasma spraying furnishes coatings with thickness from tens of micro-meters to many smaller scale meters saved with high testimony rate furthermore gives great quality and great follower coating [7].

In the present work, Cr$_2$O$_3$ coatings have been deposited on 410 steel using plasma spray process. Micro hardness, porosity of these coatings was calculated. The aim of this work is to study the effect of stand-off distance on the erosion resistance of the coated and Un-coated steel substrates.
2. Experimental details

2.1 Materials and Coating Process

Cr$_2$O$_3$ powder particles supplied by M/S M.E.C co. Pvt Ltd. Jodhpur, India were used for coating on martensitic 410 grade steel of size 35mmx25mmx4mm were prepared from the substrate. The synthetic creation of the substrate material in wt. % is as follows: C-0.15, Mn-1, Si-0.5, Cr-11.5-13.0, P-0.04, S-0.03 and Fe-balance. Plasma spray deposition technique was used for coating purpose. Prior to the coating, substrate materials were cleaned with acetone and subjected to grit blasting using alumina to increase the adhesiveness. Ni/Cr was primarily coated on steel substrates and it act as bond coat between substrate and Cr$_2$O$_3$ powder coatings. 200 micrometer of coating thickness was achieved. Process parameters used for coating were kept constant for throughout the process.

Table 1: Physical and chemical properties of Cr$_2$O$_3$ powder

| Compound Formula | Molecular Weight | Appearance       | Melting Point | Boiling Point | Density | Monoisotopic Mass | Exact Mass |
|------------------|------------------|------------------|---------------|---------------|---------|-------------------|------------|
| Cr$_2$O$_3$      | 151.99           | Green Powder     | 2435 °C (4415 °F) | 4000 °C (7232 °F) | 5.22 g/cm$^3$ | 151.866 g/mol | 151.866 g/mol |

Table 2: Physical and chemical properties of Base Material (AISI 410 Steel)

| Tempering Temperature (°C) | Yield Strength (MPa) | Elongation (% in 50mm) | Density (kg/m$^3$) | Elastic Modulus (GPa) | Electrical Resistivity (nΩ m) |
|---------------------------|----------------------|------------------------|--------------------|-----------------------|-------------------------------|
| 650                       | 270                  | 29.5                   | 7800               | 200                   | 570                           |

2.2 Coating characterization

Characterization of the Coated as well as un coated steel substrates was carried out using Scanning electron microscopy technique, microphotographs reveals that uniform distribution and dense coating has been achieved using plasma spray process. EDS spectrum analysis confirms that presence of Ni/Cr and Cr$_2$O$_3$ particles on the substrates. Coating porosity was examined using image analysis technique with the help of optical microscope and obtained very less porosity of average 3%.

Cr$_2$O$_3$ coatings show more hardness value (823HV$_{0.1}$) as compared to un-coated substrates (211HV$_{0.1}$).

2.3 Erosion test

Dry air erosion test was performed on coated and un-coated steel substrates utilizing air-jet erosion test rig according to ASTM G-76. Coated and Un-coated substrates were first cleaned with acetone, dried with compressed air until the removal of moisture from the surface and weighed using a digital balancer with least count of 0.0001g. During the time of erosion test the samples were fixed to the sample holder of test rig and exposed to high velocity jet of silica sand particles of average grain size 312 µm. Erosion test was performed by varying the process parameter stand-off distances (10mm, 20mm, 30mm, 40mm) by keeping time as 5min and angle of impingement 60° as constant. After every set of work immediately the substrate is removed and is cleaned with acetone. After cleaning, the sample was allowed to dry and weighed to find the increasing mass loss.
3. Results and Discussion

3.1 Effect of stand-off distance on Erosion rate

Figure 1 and 2 shows the SEM image of un-coated steel and Cr₂O₃-coated substrates before test eroded at different stand-off distance. Microphotographs confirm that, at stand-off distances 10mm, 20mm, 30mm and 40mm, the material erosion takes place on the samples forming elliptical shape. The area of erosion is different for different distances. This is due to the change in the distance between the specimen and the nozzle from which the erodent is made to imping on the specimen.

3.2 Erosion mechanism

The SEM image reveals the impression of erodent, which impinges on the specimen at different stand-off distances, causes erosion of the coated and un-coated substrates. As seen in the SEM images, the silica sand which is used as the erodent material is seen on the material. This shows that erosion has occurred due to successive impingement on the material which leads to the formation of groove, crater, and formation of lips and all these is seen in figure 3, figure 4, figure 5, figure 6 & figure 7.

The substance by which material is expelled from a covering under erosive condition might be either pliable or weak. The ductile disintegration happens by cutting and twisting mechanism, whereas brittle disintegration happens by breaking and chipping [8]. After the test it is observed that the erosion is maximum at 30mm stand-off distance. And this is observed in both uncoated as well as coated material. But in case of 40 mm the material loss is less due to angle of diverging of sand particle increases this leads to minimum weight loss of substrate material. From SEM pictures, it can be seen that the strong molecule disintegration rate of the substrate steels, is most extreme at 30mm standoff separation. The material experience plastic twisting and is later expelled by consequent effects of the erodent at first glance. The cutting happens by the effect of the sand particles and lips are framed at the bank of the grooves [9]. Figure 8 shows the EDS spectrum of the coated material. Figure 9 shows the erosion rate of both uncoated and coated material with respect to the stand-off distance.

Figure 1: SEM microphotograph of un-coated steel before test
Figure 2: SEM microphotograph of Cr₂O₃-coated steel before test
Figure 3: SEM microphotograph of un-coated steel after test

Figure 4: SEM microphotograph of Cr$_2$O$_3$ coated steel at 10mm stand-off distance

Figure 5: SEM microphotograph of Cr$_2$O$_3$ coated steel at 20mm stand-off distance

Figure 6: SEM microphotograph of Cr$_2$O$_3$ coated steel at 30mm distance stand-off distance

Figure 7: SEM microphotograph of Cr$_2$O$_3$ coated steel at 40mm stand-off distance

Figure 8: EDS analysis
4. Conclusion

- Plasma spray technique was used to deposit Cr$_2$O$_3$ coating on 410 steel successfully and EDS spectrum analysis confirms the presence of Ni/Cr and Cr$_2$O$_3$ elements.
- Coating with an average hardness value 823HV$_{0.1}$ and porosity of 3-4% has been achieved.
- Plasma sprayed Cr$_2$O$_3$ coating shows better erosion resistance as compared to base substrate at all stand-off distances.

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