Study phase and microstructure of atmospheric plasma sprayed 60% (Mo+Fe) +20%Mo+10%CrC+10%NiCr coating for piston ring application

[1]**Dr. Shailesh Mani Pandey**
[1]Assistant Professor, [1]Mechanical Engineering,
[1]Delhi Technological University, New Delhi, India

Abstract- Molybdenum and chromium coatings were deposited on cast iron using atmospheric plasma spray process. The goal of this research is to boost the performance and life of engine parts. The primary areas of research under consideration are the wear behaviour of cylinder liners and piston rings. Since coatings can increase hardenability, toughness and wear resistance of the substrate plate, the thermal spray techniques were used for coating the piston rings. A powder mixture of Molybdenum Disulphide, NiCr, CrC and Molybdenum were deposited as piston ring coatings on cast iron substrate The results show that the obtained composite coating has a uniform, laminar and dense microstructure with good coating adhesion with the substrate. The thickness of the composite coating on the substrate is about 371µm.

Keywords: Piston ring coating, SEM, XRD.

Introduction

Manufacturers of the internal combustion(IC) engine facing the challenge to reduce fuel consumption and emissions by improving engine efficiency. Only 21.5% of the total fuel energy is available for car's motion[1][2][3][4][5][6]. The major part of the fuel energy is consumed to overcome friction only 28% (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 requirment of 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[4]. 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 friction behaviour 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 chromium plating cause effects on human health because of the use Cr6+ ions in the galvanic process[7]. The improvements of the thermal spray process allow the chromium coating replacement with a comparable or superior surface and more environment-friendly coatings. At present plasma 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 workpiece. In this study, a coating of 60% high iron carbon molybdenum powder blended with 20% pure molybdenum, 10% chromium carbide and 10% Nickle Chromium {60%(Mo+Fe)+20%Mo+10%CrC+10%NiCr}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.

Experimental procedure

substrate preparation

The substrate material is heated until it is in liquid (perfectly melted) state. This melted material is then poured into a mould containing the cavity having a shape similar to that of required for the experiment. Cope and drag used for the casting is shown in figure 1 (a & b) respectively. The substrate melt, after being poured, is allowed to solidify. This solidified part is known as casting. This casting is then ejected from the mould and sent for further processing, i.e. grinding operation to obtain a clean and smooth surface with minimum possible irregularities. The experience of the designer and material's strength determines the soundness of casting[8]. This entire substrate is prepared using stag casting all in one go to achieve maximum uniform composition. After solidification, the casting is removed from the mould by breaking the sand mould, and sand blasting operation is performed. The powder of Carbon (C), Silicon (Si), Magnesium (Mg), Phosphorous (P), Sulphur (S), Chromium (Cr) and Copper (Cu) is used for the preparation of charge. The above charge is used for Induction Arc Furnace at temperature 1540°C. The composition of the substrate material is shown in table 1.

Figure 1 (a) Cope and (b) drag of mould used for the casting

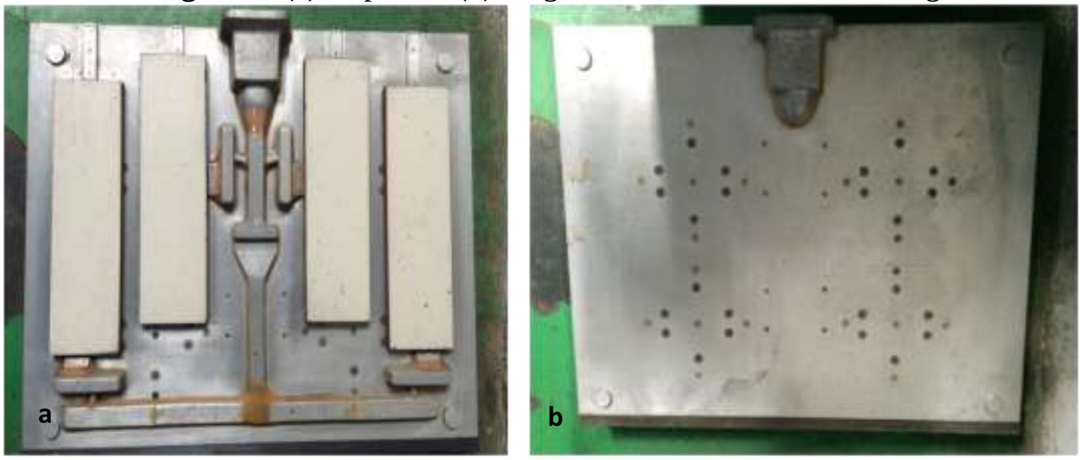


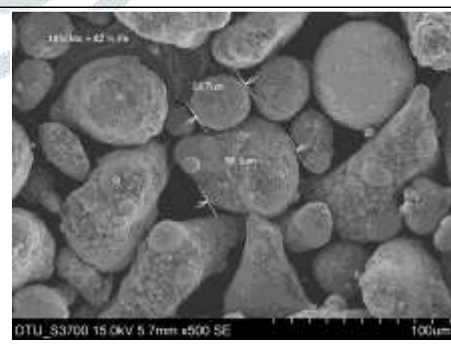
Table1 substrate material composition

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

Coating preparation: atmospheric plasma spray coating

The substrate is made of cast iron similar to that piston ring material, with dimension 90x90x2 mm was plasma sprayed with a Sulzer-Metco PT-F4 torch in an isolated environment using a robot. The robot ensured controlled and reproducible trajectories and speed. Ar-H_2 were used as Primary gas and secondary gas respectively. Before spraying, the surface of the substrate was sandblasted with 35-mesh al_2o_3 particles to a roughness value(Ra) of 10µm in order 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 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 3 shows the operating parameters of coating setup. the coating 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. Whose chemical composition and SEM images are shown in table 2 the powder particle size varied from 40 – 50 µm.

Table 2 SEM micrographs of substrate powder

Sr. No	Name	Composition	Density/ Uses/ Melting Point	SEM Micrographs
1	Metco (350NS)/ Iron molybdenum composite powder	Fe16Mo2C0.25Mn	2.8 g/cm^3- 3.4 g/cm^3 Wear and scuff resistance 1400 °C	
2	Amdry(313)/ molybdenum powder	99.5% (by wt.) of Molybdenum	2.5 g/cm^3 - 5.9 g/cm^3 Wear and scuff resistance 2620^{0}C	

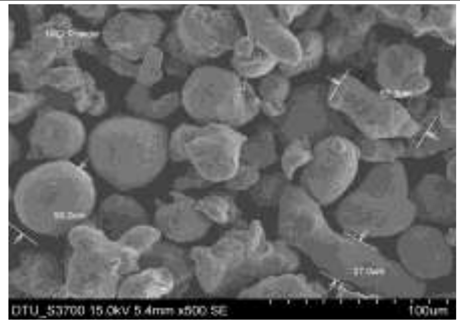
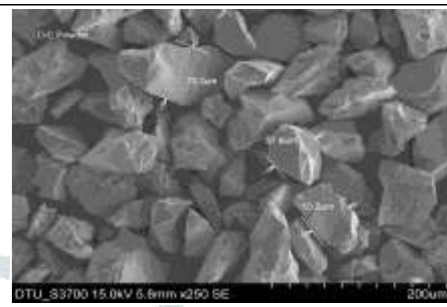
3	Metco(43) F-NS / nickel chromium alloy powder	Ni20Cr	3.1 g/cm^3 - 4.6 g/cm^3 Corrosion-resistant bond coat 1400 ^{0}C	
4	Metco(70) CNS / chromium carbide powder	Cr_3C_2	2.7 g/cm^3 - 3.0 g/cm^3 Wear resistance 1930 °C	

Table 3 coating parameters

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^o)	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)

Result and discussion

Coating structure analysis

The microstructure of the coating is as important as the chemical composition of the coating material. The sprayed coating progress as the spray gun repeatedly traverses over the surface and applies the coating in layers, with a typical layer thickness of 10 to 20 µm. Oxides can 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.

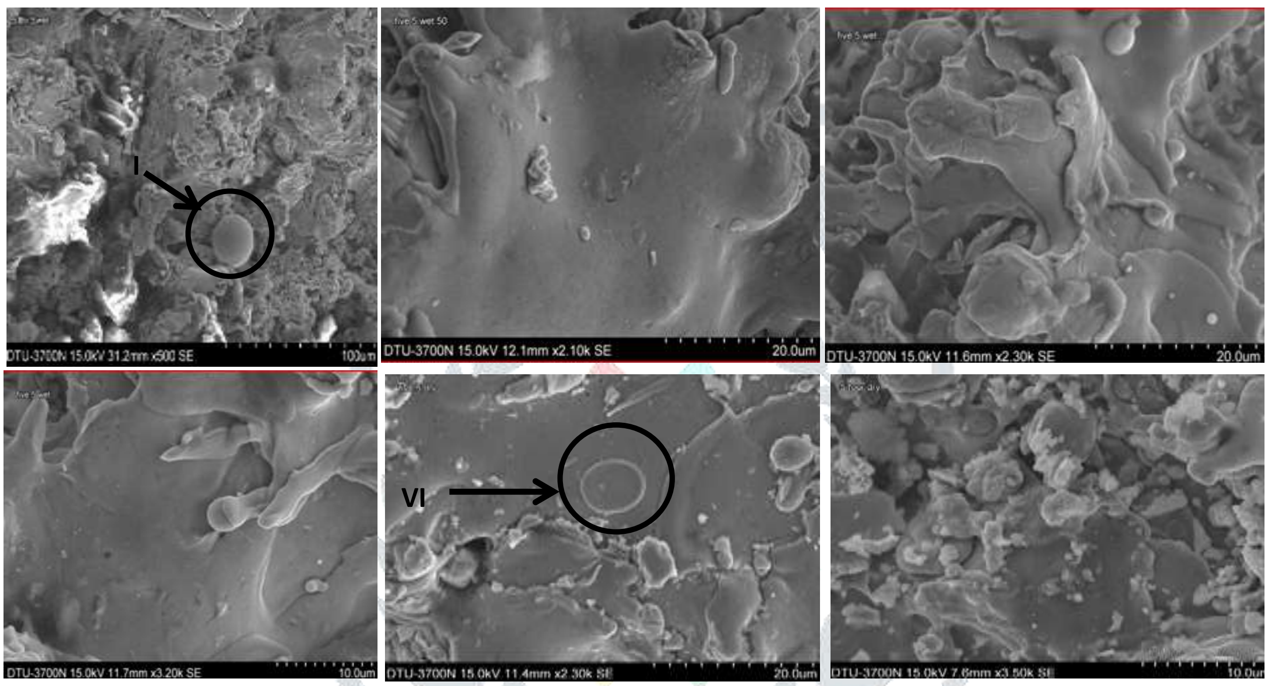
The microstructure of the coating, observed by the scanning electron microscope are shown in Figure 2. The micrograph of coating surface is shown in figure shows a typical lamellar structure. The interior coating body is composed of numerous flat particles , Unmelted Mo, pan cake splat, an irregular layer of coating, fully melted, disc splat and partially melted region.

The micrographs of the coating suggest that the splat of the sprayed material does not seem to form a continuous layer in figure 2(IV), but at the cross section, it was observed that the coating was more homogeneous and regular. 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 3 shows a photomicrograph of x-section of the sprayed coatings. The coating thickness can be up to several microns shown in figure 3(a). Here the typical coating thickness is from 350 to 400µm. Figure 3(b&c) recognises the laminated structure and existing porosity (small black regions). The round black spot (figure 3 c) in micrographs is those that did not melt completely before re-solidifying.

XRD analysis

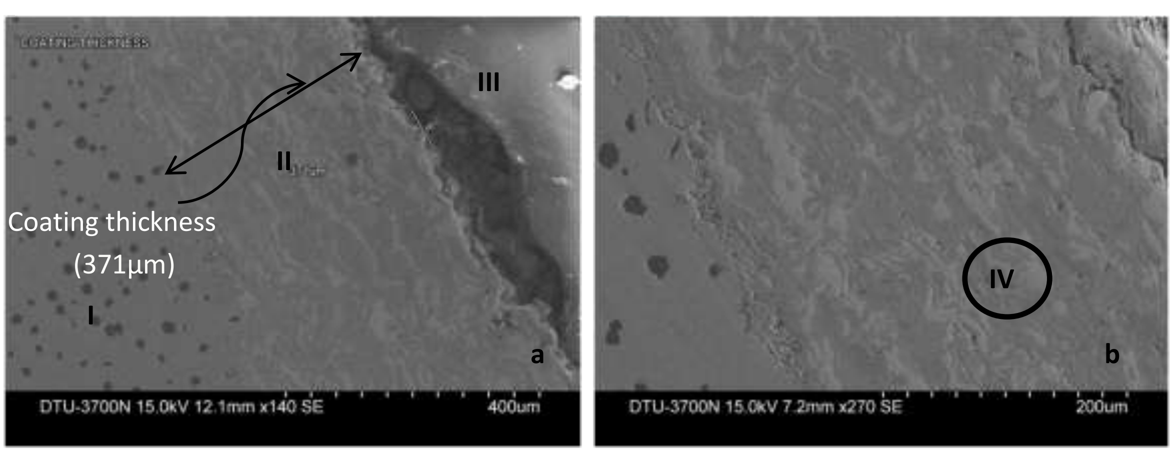
X-ray diffraction(XRD) shown in fig.4 is the most powerful and the least expensive technique for identifying coating crystallographic structures. In the as-deposited condition, phase analysis of the coating is shown in fig, the main phase of the coating are Cr2C2,Fe0.875Mo0.125,Cr0.5Mo0.5. it can be inferred that Cr_3C_2 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 be heighten the coating's resistance to wear.

Figure 5 SEM micrograph of plasma coated surface at different positions



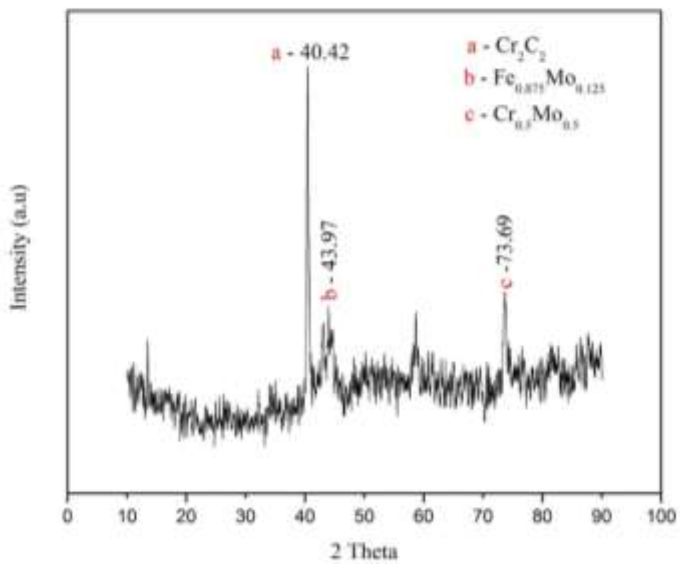
I: Unmelted Mo at 100µm; II&III: Pan Cake splat at 40µm & 20µm; IV: Irregular layer of coating; V: Fully melted region; VI: Disc splat; VII & VIII: Partially melted region at 20µm & 10 µm.

Figure 7 Cross-section SEM micrograph of coated substrate at (a) 400 µm (b) 200 µm and (c) 10.0µm



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

Figure 3 X-ray diffraction pattern of the coating



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 microstructure of plasma sprayed coating shows a dense and laminar structure with a good coating adhesion to the substrate. 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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