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Transitional Wear of Plasma Spray Cr_2O_3 and Cr_3C_2 Coatings Deposited on Low Carbon Steel

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***Abstract:** In the present work, transitional wear of atmospheric plasma sprayed Cr_2O_3 and Cr_3C_2 coatings on low carbon steel substrate have been investigated with coating thickness of 100µm and 200µm. The produced coated and uncoated mild steel substrate samples were characterized by means of microscopic examinations, hardness and sliding wear tests for varying parameters of load, sliding speed, and sliding distance, SEM analysis were carried out for characterization studies of worn surface of samples. The obtained results revealed that the wear rate was much lower in Cr_3C_2 coated samples followed by Cr_2O_3 coated samples on mild steel substrate. When comparison to chromium oxide composite coatings the chromium carbide coatings showed better improved results*

***Keywords:** Chromium Oxide/ Carbide, Sliding wear, Atmospheric Plasma Spray, Coatings, Mild steel*

I. INTRODUCTION

Low carbon steel has been used in a variety of industrial applications because of its malleability, weldability, and low cost. However, due to the abrupt transition of wear modes low carbon steel alloy not recommended for tribological applications particularly for components operating in the dry sliding condition [1-3]. The wear transition modes can cause a lot of material loss which can lead to failure of machine components. The mechanical components are designed for a dry sliding environment making it suitable for tribological uses [4]. Hence to overcome this, it is necessary to modify the surface of mild steel through the coating process. The surface engineering employs different types of surface modification techniques to improve the anti-friction, wear and corrosion resistance of materials [5]. Surface coatings are primarily used to improve the wear, scratch resistance, corrosion resistance, increase hardness and reduce friction coefficient. Based on the deposition process the industrial coating methods are classified such as hot dipping, sputtering, thermal spraying, physical and chemical vapour deposition process.

Among these the thermal spraying is the most commonly used method in petrochemical industries, oil refineries, gas turbine engines and other automobile applications [6-7].

Thermal spray coating technologies are categorized according to the heat source utilized for coating such as low pressure plasma spraying, atmospheric plasma spraying, vacuum plasma spraying, high frequency pulse detonation, and high velocity oxygen fuel spraying. among the thermal spraying techniques (air plasma spraying) APS is one of the most versatile and effective coating methods for coating of metals, 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 to adopt plasma spray techniques effectively, however the ceramic coatings proven superior than their metallic components in abrasion resistance.

Ceramic coatings have been shown during the last two decades to be one of the best materials for improving the serviceability of machine components, particularly for enhancing wear and corrosion resistance [8-9].

Cr_2O_3 is the hardest and most extensively utilized oxide ceramic material for thermally sprayed coating solutions. It has a low coefficient of friction, a high melting point, is chemically inert, and is resistant to wear and corrosion. Because of its adiabatic and optical characteristics, it may be utilized as a protective surface coating material in microelectronic and tribological applications [10].

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, as a protective 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 [11-12].

In view of the above, current study aims to develop a plasma sprayed Cr_2O_3 and Cr_3C_2 coatings deposited on mild steel substrate. The sliding wear experiments were conducted on developed both coated and uncoated specimens under various loads, sliding speed, and sliding distances are studied in this work.

II. EXPERIMENTAL DETAILS

2.1Substrate material

Commercially available low carbon steel plates were used as the substrate material for the deposition of chromium based composites coatings due to its various range of industrial application in the marine, automotive and aerospace industries.

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The commercially available mild steel samples having dimensions 100mm×100mm×10 mm were prepared. The elemental composition of substrate material was shown in Table 1

Table.1 Elemental composition of mild steel

Element	Fe	Mn	S	C	Si	Cu	P
Wt%	98	1.03	0.50	0.25-0.29	0.28	0.20	0.040

2.2Feedstock materials

In this study the commercially available chromium oxide and chromium carbide coating powders with particles dimension was 40±5microns were used to coat on a mild steel substrate, these coating powders were deposited on substrate samples by employing an atmospheric air plasma spray system facility available at M/S Metalizing equipment Pvt Ltd, Jodhpur, India. To analyze the morphological details of powders particles SEM analysis was carried out.Figure.1 (a) depicts the SEM and EDAX pattern of Cr_2O_3 feedstock powder particles, from the SEM images, it is noticed that the Cr_2O_3 powder particles exhibits angular shape, also Cr_2O_3 particles shows dark spots that correspond to micro porosities as seen in micro images.

The EDAX spectrum of Cr_2O_3powder particles confirms the presence of chromium and oxide as major phases in the product and also theFigure.1(b) depicts the SEM and EDAX pattern of Cr_3C_2 powder, 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.edax pattern of Cr_3C_2powder particles confirms the presence of chromium and carbon as major phases along with other elements.

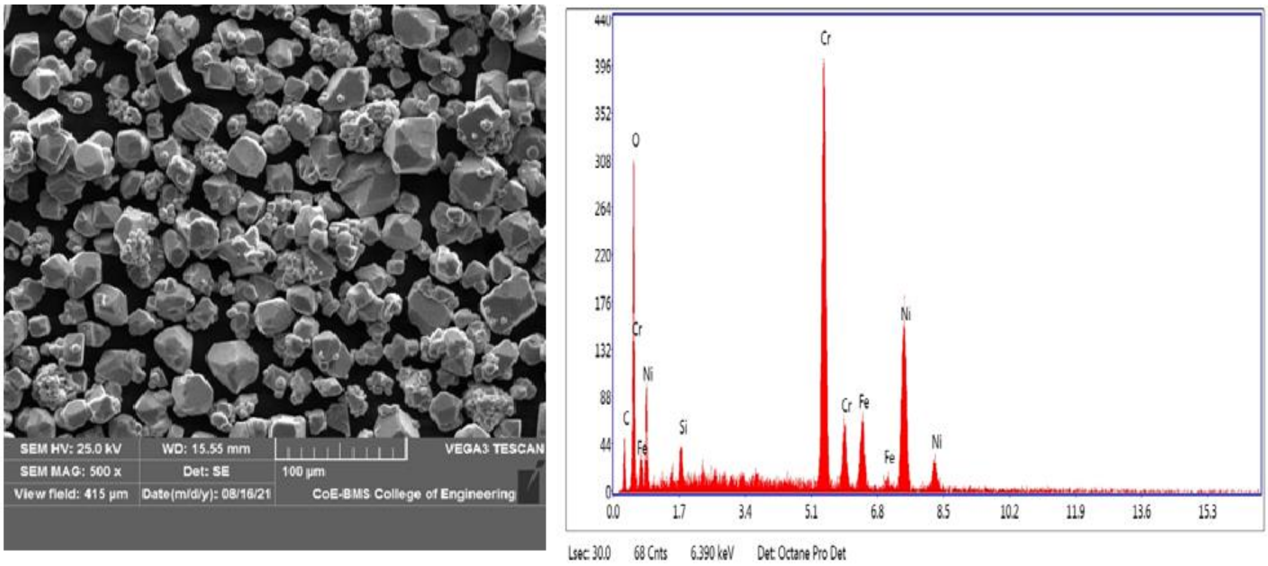

Fig.1 (a) SEM and EDAX pattern of Cr_2O_3

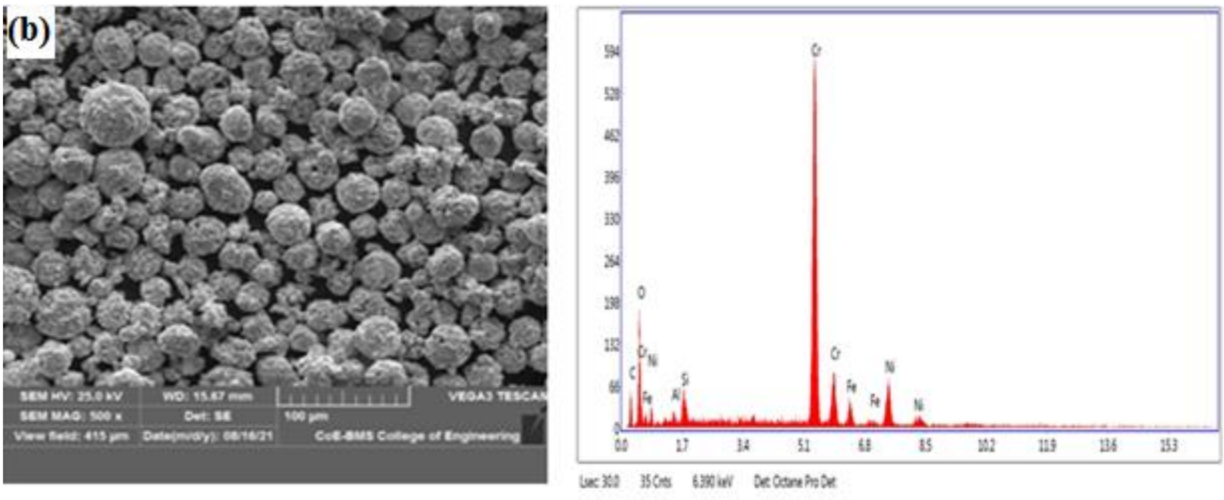

Fig.1 (b) SEM and EDAX pattern of Cr_3C_2

2.2 Plasma spraying

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 good bonding between the substrate and coating [13]. By using APS technique a metallic bond coat thickness of 50µm is applied to the substrate using nickel chromium powder to minimize the thermal expansion coefficient mismatch between the ceramic top coat and the metal substrate.

In this technique the plasma ionized feed stock powder is sprayed onto the substrate from a 127mm standoff distance using a Suzler-Metco 3MB torch gun with a GH nozzle and carrier gases of Argon and Hydrogen. The 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

2.3 Micro hardness Test

The Vickers micro hardness test was performed on both chromium oxide and carbide coated and uncoated specimens with a load of 100gm and a dwell period of 10s. Hardness at three different indentations on the specimen and the mean average of three readings was considered as the material's micro hardness value.

2.4. Sliding wear analysis

Figure 2.displays the schematic sketch of a tribometer, the sliding wear experiment performed at room temperature with a constant velocity (1ms^{-1}) and a sliding distance of 250 m under different loaded conditions (20, 40, 60 and 80 N) according to ASTM G-99 standard. The difference in weight loss is measured with an accuracy of 0.01 mg using a digital micro balance; the worn surface of pin samples was examined by using a Scanning electron microscope.

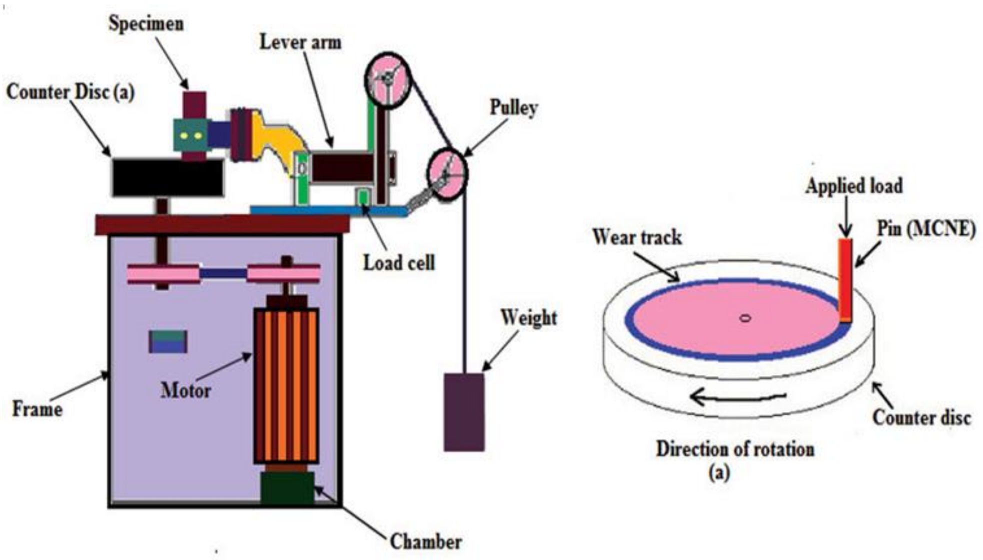

Figure 2 A Schematic Sketch of pin-on-disc Wear Testing Machine

III. RESULTS AND DISCUSSION

3.1 Hardness

Figure.3 depicts the micro hardness variation of coated and uncoated 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 200micron Cr_2O_3 coating is having more hardness than that of mild steel with 100micron coating.

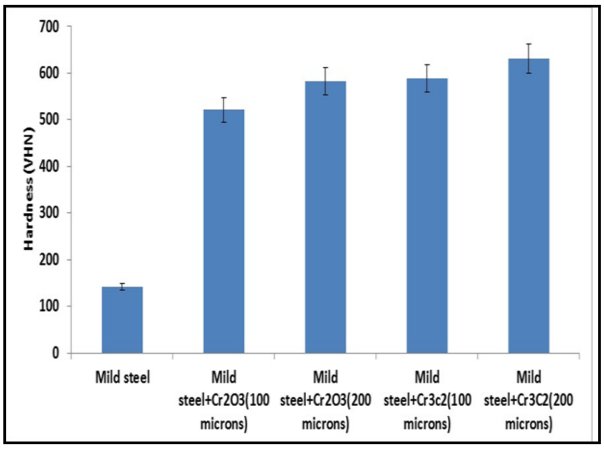

Fig.3 Variation of hardness of uncoated and coated mild steel substrate

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 less 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 mild steel substrate, Cr_3C_2 coatings exhibit a greater improvement in hardness.

3.2. Sliding Wear

3.2.1Effectof Coating

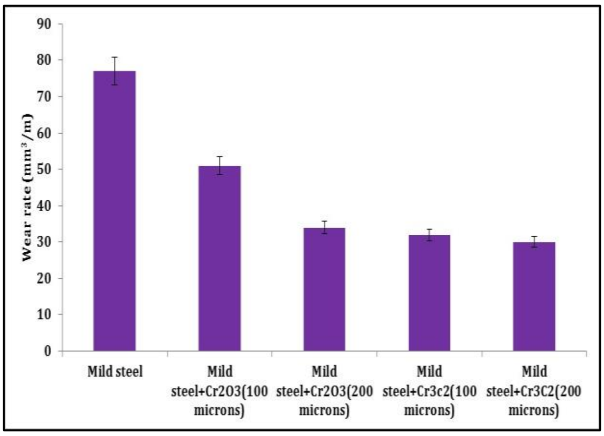

Fig.4 Variations of wear rate of coated and uncoated mild steel substrate material for sliding wear

Figure.4 depicts the variation of wear rate of both coated and uncoated mild steel substrates for a given load, sliding velocity and sliding distance. It is observed that the wear rate of uncoated mild steel is higher when comparison with the coated materials and also both Cr_3C_2 (Chromium Carbide) with100micron & 200micron thickness have comparatively lower wear rate than Cr_2O_3 (Chromium Oxide) coating with 100micron & 200micron.Thus the coating improves the wear resistance of the substrate material and chromium carbide coatings offering more resistance than chromium oxide. It is obvious that both combination of coated material have significantly lower wear rate. This is mostly owing to the coating materials possesses higher hardness value on the substrate, which allows it to withstand material loss. When compared to Cr_2O_3 coated samples Cr_3C_2 coatings offers improved wear rate due to greater micro hardness and density as well as lower porosity, as the coating thickness increases the resistance to wear increases, however, it is clear from the micrographs that the coated samples have a lower micro porosity which is associated with uniform and thick chromium coating deposition. Wear resistance, micro hardness, and corrosion resistance are all improved with these coatings' properties. Chromium is important for preventing wear and corrosion on the surface of mild steel substrates. A thin protective coating is generated when chromium reacts with oxygen and carbon. A thin protective, stable surface film on a mild steel substrate prevents wear and corrosion, as well as acting as a barrier that prevents oxygen and water from reaching the mild steel underlying surface.

3.2.2 Effect of load

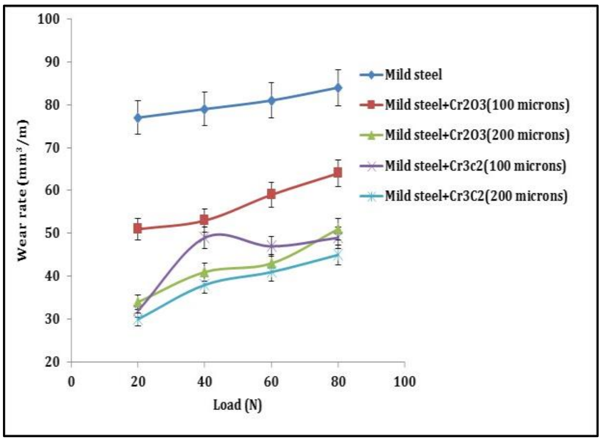

Figure 5. Variations of wear rate of coated and uncoated mild steel substrate material for different loads

Figure.5depicts the wear rate variation of uncoated and coated mild steel substrate samples under varied loading of 20, 40, 60, and 80 N and a constant sliding velocity of 0.523m/s with a sliding distance of 250m respectively. Wear rate has been seen to increase with increasing load for both uncoated and coated materials. Greater stress combined with augmented load causes surface asperities to deform and degrade material surface among the coated and un coated materials [17], the mild steel with Cr_3C_2 coatings offers lowest wear rate this is because the mild steel with Cr_3C_2 coatings is denser, harder and has less porosity making it more wear resistant,

3.2.3 Influence of Sliding Velocity

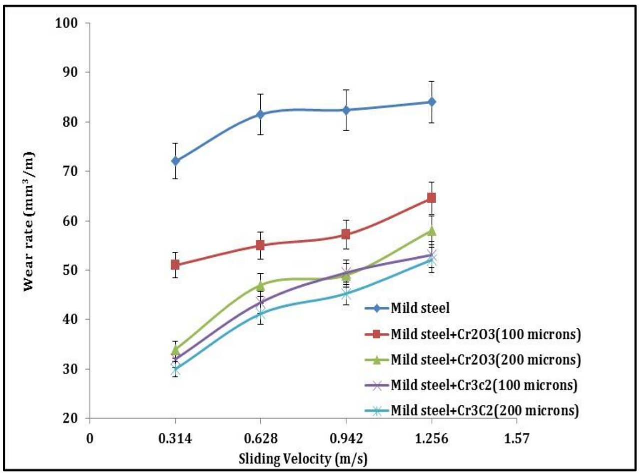

Figure. 6 Wear rate variation of coated and uncoated substrate for different sliding velocity

Figure 6.Illustrates the wear rate variant of coated and uncoated mild steel substrate at different sliding velocities. Irrespective of sliding velocity, the base alloy has a greater than other coated materials, Cr_3C_2 (Chromium Carbide) coating showed lower wear rate and it is minimum for 200micron thickness coating. According to study, wear rate is proportional to sliding velocity for both specimens, this phenomenon was explained by the fact that higher sliding velocity combined with increased temperature causes thermal softening of the coating, resulting in a decrease in undersurface shear strength and hardness [18-19]. In addition, when the sliding velocity increases, thermal tribo-friction causes an increase in wear rate. Because of its lower friction co-efficient and higher surface hardness of mildsteel-Cr_2O_3coatings, the combination of mildsteel-Cr_3C_2 coating offers excellent sliding wear resistance when compared to uncoated substrate. In addition, as compared to uncoated substrate, mild steel-Cr_3C_2 coated substrate showed a marginal increase in wear rate. The particles may deeply penetrate into the substrate surface during the early coating trials of deposition with a 100micron thickness may explain the increased hardness with increasing coating thickness.

The first layers of chromium-based coatings on mild steel substrates are expected to have cracks, pores. As the thickness of coating increases the porosity tends to decrease and the deposited layer become denser. This could be due to multiple layers are developed on the substrate, the thick coatings (200micron) have a lower porosity and a higher hardness than thin coatings (100 microns) results in improved wear.

IV. WORN SURFACE ANALYSIS OF SLIDING WEAR SAMPLES

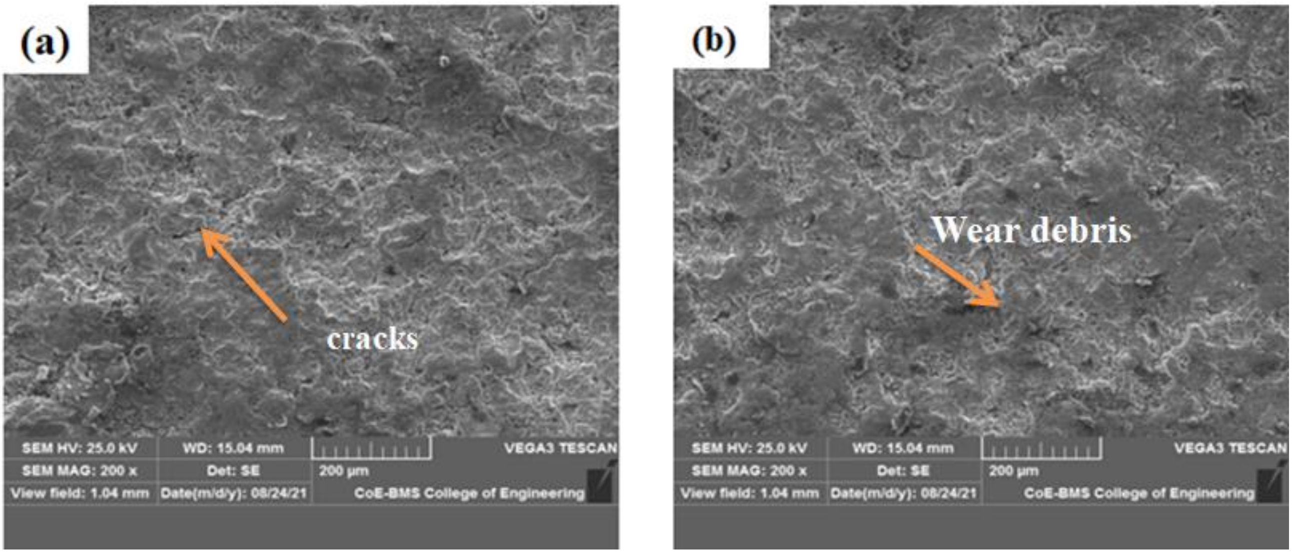

Figure 7 (a) and (b) SEM images of worn uncoated mild steel specimen

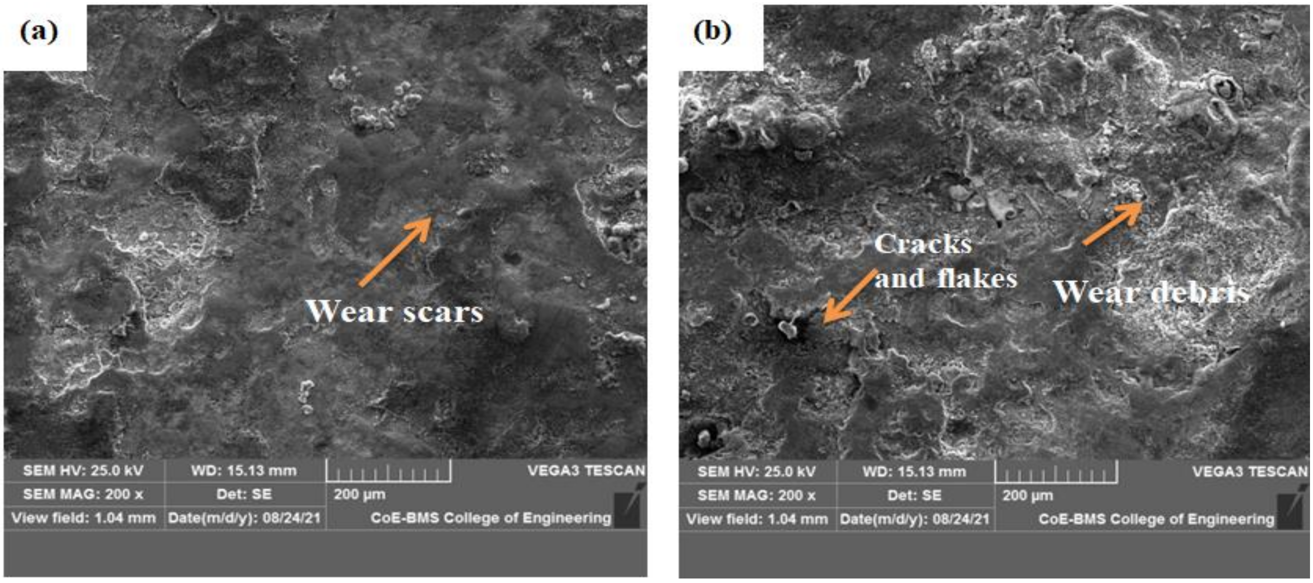

Figure.8 (a) and (b) SEM images of worn mild steel-Cr_2O_3coated-pinsurface

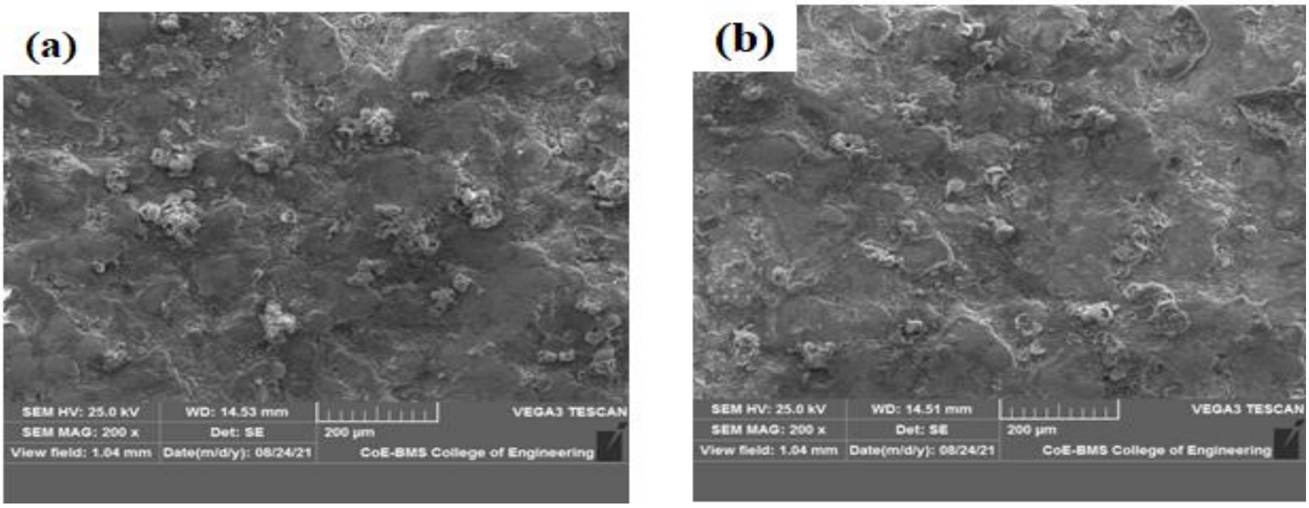

Figure 9 (a) and (b) SEM micrographs of worn Mild steel-Cr_3C_2Coated pin surface

Figures 7(a) and (b) depict SEM micrographs of an uncoated mild steel substrate after a wear test. As seen by broad and shallow grooves on the surfaces, the substrate material has been exposed to severe wear. The substrate surface has also been demonstrated to be extensively worn; resulting in roughening and the creation of particle debris, groove markings and scratches can also be visible in the wear track of the substrate [20]. Figures 8(a) & (b) and 9(a)&(b) shows the SEM micrographs of worn mild steel-Cr_2O_3 and mild steel-Cr_3C_2 coated samples with coating thicknesses of 100micron and 200micron following wear test under a load of 20N over a sliding distance of 250m respectively. it is observed that the coated samples exhibit reduced plastic deformation. The wear track shows the limited micro-cutting is evidenced on samples but a significant brittle fracture of the coatings [21].Figure8 (a) and (b) depicts wear induced cracks and flakes which results in de-lamination; however this de-lamination wear characterized by nucleation of cracks and its movement which leads to wear loss owing to the formation of large particle debris.

Figure 9(a) and (b) depicts the worn surface of mild steel-Cr_3C_2coated samples. It is observed that worn surfaces have limited micro and macro cutting, as well as the presence of sparsely wear debris. This meant that brittle fracture of the coating and wear scars caused by repeated contact would lead to high temperatures and plastic flow [22]. The mild steel-Cr_3C_2 coatings are more wear resistant than mild steel-Cr_2O_3 coatings and uncoated substrates.

V. CONCLUSIONS

1. In the current study, plasma sprayed Cr_2O_3 and Cr_3C_2 powder coatings were successfully developed on mild steel substrate with 100micron and 200 micron coating thickness,
2. Pin-on disc equipment was used to conduct sliding wear tests on the wear specimens. The impact of applied load, sliding distance, and sliding velocity on the wear of coated and uncoated samples was investigated.
3. The denser and uniform deposition of plasma-sprayed Cr_2O_3-mildsteel and Cr_3C_2-mildsteel coatings with an enhanced hardness has improved anti wear when compared to uncoated mild steel substrate.
4. Wear rate has been seen to increase with increasing load for both uncoated and coated materials
5. When compared to Cr_2O_3 coated samples Cr_3C_2 coatings offers improved wear rate due to greater micro hardness and density as well as lower porosity, as the coating thickness increases the resistance to wear increases
6. The worn surfaces are identified using micro images; indicating failures involving significant shear and plastic deformations in case of mild steel substrate, minor brittle, micro and macro fragmented damages with reduced plastic flow were observed on coatings of Cr_2O_3-mildsteel and Cr_3C_2-mildsteelsamples.

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