Microstructural charaterisation of high iron carbon molybdenum coatings

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ABSTRACT

Original equipment manufacturers now days are concentrated on improving the engine performance and efficency. To improve the tribological characerstics of the engine, the thermally sprayed technique arebeing used for depositing the coating on various parts. To provide a reliable basis for the practical application in automotive industry, a composite powder containing 60% high carbon molybdenum, 20% pure molybdenum, 10% CrC and 10% NiCr deposited on the cast iron substrate by atmospheric plasma sprayed method. In this paper microstructure and phases analysis of the deposited coating by scanning electron microscope and X-ray diffraction was performed. The results show that the obtained composite coating has a uniform, laminar and dense microstructure with goodcoating adhesion with the substrate. The thickness of the composite coating on the substrate is about 371µm.

1. INTRODUCTION

Orignal equipment manufacturers are facing the challenge to decrease fuel consumption and emissions by improving engine efficiency. Aproxx 22% of the fulenergy is available for car's motion[1][2][3][4][5][6]. The major part of this fuel is expended to overcome friction, aprox28% (excluding rolling resistance)of the total fuel energy is used to overcome engine friction losses including piston skirt friction, piston rings, and bearings.Because of these losses, there is a requirementof considerable reduction in engine frictional losses. The components of the piston and cylinder system and crankshaft drive are at the centre of these development efforts. The piston ring pack has a significant potential for bringing down friction losses due to its impartially high (24%) share of mechanical frictional losses[7][8][9]. When considering measures to optimise, the tribological system of the piston ring and cylinder surface, piston ring coatings play a progressively important role as they can directly influence the wear and frictionbehaviour and the resulting scuff resistance.

Automotive manufacturers have specified hard chromium coating for piston rings for decades because of its wear and corrosion resistance, however hardchromium plating cause effects on human health because of the use Cr^6+ ions in the galvanic process[10][11][12][13]. The improvements of the thermal spray process allow the chromium coating replacement with a comparable or superior surface and more environment-friendly coatings[14][15]. At present plasma, the sprayed coating has shown significant improvements in reducing wear and CoF in piston rings. Plasma spray processes utilise the energy contained in a thermally ionised gas to melt partially and propel fine powder particles on to a surface such that they adhered and agglomerated to produce coatings. Plasma itself consists of gaseous ions, free electrons, and neutral atoms. The functions of a plasma spray torch are to generate and sustain a captive high-temperature region so that powder particles introduced into that region can be heated and accelerated on to a work piece[16][17]. In this study, a coating of 60% high iron carbon molybdenum powder blended with 20% pure molybdenum, 10% chromium carbide and 10% Nickel Chromium was sprayed using atmospheric plasma spraying technique on a cast iron substrate. The microstructure and phase of high iron carbon molybdenum based coating were studied in this paper, to provide a reliable basis for the practical application in automotive industry.

2. EXPERIMENTAL PROCEDURE

2.1 SUBSTRATE PREPARATION

The substrate plate is made through casting process. materialis first heated until it is in theliquid state and then pouredinto a mould containing the cavity having a shape similar to that of required for the experiment. Cope and drag used for the casting respectively. Theafter being qpoured; substrate melt is allowed to solidify. This solidified part is known as casting.This entire substrate is prepared using stag casting all in one go to achieve maximum uniform composition. After solidification, the castingwas ejected from the mould, by breaking the sand mould, and sand blasting operation, grinding operation were performed to obtain a clean and smooth surface with minimum possible irregularities[18].The powder of Carbon (C), Silicon (Si), Magnesium (Mg), Phosphorous (P), Sulphur (S), Chromium (Cr) and Copper (Cu) was used for the preparation of charge. The above chargeused for Induction Arc Furnace at temperature 1540°C. The composition of the substrate material is shown in Table 1.

Table 1 Substrate Composition

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

2.2 COATING PREPARATION: ATMOSPHERIC PLASMA SPRAY COATING

The substrate plates made of cast iron similar to that of piston ring material, with a dimension of 90x90x2 mm was plasma sprayed with a Sulzer-Metco PT-F4 torch in an isolated environment using a robot to ensure controlled and reproducible trajectories. Ar-H_2 was used as primary gas and secondary gas respectively. Beforespraying, the surface of the substrate was sandblasted with 35-mesh Al_2O_3 particles to a roughness value of 10µm to enhance the adherence while coating. 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 primary 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 fixed in the fixture of the Plasma Spray Machine. Table 2 shows the operating parameters of coating setup. Thecoating material used to spray was a composite powder of 60% wt. high iron carbon molybdenum blended with 20% wt. pure molybdenum, 10%wt chromium carbide, 10% wt nickle chromium. The powder average particle size varied from 10 – 50 µm.

Table 2 Process Parameter of Plasma Spray Coating

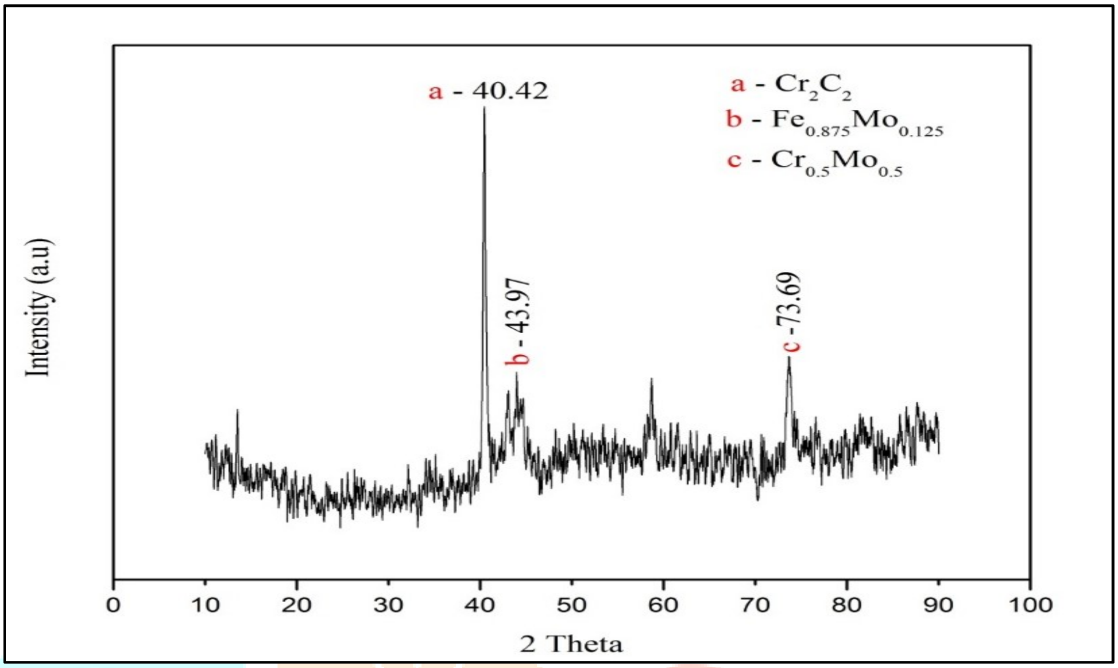
Sr. No	Process Parameter	Specification
1	Powder Port Internal Diameter	2.2 (mm)
2	Water Flow Rate	4.0 (l/m)
3	Temperature Of Chiller	17 (ºC)
4	Distance Between Spray Gun & Mandrel (At gun angle 300°)	140 (mm)
5	Argon Flow Rate	1.87 (m^3/s)
6	Hydrogen Flow Rate	0.21 (m^3/s)
7	Argon Pressure	6.5 (bar)
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 (°)
14	Cooling Air Pressure	46 (bar)
15	Powder Driving Temperature	120 (ºC)
16	Powder Mixing time in V-type mixer	5400 (s)

3. RESULT AND DISCUSSION

3.1 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 coatingare shown in Fig-2, the main phase of the coating is Cr_2C_2, $Fe_{0.875}Mo_{0.125}$, $Cr_{0.5}Mo_{0.5}$. 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



3.2 COATING STRUCTURE ANALYSIS

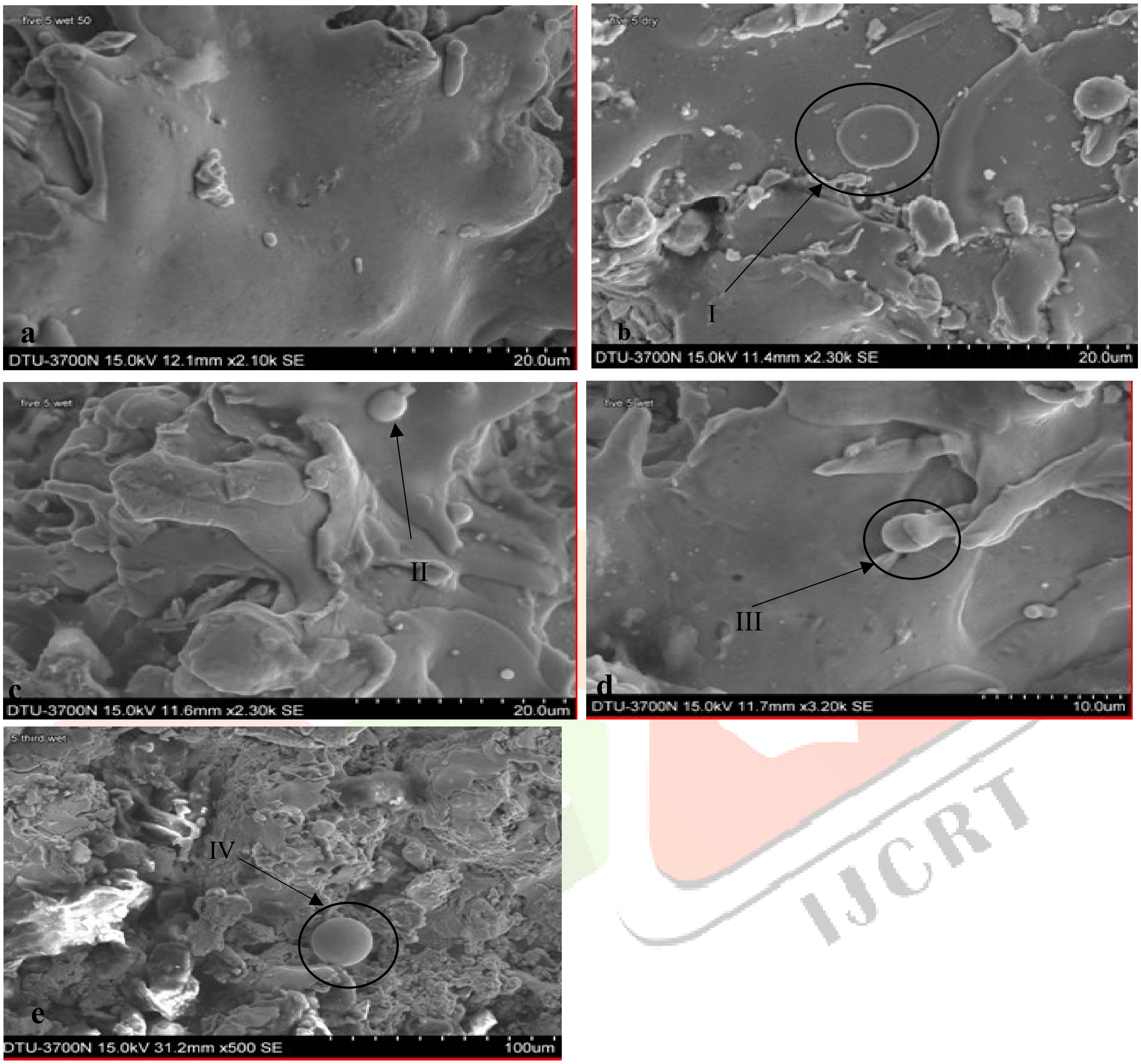
Scanning electron micrographs (SEM) of the as sprayed plasma sprayed coating under investigation are shown in Fig 3. The coating progress as the spraying gun repeatedly traverses over the surface and applies the coating in layers, with a typical layer thickness 371 µm as shown in Fig 4. Plasma spraying is a process where particles typically 10–100 mm in diameter are rapidly melted and accelerated to produce a stream of molten particles onto a substrate. On impact the liquid droplet flattens to form a disc, the detailed shape of which is determined by surface tension, density,viscosity and velocity of the liquid droplet. In most conditions solidification occurs as flattening of the liquid droplet proceeds, i.e. 'splat' type morphology. Therefore, within 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 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 atmosphere.

The microstructure of the coating, observed by the scanning electron microscope is shown in Figure 3. The micrograph of coating surface shown shows a typical lamellar structure. The interior coating body is composed of numerous flat particles, partially melted Mo, an irregular layer of coating, fully melted, 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)

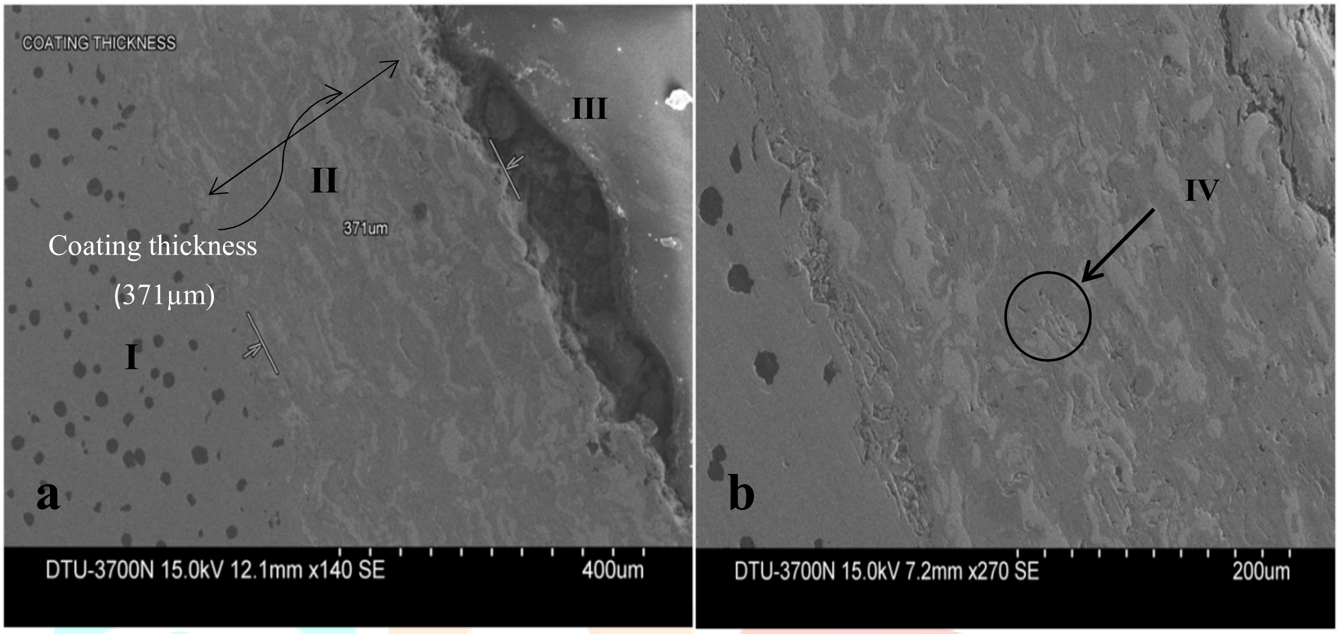
Figure 4 shows a photomicrograph of x-section of the sprayed coatings. The coating thickness can be up to several microns shown in figure 4(a). Here the typical coating thickness is from 350 to 400µm. Figure 4 (b) recognises the laminated structure and existing porosity (small black regions). The round 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

4. CONCLUSION

Plasma sprayed composite coating (60% high carbon molybdenum, 20% pure molybdenum, 10% CrC and 10% 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 different powder vary 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 371 µm, as observed by SEM.

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