Characterization of Molybdenum Based Composite Coatings for Piston Ring Applications

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Abstract- Friction and wear in different engine components have a crucial effect on the engine performance, combustion efficiency, oil consumption and lifetime of the internal combustion engine. The wear of the coating is one of the most important parameters of piston rings coating. The coating is one of the novel techniques to reduce the frictional forces and improve the mechanical properties of engine components. In the current experiment CrC-20%NiCr coating was deposited on the substrate (cast iron) via atmospheric plasma spraying method. The phase and microstructural analyses of the coating were examined using using scanning electron microscope and X-ray diffraction.

Keywords: SEM, XRD, Friction, Piston ring

Introduction

The wear resistance of functional surfaces is the critical factor for many machine parts in industrial applications. The most widespread commercially used surface treatment aimed to ensure the surface's wear and corrosion resistance is functional hard chrome plating. The main disadvantage of hard chrome plating technology is the presence of health-endangering and environmentally problematic hexavalent chromium in the plating bath, for this reason, the use of hard chrome plating technology is subject to increasingly strict rules and restrictions, which makes it more challenging and costly[1]. One possible solution is the replacement of traditional surface treatment by thermally sprayed wear-resistant coatings. A wide range of materials can be processed using predominantly plasma, flame, and electric arc spraying for a wide variability of applications ranging from gas turbine technology to the electronics industry. For the creation of hard, wear-, and corrosion-resistant coatings, the most suitable materials are ceramics and hard metals. Plasma spraying is used for spraying the ceramics, due to their high melting points. The high velocity oxy-fuel (HVOF) spraying technology is usually selected for the deposition of high-quality hard metals and metals coatings to now, many studies have focused on the comparison of tribological properties of thermally sprayed coatings and hard chrome plating. The most comprehensive studies on hard chromium replacement Amongst thermal spraying methods is plasma spraying which is most widely applied in the automotive sectors because (a) it has a high rate of deposition, (b) the procedure chomps fuel gases which are low-cost and easily accessible, (c) the process necessitates minimum preheating and cooling during spraying, (d) the technical dependability of plasma systems is well recognized in industrial applications, and (e) spraying conditions can be effortlessly controlled by various applications. In particular, the molybdenum coatings fabricated by atmospheric plasma spraying have enhanced resistance to wear and heat, and thus this coating technology was commercialised for application to the automotive industry. However, the coatings often pose problems of embrittlement caused by high hardness, despite their excellent high-temperature hardness and corrosion resistance, when applied to automotive parts such as cylinder bores[2][3], synchronizer rings [4][5], and piston rings [6][7]. These applications require excellent wear resistance of both the coating and the counterpart material. To over- come to these shortcomings and to improve overall wear resistance, studies on molybdenum coatings have focused on enhancing overall wear resistance by blending powders such as NiCr, CrC, etc powders with molybdenum powders In this present study, 60% pure molybdenum was blended with Iron molybdenum composite powder with 20%NiCr and 10% CrC coatings, were fabricated by atmospheric plasma spraying (APS) to improve wear resistance and friction coefficient of piston rings and effects of blending elements on wear resistance of the coatings and the counterpart material as a function of wear load were investigated and their microstructures, wear properties, were evaluated. This was led to the under- standing of wear mechanisms of Mo blend coatings, based on which the correlation between microstructure, wear loss with the counter body material was clarified.

Experimental details

Coating and substrate preparation

The substrate is made of same as of piston rings material whose composition is provided in table 1. With plate dimensions of 90x90x2 mm were used. The substrate was made using the stage casting procedure and cope and drag were used for the casting process as shown in fig1. the surface of the substrate material was sand blasted with 35-mesh Al_2O_3 particles before coating for better coating adhesion. The substrate was plasma sprayed with a Sulzer-Metco PT-F4 torch in an isolated environment the robot was used to ensure the controlled environment, reproducible trajectories and speed. Primary gas Argon (Ar) and secondary gas Hydrogen (H_2) were used which get mixed inside the chamber and flow through a gun calibre. A high voltage spark is generated which leads to form a mega spark at the spark plug. The mega spark ionises the air between the nozzle and the electrode resulting in electric conduction between them without their contact. Due to this high-temperature mega spark, the moving hot gases turn into plasma. During spraying, a cooling system applied that consisted of air jets and venturi nozzles. The dependency of microstructure and the power of the plasma jet (13-19.5 kW) were a major concern during the process. The substrate prepared through casting, which was further cleaned by sand blasting, was used in plasma spray for coating purpose. The substrate was fixed in the fixture of the Plasma Spray Machine. Table 2 shows the operating parameters of coating setup.

Table 1 Composition of substrate material

Element	C (%)	Si (%)	Mn (%)	P (%)	S (%)	Cr (%)	Cu (%)
Target	3.75±0.05	2.70±0.05	0.53±0.01	0.36±0.02	.06±0.005	0.04±0.01	0.035±0.03

Table 2 Process parameter used for atmospheric plasma spray coating

Sr. No	Process Parameter	Specification
1	Powder Port Internal Diameter	2.2 (mm)
2	Water Flow Rate	4.0 (l/m)
3	Temperature Of Chiller	17 (ºC)
4	Distance Between Spray Gun & Mandrel (At gun angle 300º)	140 (mm)
5	Argon Flow Rate	1.87 (m^3/s)
6	Hydrogen Flow Rate	0.21 (m^3/s)
7	Argon Pressure	6.5 (bar)
8	Hydrogen Pressure	5.5 (bar)
9	Powder Flow Rate	50 (g/min)
10	Voltage	70 (V)
11	Current	460 (A)
12	Gun Feed	10 (mm/min)
13	Gun Angle During Spray	30 (º)
14	Cooling Air Pressure	46 (bar)
15	Powder Driving Temperature	120 (ºC)
16	Powder Mixing time in V-type mixer	5400 (s)

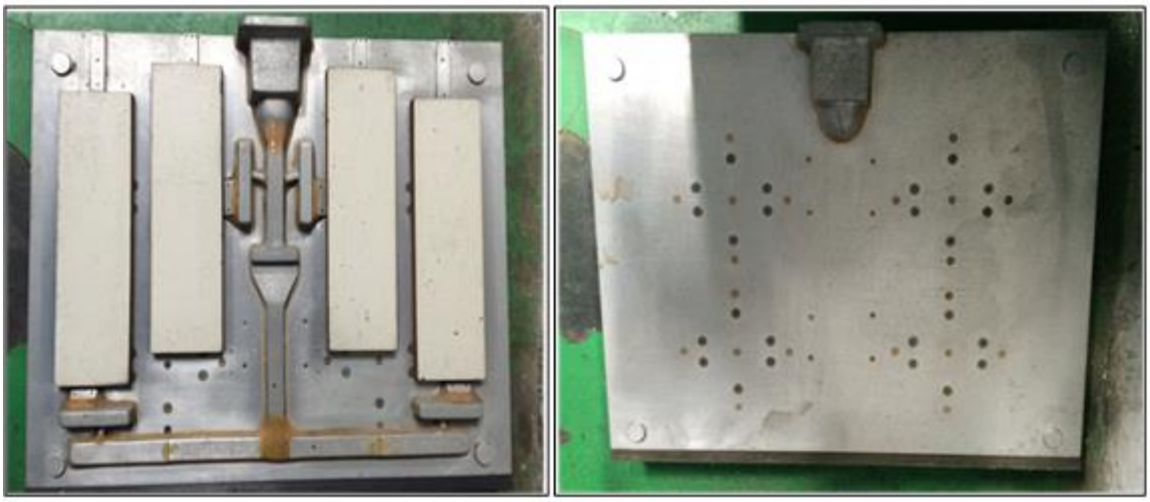


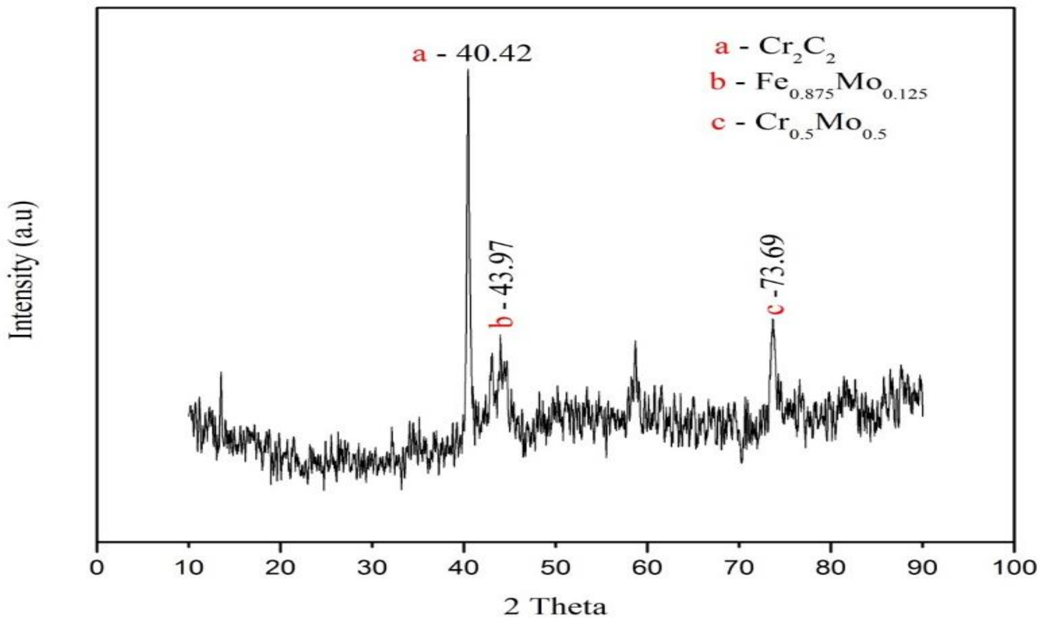
Figure 1(a) & (b) Pattern used for stag casting of substrate

Result and discussion

XRD ANALYSIS

X-ray diffraction(XRD) is the most powerful and the least expensive technique for identifying coating crystallographic structures. In the as-deposited condition, the phase analysis of the coating are shown in Fig-2, the main phase of the coating are Cr2C2, Fe0.875Mo0.125, Cr0.5Mo0.5. It can be inferred that Cr3C2 decomposed during plasma spraying, forming carbides of Cr element. These carbides are the hard phase, having a high hardness and a strong wear- resistance. These hard phases distribute uniformly, disperse in the coating and have a high strength with the matrix, which can heighten the coating's resistance to wear.

Figure 1 X-ray diffraction pattern of the coating

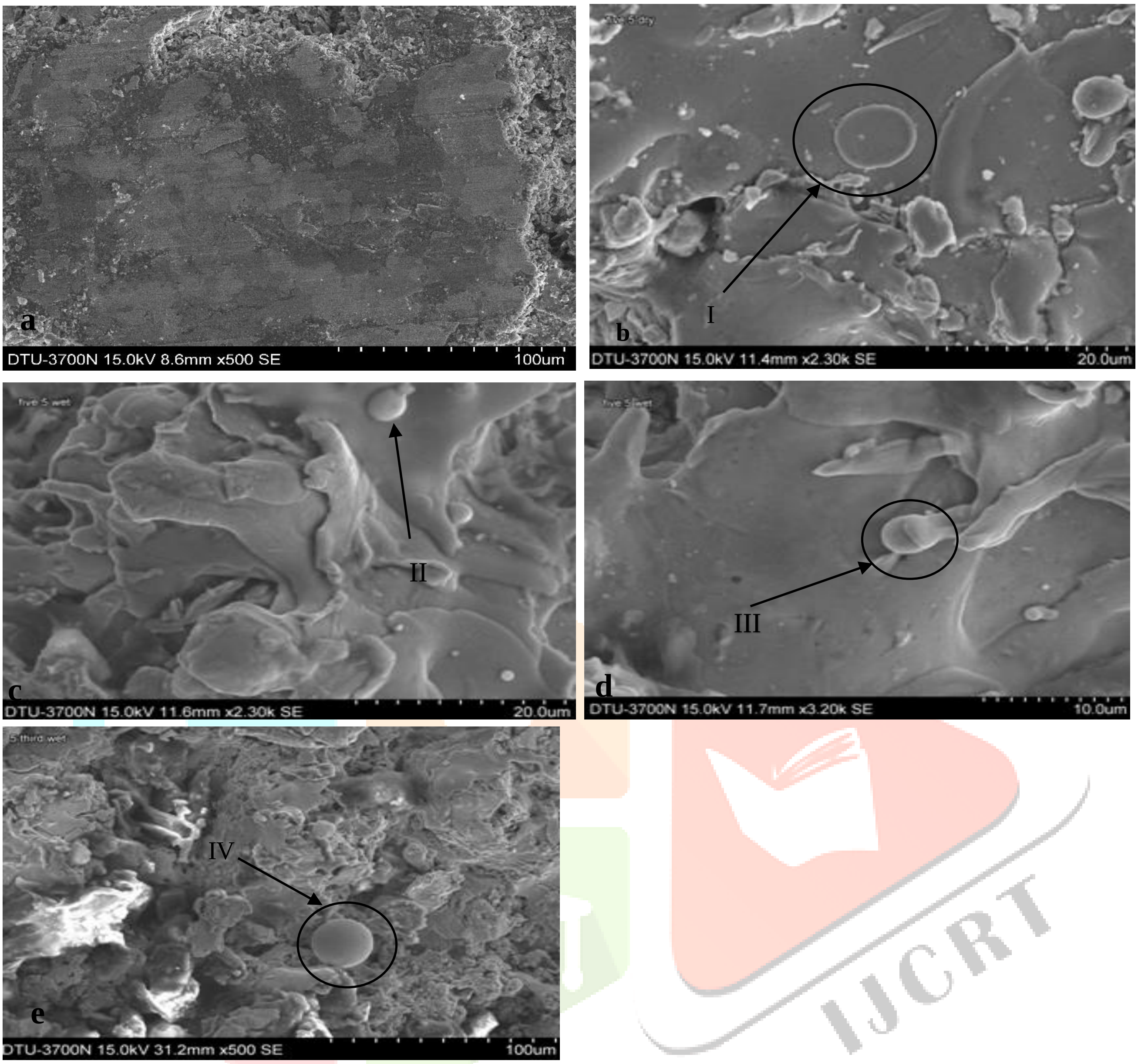


COATING STRUCTURE ANALYSIS

Plasma spraying is a process in which particles characteristically 10–100 µm in diameter are quickly melted and accelerated to produce a stream of molten particles onto a substrate. On impact the liquid droplet squashes to form a disc, the comprehensive shape of which is determined by surface tension, density, viscosity and speed of the liquid drop. In most circumstances solidification occurs as levelling of the liquid droplet proceeds, i.e. 'splat' type morphology. Therefore, inside a limited size range, the particle morphology in the coating is dependent on the both the degree of superheat in the droplet and the velocity of the droplet as it impacts on the substrate surface. The lower the degree of superheat and particle velocity, less flattening of the droplet will occur, i.e. the 'splat' is less elongated in the direction parallel to the surface. Oxides can also be formed during the time between the passes on the outer surface of the layer. This oxidation can be decreased by spraying in a vacuum or inert atmosphereThe morphology of the Mo based coating is characterized by scanning electron microscope(SEM). The thickness of the coating was found around 409 µm which can be clearly seen in figure-2 SEM micrographs of the as sprayed plasma coating under investigation are shown in Fig 2. The coating progress as the spraying gun repeatedly appply layers on the subatrate as it pass through over the surface, with a typical layer thickness 370- 410 µm as shown in Fig 3

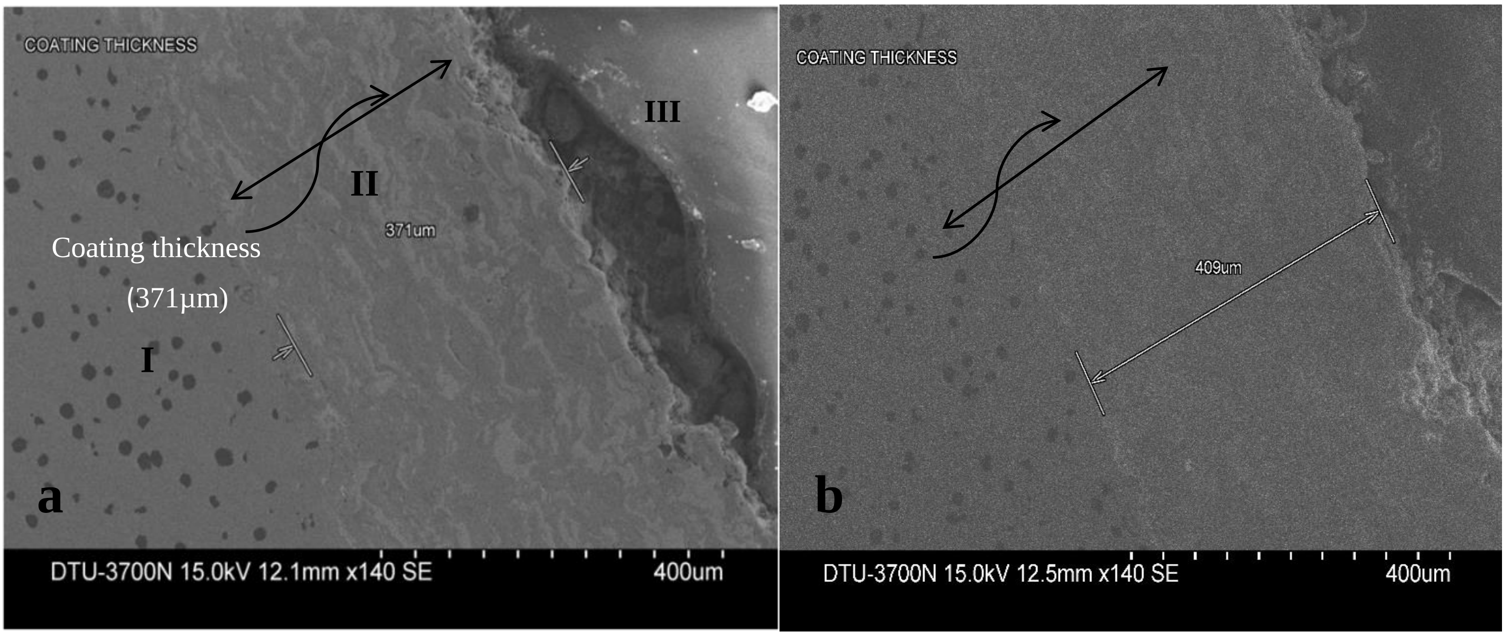
The microstructure of the coating, observed by the SEM micrographs are shown in Figure 3. The micrograph of coating surface shown, shows a typical lamellar structure. And cross section image shows a good coating adhesion. The interior coating body is composed of numerous flat particles, partially melted and fully melted Mo particle, disc splat, partially melted region and unmelted Mo particle.
The micrographs of the coating suggest that the splat of the sprayed material does not seem to form a continuous layer in figure 3(e), but at the cross section, it was observed that the coating was more homogeneous and regular in Fig.4. The microstructure seen in the present study is analogous with the findings reported in the studies of various researchers (Vicenzi et al., 2008; Lin et al., 2015; Pandey et al., 2017)
Figure 4 shows a photomicrograph of x-section of the sprayed coatings. The coating thickness can be up to several microns shown in figure 4(a). Here the typical coating thickness is from 350 to 400µm. Figure 4 (b) recognises the laminated structure and existing porosity (small black regions). The round black spot (figure 3 b) in micrographs is those that did not melt completely before re-solidifying.

Figure 2 SEM images of the coating



I-Disc splat; II -partially melted particle; III- partially melted Mo particle; IV- unmelted Mo particle
(a)- fully melted; (b)-partially melted region; (c)-irregular layer; (d)-partially melted particle; (e) irregular layer

Figure 3 SEM images Coating Thickness



I: Substrate material; II: Coating thickness; III: Mounting material; IV: Porosity

CONCLUSION

Plasma sprayed composite coating (60% high carbon molybdenum, 10% pure molybdenum, 10% CrC and 20% NiCr) has been deposited on the piston ring is investigated by scanning electron microscope and X-ray diffraction. The following points are concluded from the experimental results are as follows:

- The grain size of the coating powder varies from 10-50 µm
- The X-ray diffraction results of the coated sample show the sharp peaks of Cr_2C_2, $Fe_{0.875}Mo_{0.125}$ and $Cr_{0.5}Mo_{0.5}$; it can be inferred that Cr_3C_2 decomposed during plasma spraying, forming carbides of Cr element. This is the clear evidence for the formation of the different structure in the coating.
- The microstructure of the plasma sprayed coating shows a uniformly dense, laminar structure with an exceptional coating adhesion with the substrate. It also shows Unmelted Mo and partially melted Mo particle. With some disc splat, and an irregular layers of coating at some places as investigated by SEM results.
- The observed coating thickness of the coating was found to be about 370- 409µm, as observed by SEM.

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