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Slurry erosion wear behaviour of plasma sprayed Cr_2O_3 & Cr_3C_2 Coatings deposited on mild Steel substrate

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Abstract: *In the current research work, slurry erosive wear behaviour of plasma sprayed Cr_2O_3 and Cr_3C_2 coatings on low carbon steel substrate have been investigated with coating thickness of 100 and 200micrometers, The developed coated and uncoated substrate samples were characterized by means of microstructure studies, Vickers's micro hardness, and slurry erosive test for varying the process conditions on the erosive test rig. When compared to chromium oxide coated and uncoated mild steel substrates, plasma sprayed chromium carbide coatings on mild steel substrates exhibited higher resistance to wear under all test conditions studied. This could be due to the coated steel substrates' higher hardness and less porosity.*
Keywords: Atmospheric plasma spray, Mild steel substrate, Chromium Oxide, Chromium Carbide, Erosive Wear

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I. INTRODUCTION

Slurry erosion can be defined as an abrasive wear process in which the repeated impact of small solid Particles entrained in a compressed moving air against a surface result in the removal of material from that surface. As a result, the lifespan of machine parts utilised in various industrial applications is reduced [1]. Slurry erosion is an abrasive wear process that involves the repetitive contact of small solid particles entrained in compressed moving air against a surface, resulting in material loss from that surface. As a result, the mechanical parts used in many industrial applications have a shorter life, which can lead to failure of machine components [2]. Hence to overcome these issues it is necessary to enhance the anti-wear properties of the existing metals by utilizing the surface modification techniques [2-3]. The several industrial surface coating methods are classified as under which includes hot dipping, thermal spraying, sputtering, physical, and chemical deposition techniques are used, among these the Thermal spraying has emerged as a suitable and effective method widely used in petrochemical industries, oil refineries, gas turbine engines and other automobile applications, The atmosphere plasma spraying process (APS) is one of the most versatile and effective coating method for coating metals, ceramics and cermet on the component surfaces, or rebuilding damaged parts, several industrial sectors need oxides, carbides and ceramics particularly Cr_2O_3, Cr_3C_2, Al_2O_3, TiC, TiO_2, SiC, WC and ZrO_2 for wear-resistant applications, however the ceramic coatings proven superior than their metallic components in abrasion resistance. Various types of steels that are used in industries like construction, transportation, agriculture, marine, and oil industries for making different components for different applications , but low carbon steels plays a important role in structural applications due to low cost, ease to manufacture, good specific strength and low density[4]. In addition have limited features like low hardness, poor wear and corrosion resistance, so low carbon alloys steels have limited usage where erosive wear and corrosion resistance are significant.[5] To overcome the above limitations Surface coatings are primarily used to improve the wear, scratch resistance, corrosion resistance, increase hardness and reduce friction coefficient [6-7],The objective of this research is to improve the surface properties of low carbon alloy steel and expand its industrial applications on the other hand, Cr_2O_3 is an excellent hardest ceramic material with lower friction, greater wear, and superior oxidation and corrosion resistance than other oxide ceramics, however due to these properties the coatings are used to extend the wear life of components [8].Chromium carbide (Cr_3C_2) is used in the surface treatment of metal components owing to its high melting temperature, strength, hardness, and corrosion resistance, however because of these properties, coating in corrosive environments because of its mechanical strength and chemical stability, Chromium carbide has been used in cutting tools, rocket nozzles, drill bits and dies[9].

In light of the above, the current study is aims to develop plasma sprayed Cr_2O_3 and Cr_3C_2 powder coatings deposited on substrate. The produced both coated and uncoated specimens were subjected to slurry erosive wear tests and the erosion performance was evaluated under optimum process conditions.

II. MATERIALS AND METHODS

2.1. Substrate Material

Commercially available low carbon steel plates were chosen as the substrate material due to its applications in the field of marine, automotive and aerospace industries; Low carbon steel has a superior strength, lower density, poor wear and corrosion resistance. The table.1 provide chemical composition and mechanical properties of low carbon alloy steel, these plates were cut and ground to specifications of 100 mm x 100 mm x 10 mm.

Table.1 The elemental composition and properties of substrate material

MATERIALS	CHEMICAL COMPOSITION %				MECHANICAL PROPERTIES		
Low Carbon Mild Steel	C Max	S Max	P Max	Cu max	Tensile Strength	Yield Stress	Elongation %
	0.20	0.055	0.055	0.30	42-54	26	23

2.2. Coating Material

The commercially available grade Cr_2O_3 & Cr_3C_2 powders utilized as coating materials for deposition, which was blend homogeneously in equivalent weight ratios. The coating Powders was procured from M/s Tesspo international Bangalore, India, the size of the powder particles 40±5microns .the scanning electron microscope used to analyse the morphology of powder particles; fig.1(a) shows the SEM image of chromium oxide powder particles. From the SEM images observed that chromium oxide particles shows block spots that corresponds to micro porosities. It exhibits in angular shape, in addition nearly cubical particles. Figure.1 (b) depicts the SEM image of Cr_3C_2 Powder particles, these powder particles were smooth, irregular, spherical, orthorhombic shape and almost 100% dense, further, and it has been observed that the Cr_3C_2 powder particles have a spongy structure with sub-micron particles.

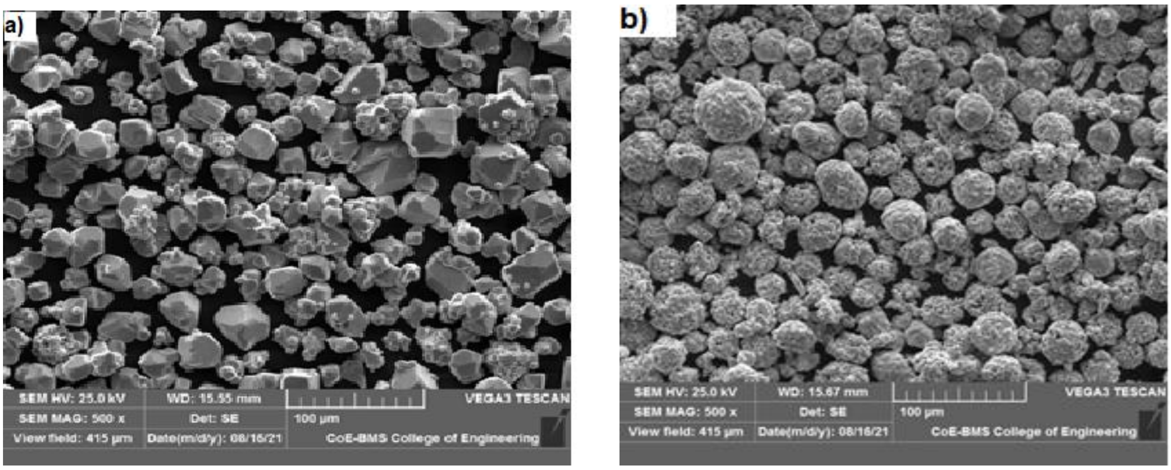

Figure.1SEM image of (a) Cr_2O_3 particles (b) Cr_2C_3 particles

2.3. Plasma spray coating

The mild steel plates were thoroughly cleaned with acetone solution to eliminate dust particles from the surface and grit blasted before Coating deposition in order to keep constant surface roughness (Ra) of 1.5m, and excellent bond between substrate and coating [10-11].To reduce the mismatch between the ceramic top coat and the metal substrate's thermal expansion coefficients, APS metallic bond coat thickness of 50m is applied to the substrate using nickel chromium powder. In this technique the plasma ionized feed stock powder is sprayed onto the substrate from a 127mm standoff distance utilizing a Metco-3MB gun with a GH nozzle and carrier gases of Ar and H_2 [12].Coatings of chromium oxide and chromium carbide powders on mild steel substrate with different thickness 100micron and 200micron were sprayed. Further, Hydrogen and Argon carrier gases were used with flow rates of 80–90lpm and 20–25lpm, respectively. Furthermore, the Current and voltage of 60V&500A was kept constant throughout the experiments during coating and the flow rate of 50g/min

2.4 Microstructure, Hardness and Slurry erosion test

Microstructure, hardness, and slurry erosive studies have been conducted on developed both uncoated and chromium-based coating samples, SEM was used to analyse the cross-section and top surface of substrate and its coatings samples, the Vickers Micro hardness experiment was performed according to ASTM standards, The hardness values on the test samples were measured at three different surface locations, and the material's micro hardness value was calculated using the average of the three readings.

Microstructure, hardness, and slurry erosive studies have been conducted on the chromium-based coating that was produced. On metallographically polished cross-sections as well as the top surface of coatings, optical and SEM pictures were acquired. The hardness of the coatings and substrate material is an important consideration for slurry erosive wear behaviour. In this study, the Vickers micro hardness test was performed according to ASTM standards; hardness values were measured at three different surface areas on the specimen, and the average of three readings was used to calculate the material's micro hardness value.wear tester as shown in Fig.1. Prior to the tests, the samples were thoroughly cleaned with acetone and its initial weight was measured using an electronic balance of accuracy 0.01mg. The specimens were then fixed to the spindle of the tester with the samples fully immersed in slurry media of 3.5%NaCl and silica sand of particular grit size. Tests were conducted for various slurry concentrations and coating thicknesses. The particle size of sand particles was 600 µm while the speed of rotation and time period were maintained at 500rpm and 15hrs respectively. After the test, the specimens were cleaned with acetone and its weight is measured to assess the slurry erosion wear loss of the sample Wear of Inconel-718 coated on Al6061 specimens were studied using standard slurry erosive wear tester as shown in Fig.1. Prior to the tests, the samples were thoroughly cleaned with acetone and its initial weight was measured using an electronic balance of accuracy 0.01mg. The specimens were then fixed to the spindle of the tester with the samples fully immersed in slurry media of 3.5%NaCl and silica sand of particular grit size. Tests were conducted for various slurry concentrations and coating thicknesses. The particle size of sand particles was 600 µm while the speed of rotation and time period were maintained at 500rpm and 15hrs respectively. After the test, the specimens were cleaned with acetone and its weight is measured to assess the slurry erosion wear loss of the sample Figure.2 depicts a slurry erosive pot tester used to perform erosive wear tests on coated and uncoated samples, It made up of six stainless steel slurry cups with six vertical spindles in the centre of each slurry cup that are coupled to the electric motor through a belt drive. The samples were cleaned with acetone solution and dried with hot air to remove moisture content and their initial weight was calculated with a 0.1mg precision scale. The specimens were then mounted on the test spindle and immersed in a slurry media comprising 3.5 percent Nacl and a specific grit size of silica sand, the slurry wear tests carried out for various slurry conditions and coating thickness. After the experiment the test samples were cleaned with acetone and weighed to determine the weight loss.

1. **Spindle unit**
2. **Slurry unit**
3. **Precision guides**
4. **Powder coated tabular structure**
5. **Thermocouple**
6. **Water cooling unit**
7. **Motor drive**

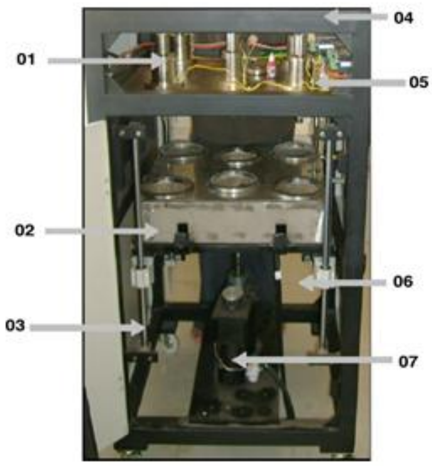

Figure.2 Slurry erosive pot tester

III. RESULTS AND DISCUSSION

3.1Micro characterization of coatings

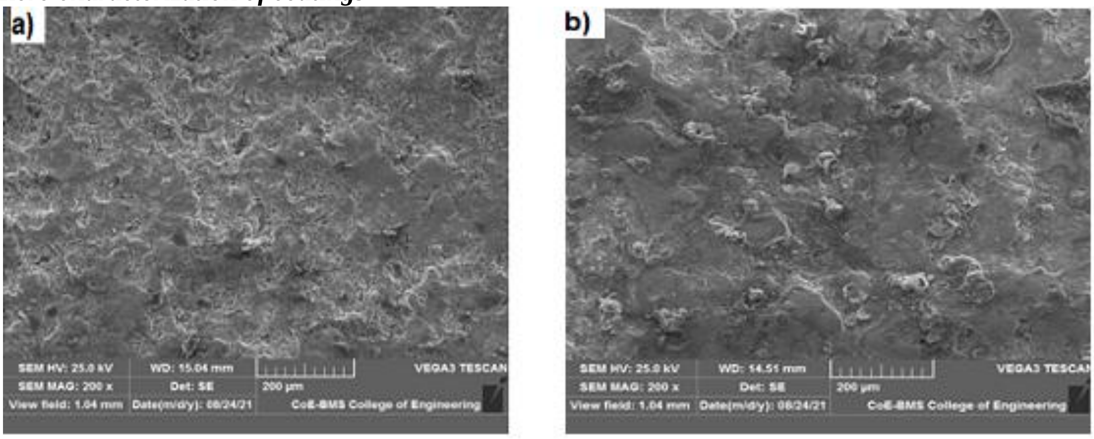

Figure.3 SEM images of a) Cr_2O_3-mildsteel coated specimen and b) Cr_3C_2-mildsteel coated specimen

The SEM images of plasma sprayed chromium oxide coatings deposited on mild steel substrate are shown in Figure 3(a) it is observed from the micrographs that coatings demonstrates dense and homogeneous deposition with a lamellae structure with no visible cracks or porosity, in certain areas Micro holes were found within the splats and between the splats. Micro pores and fractures in deposited coatings may be caused by impingement of completely melted or partially melted Cr_2O_3 particles, these coatings made up of mixture of hard oxides. When compared to uncoated substrate it is expected that a developed composite coatings made from hard and low grade materials could possess a better slurry erosion resistance.

The SEM images of chromium carbide coatings deposited on mild substrate shown in figure.3(b) the analysis of Cr_3C_2-mildsteel composite coating samples reveals homogeneous dispersion of Cr_3C_2 powder particles on mild steel substrate with lower porosity. The images further indicated that the presence of a splat-like cross-sectional microstructure, The coated surface has shown interlocked molten splats with few un melted particles fixed at some locations with uniform microstructure.

3.2. Micro hardness

Figure.4 depicts the Vickers's micro hardness variant of uncoated and coated substrate material, when compared to an uncoated substrate, chromium-based coatings showed improved hardness values of the mild steel; the thicker coatings provide better hardness than thinner coatings as mild steel coating with 200microns Cr_2O_3 coating is having more hardness than that of mild steel with 100microns.

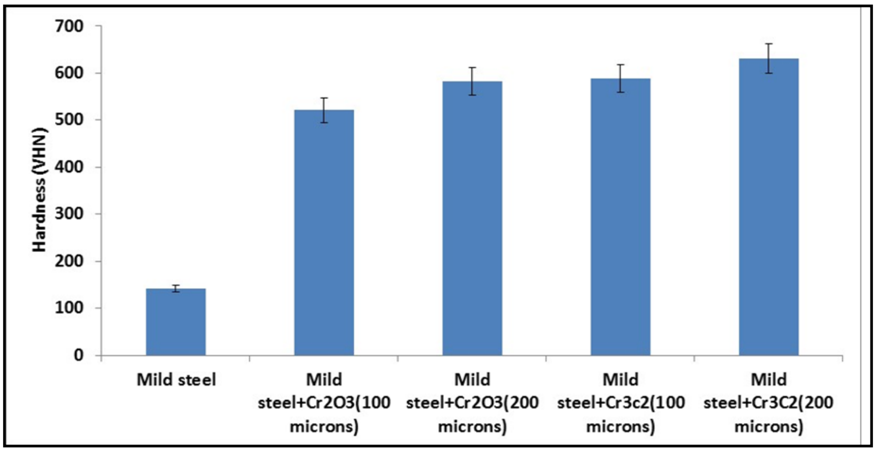

Figure.4 Hardness Variation of uncoated and coated mild steel substrate

Further, we can observe that highest hardness can be achieved by coating Cr_3C_2 of 200micron thickness over mild steel substrate. Since both chromium oxide and carbide is a ceramic hard material, the inclusion of stable Cr_3C_2 with structure is known to increase the coatings' toughness and hardness [14]. Further Cr_3C_2 Coatings have a higher hardness due to lesser porosity, dense deposition, and a homogenous microstructure. The higher coating thickness may improve hardness due to the particles' better ability to penetrate deeply into the substrate surface. Excellent bonding is formed with the mild steel substrate resulting in reduced microscopic holes and defects [15-16]. As a result the coated layers become denser and fewer prone to peening ability which results in thicker coatings (200microns) with less porosity and better toughness than thin coatings (100microns). When compared to Cr_2O_3 coatings on substrate material the Cr_3C_2 coatings exhibit a greater improvement in hardness.

3.3Iinfluence of process parameters on slurry erosive Wear
3.3.1 Influence of slurry concentration

Figure.5 demonstrate the influence of slurry concentration on weight loss of both coated and uncoated substrate material with different slurry concentrations of 50 to 200 g/lit, under steady speed of 500 rpm, duration of 5hr and particle size of 210 micrometre. It is noticed that from graph increased slurry concentrations of 50 to 200gms/lit results in increased weight loss of uncoated mild steel substrate. However further marginal weight loss for coated substrate material. It can be accomplish that a high concentration sand particle improves the probability of interaction with the target surface resulting in extreme erosive wear with the least amount of particle surface degradations. Furthermore, at all slurry concentrations studied, chromium carbide coatings showed excellent weight loss reduction compared to chromium oxide coated and uncoated substrate material, furthermore, it is observed that increase in coating thickness there is reduction in slurry erosive wear loss. The improvement in wear loss of coated samples is mainly due to increase in strength, hardness and toughness of coatings,

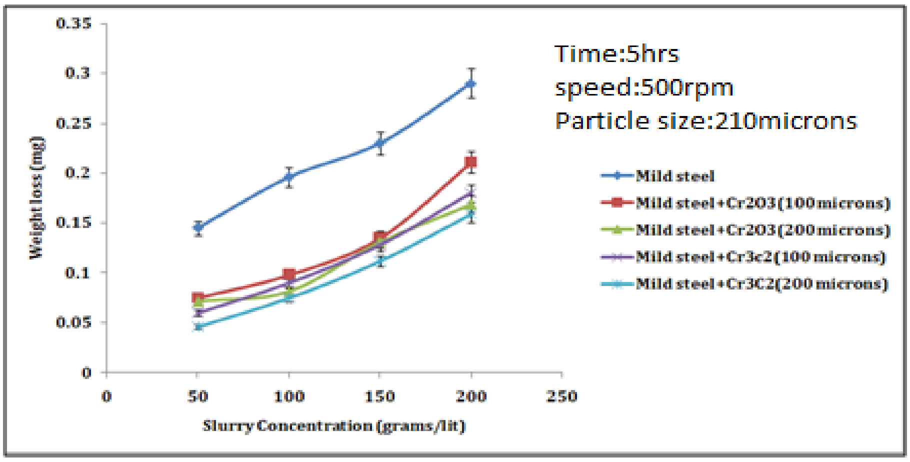

Figure.5 Effect of Slurry concentration on weight loss

3.3.2. Effect of Coating thickness

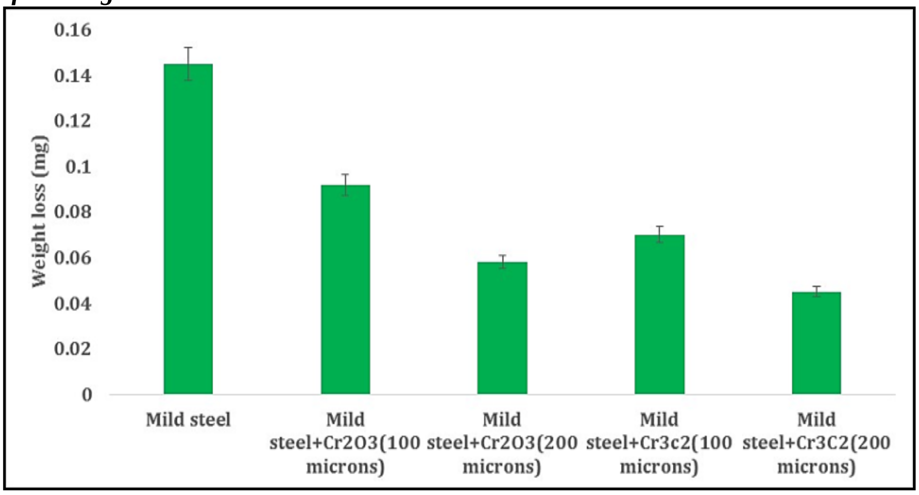

Figure.6 Effect of coating thickness on weight loss

Figure.6 depicts the effect of coating thickness on weight loss for a given test period, slurry concentration, slurry rotation speed, and impinging particle size. Coated samples showed the least weight loss when compared to uncoated mild steel substrate, owing to the coating material's ability to resist material loss on the coating surface. In addition to the hardness and corrosion resistance of chromium based coated particles the newly developed chromium based composite coatings offer better slurry wear resistance, Furthermore, as thickness of coating increases resistance of slurry erosive wear increases, weight loss decrease, and micrographs show that coated materials have a minimum micro porosity, which is associated with uniform thick deposition of chromium oxide and carbide. When compared to an uncoated mild steel substrate, this coating provides more hardness, wear and corrosion resistance, the chromium oxide and carbide coatings provide better wear resistance.

3.3.3 Effect of time

Figure.7 shows the weight loss variation of coated and uncoated samples over various test durations. The amount of damage increases as the contact time between the erodent and the target surface increases[15], as the kinetic energy and momentum of the erodent particles are transferred to the target surface during particle collisions, resulting in more excessive material removal for both coated and uncoated samples,[16] wear resistance of coated substrate shows greater wear resistance when compared to the un coated substrate at all test durations studied, Plastically deformed craters are caused by the abrasive impact of sand particles which forms cracks owing to micro-cutting, influencing material removal and the lower relative hardness substrate than uncoated mild steel substrate.

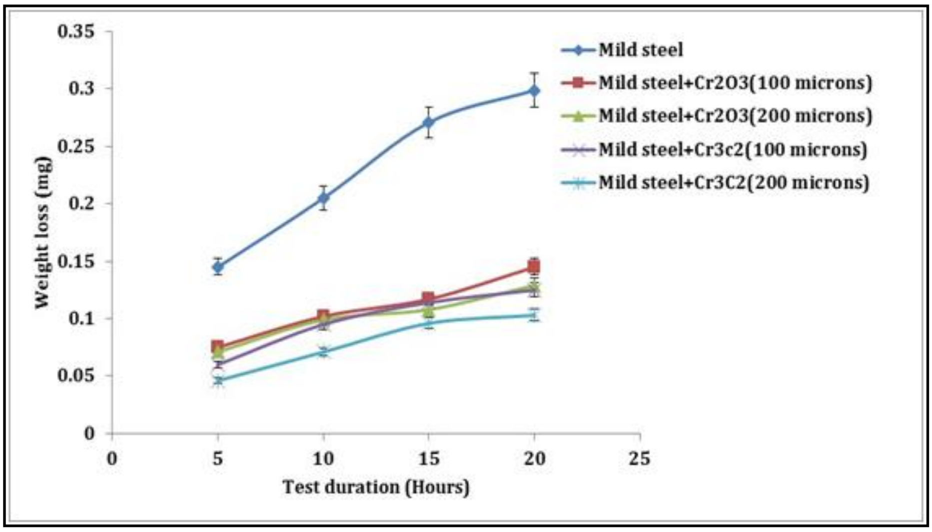

Figure.7 Test duration on weight loss

3.3.4 Effect of particle size

Figure.8 shows the effect of particle size on weight loss of uncoated and coated mild steel substrates with particle size varying from 210 to 625micrometre and constant test time, slurry speed, and concentration. According to study, weight loss increased as particle size increased according to study. Furthermore, as the thickness of the coating increases weight loss decreases. This is due to the ability of larger particles' to apply their energy and mass directly to the target material surface with little contact under fixed slurry concentrations. In addition, an increase in impinging particle size would result in an increase in the particle's surface area with other cutting edges, resulting in wear. Smaller impinging particles have less impact stress since their energy is smaller, resulting in less weight loss.[17] While uncoated mild steel has lesser resistance and corrosion resistance than coated mild steel, the SEM images clearly show that it was eroded more severely, Furthermore indentation pits, craters and grooves, on eroded uncoated substrate have been observed, which are primarily affected by slurry particle impingement and corrosion. The morphology of coated samples revealed that the erosion and abrasion have a significant impact on the material removal process, [18] and that weight loss decreases as coating thickness increases.

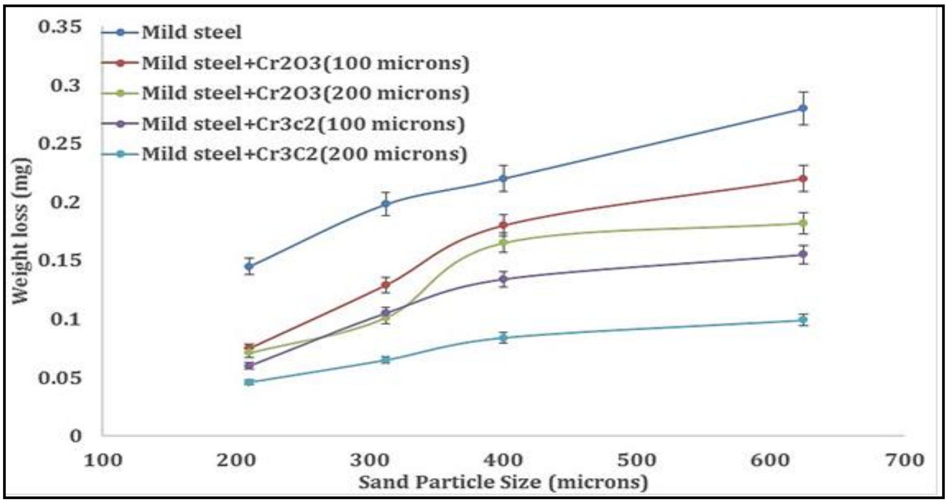

Figure.8 Effect of particle size on weight loss

3.3.5 Effect of slurry speed

The weight loss variation of coated and uncoated mild steel substrate material with different slurry rotation speeds is shown in figure.9. When compared to lower speeds a maximum rotation speeds of 1500rpm captures an incredible material loss, this is mostly due to a rise in slurry speed, which increases erodent kinetic energy and the rate of slurry contact with target surfaces. This additional energy is then converted into heat and plastic deformation leading in higher weight loss and localised attacks in various locations. [19] The amount of damage increased with slurry speed resulting in lips, grooves and craters on coated and uncoated surfaces, the composite coatings showed the least degradation due to its enhanced surface hardness and density of coating which improves the erosive wear resistant.

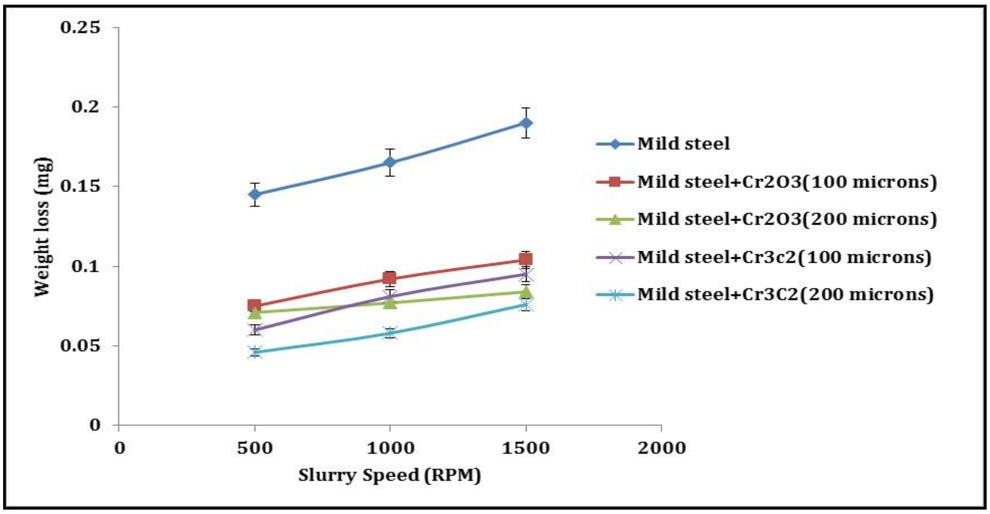

Figure.9 Effect of slurry speed on weight loss

IV. CONCLUSIONS

The current paper describes the slurry erosion performance of chromium oxide and carbide coatings on mild steel. The following conclusions are possible:

- Plasma-sprayed chromium oxide and carbide powder were effectively deposited on mild steel substrate material at coating thicknesses of 100 and 200 microns.
- The developed chromium-based composite coatings shows greater hardness due to lesser porosity enhanced intrinsic material characteristics and feedstock powder phase uniformity.
- Slurry erosion resistance has increased due to thick and homogeneous deposition of hardened plasma-sprayed chromium oxide/carbide composite coatings.
- In comparison to chromium oxide coatings on substrates, the performance of chromium carbide coatings improves as the coating thickness increases.

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