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Influence Of Hardness By WC Based Coating On Alsi Alloy And Grey Cast Iron Using HVOF Coating Method

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Abstract : *Grey Cast Iron and AlSi alloy are the more commonly used materials for cylinder liner applications in automobiles. With the upcoming need for an efficient utilization of fuel resources and alternate fuel resources, there is a subsequent need for the improvement of surface properties as well as to reduce the engine weight. Hard Chromium coatings exhibit attractive properties such as high hardness and excellent wear resistance and have been widely used in the automotive, aerospace and manufacturing industries. The main limitation is that chromium coatings are not environmentally friendly coating and thus replacements are sought. In this paper, the potential of WC based coating deposited on AlSi Alloy and Grey Cast Iron using HVOF (High velocity oxygen fuel) coating have been discussed. The role of surface flattening behavior of these materials by WC based coating is also discussed. The thickness of the coating was measured using SEM (Scanning Electron Microscope). A significant improvement in the hardness was noted as a better surface behavior which was measured using Vickers micro hardness. .*

Keywords : *HVOF Coatings, WC based Coatings, Cylinder Liner materials, Surface flattening behviour.*

I. INTRODUCTION

One third of car´s fuel consumption is spent in overcoming friction, and this friction loss has a direct impact on both fuel consumption and emissions [1]. Therefore, from the viewpoint of both energy saving and environmental protection, it is of considerable issue to reduce friction and control wear. Moreover automotive engine components such as engine cylinder have to sustain high wear resistance and low friction under relatively hostile conditions. The reduction of friction losses in automotive engines offers big potential when looking for possibilities to cut down fuel consumption. In the engine block, the inner wall of the cylinder bore forms the sliding surface for the piston and piston rings assembly. Thus the specification of the cylinder bore material as well as the topography and the quality of the running surface in the cylinder bore play a crucial role in the optimization process of the tribological system "Cylinder-Piston-Piston ring". Grey cast iron provides itself a good tribological behaviour for the "Cylinder-Piston-Piston ring"system [2]. However, the ongoing substitution of cast iron in engine blocks by aluminium casting alloys requires the development of a new “tribological system”. Aluminium casting alloys are not sufficiently wear resistant for this application [3], [4]. During last several decades, numerous coatings and deposition methods have been successfully developed, and used to reduce friction and to protect surfaces from damage in mechanical systems. From this, coatings was found one of the most effective and flexible solutions for wear problems. In Recent years, HVOF coatings prove to be very dense, strong and show low residual tensile stress or in some cases compressive stress, which enable very much thicker coatings upto 3-4 mm [5]. Unlike the electrolytic process that is used to apply hard chrome plating, the HVOF process creates no contaminated waste or rinse water streams to be disposed of later, and it eliminates potential worker exposure to hexavalent chrome [6]. It is also faster than chrome plating (with typical coating deposition possible in an hour or two, vs. 24 hours required for hard chrome plating) [5]. HVOF coatings do not suffer from hydrogen embrittlement (as can hard chrome coatings), so the time and cost required for embrittlement relief treatment is eliminated.

All of these factors work in tandem to lower the frequency of repairs and facilitate faster turnaround during overhaul and maintenance activities (which reduces out of service time), thereby reducing the overall lifecycle costs associated with these critical parts.Literature survey indicates that the cylinder liners are made of pearlitic grey cast iron of the grade 35 (ASTM A48) providing 248MPa of tensile strength and 95–104 HRB (200–262 HB) of hardness. The graphite flakes reveals an ‘A’ or ‘B’ distribution [7]. The microstructure of grey cast iron SAE G3500 was identified as pearlite in the microstructure and carbon ranges from 3-3.5 % in the composition. It provides mechanical properties such as hardness ranges from 207-255 HB and tensile strength of 240 N/mm2 [8].Literature survey also suggests suitable block materials for a lined engine would be LM9, containing 12% silicon with a small addition of magnesium to make it heat-treatable or LM25 solution treated and artificially aged, as in the Rover K series engine. The use of a hyper-eutectic aluminum-silicon alloy such as LM30 may allow the use of an unlined cylinder block [9].Bolelli et al [10] have discussed the WC–10%Co–4%Cr coatings deposition onto aluminium alloy 6082-T6 plates by HVOF-spraying. It was studied that the thickness of the coatings was varied from 50–150 μm. It was noted that the thinner coatings are more defective, because the flattening of cermet particles impacting onto the soft Al surface. Thicker coatings, deposited by performing several torch scans, are denser. The wear rates decreases as the coating thickness increases, the largest difference being the one between 2 torch scans and 3 torch scans. Houdkova et al [5] have discussed that the plasma sprayed ceramic coating Cr2O3, due to its tendency to exhibit brittle cracking, can only be recommended for sliding wear conditions. The micro welds caused larger coating parts to be pulled out; this was observed mainly in the Cr3C2–NiCr coating.

Fang et al [11] have discussed that HVOF sprayed WC–CrC–Ni coating by Process optimization and it was evident that during HVOF spraying, a portion of carbides of the powder, such as WC, Cr7C3, Ni3C decomposes to W2C, Cr, Ni and free carbon. It was also discussed that the hardness of the coating (1150±50 HV) is two to three times higher than that of IN 718.Prudenziati et al [12] have stated that Cr3C2-NiCr cermets are extensively used for wear and corrosion-resistant applications. Coatings of the WC-Co system generally have a high hardness and wear resistance. It was found out that the decarburization of WC, primarily into W2C, leads to degradation of properties and limits the application of the coatings to temperatures in the range of 500 °C.

II. EXPERIMENTAL DETAILS

2.1 SAMPLE PREPARATION

The samples were cut using wire (EDM) Electrical Discharge Machining for precision cutting and were machined to the dimensions of 55 mm diameter and 10mm thickness with 6mm blind hole in the centre as per the specification for ASTM standard G99. Two specimens each were fabricated from Grey cast iron and AlSi alloy by wire cut EDM , prior to coating grinding was done on both the sides to remove surface irregularities as well as any induced micro-level heat affected zone as shown in Fig. 1.The specimens were polished to achieve mirror finish to improve the surface properties. The samples were then sand blasted with silica abrasive particles size of 25±5 μm and was cleaned thoroughly using acetone. The samples were sand blasted to improve the adhesion property to facilitate for coating.

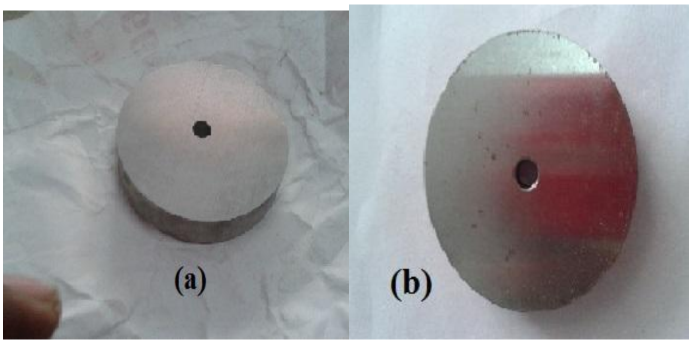

Fig. 1 Uncoated Specimen (a) AlSi Alloy (b) Grey Cast Iron

2.2 MATERIALS USED

The nominal and actual composition of substrate and grey cast iron are shown in table I and II respectively. The actual composition was identified using a preliminary chemical composition test to verify the Substrate materials.

TABLE I

NOMINAL AND ACTUAL COMPOSITION OF GREY CAST IRON SAE G3500

Elements	**C (%)**	**Si (%)**	**Mn (%)**	**Cr (%)**	**S (%)**	**P (%)**	**Fe (%)**
Nominal Composition	3-3.5	1.8-2.20	0.6-0.9	0.12 max	0.15 max	0.18 max	Remainder
Actual Composition	3.46	1.880	0.540	0.120	0.067	0.181	Remainder

TABLE II
NOMINAL AND ACTUAL COMPOSITION OF AlSi ALLOY SAE 323

Elements	**Si (%)**	**Mg (%)**	**Cu (%)**	**Fe (%)**	**Mn (%)**	**Zn (%)**	**Pb (%)**	**Ti (%)**	**Al (%)**
Nominal Composition	6.5-7.5	0.2-0.6	0.2 max	0.5 max	0.3 max	0.1 max	0.1 max	0.2 max	Remainder
Actual Composition	7.08	0.39	0.126	0.49	0.03	0.02	0.007	0.063	Remainder

2.3 SPRAY POWDER

In this study the coating powder used was a customized powder with a combination of WC, CrC and NiCr mixed together in a mechanical mixer to combine two or more good properties such as better wear and corrosion resistant . The composition of the powder was found using (EDX) Energy-dispersive X-ray Spectroscopy as shown in table III.

TABLE III
ATOMIC WEIGHT% COMPOSITION OF COATING MATERIAL

C (%)	**O (%)**	**Cr (%)**	**Ni (%)**	**W (%)**
11.80	8.74	25.17	41.65	12.64

2.4 HVOF (HIGH VELOCITY OXYGEN FUEL) COATING

DJH 2600 type gun and DJH 2603 nozzle was used to prepare the HVOF coating. The spray parameters employed are listed in Table IV. The substrates material used was Grey cast iron and AlSi alloy materials to the dimensions as per ASTM G99 standards. Spraying parameters were optimized to produce the coating as shown in Fig. 2.

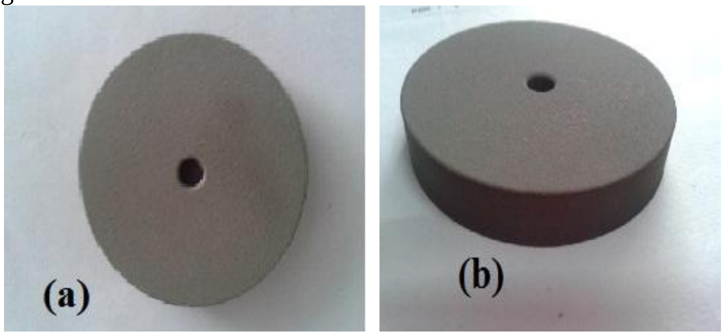

Fig. 2 Coated Specimen (a) AlSi Alloy (b) Grey cast iron

TABLE IV
HIGH VELOCITY OXYGEN FUEL COATING PROCESS PARAMETERS

S.No	Parameters	Quantity
1	Gun type(DJH2600)	1
2	Nozzle type(DJH2603)	1
2	Pressure of Oxygen	2.5 kgf/cm^2
3	Pressure of Kerosene	0.6 kgf/cm^2
4	Torch Angle with respect to Substrate	55°
5	Torch Speed	10 cm/min

II. RESULTS AND DISCUSSION

2.1 MATERIAL CHARACTERIZATION

Powder morphologies along with coating was cut along the cross-section i.e, cut perpendicular to the coating, using wire cut EDM process which was investigated using a scanning electron microscope (SEM) utilizing Secondary electron (SE) imaging and energy dispersive X-ray analysis (EDX). The samples were polished in series of coarse to fine grades of silicon carbide emery paper. The samples were then polished using a diamond paste applied over a velvet cloth on a rotating disc. Fig. 3 shows the SEM image of WC-based coating .The size of the powders varied between 12-105µm and the chemical composition of coating material was determined using EDX. The atomic weight% composition of WC-based coating is shown in table III. The particle size of WC based powder is 45±15 µm.

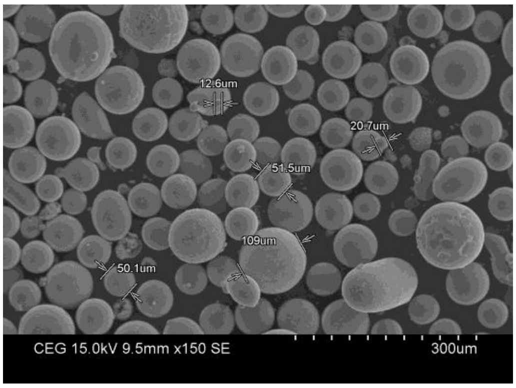

Fig. 3 SEM image of particle size

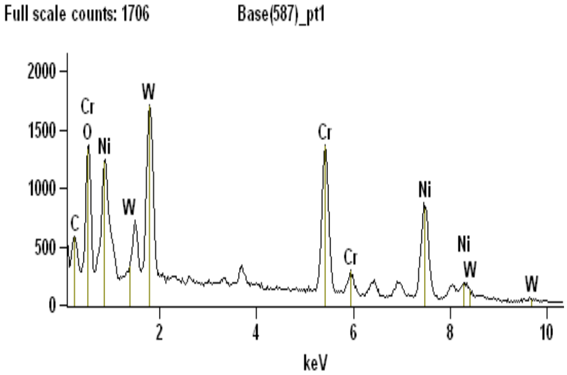

Fig. 4 EDX result of WC based coating

The results from EDX are manipulated from the graph as shown in Fig. 4 which depicts the counts obtained for each elements of periodic table present in the specimen versus voltage consumed by each element which depicts the percentage of elemental composition present in the specimen as shown in Table III. It is observed that the oxidation levels were significantly high as 8.74%. The EDX result of WC based coating is shown in Fig. 4 below depicting the variation of W, Cr, C and Ni. It is found that Ni content is twice as high as Cr in composition. The C content is found to be moreover the same in composition as W content. It also contains some impurities such as Ca, P and some Si content from substrate material.

3.2 THICKNESS AND SURFACE FLATTENING BEHAVIOUR

The SEM images in Fig 5 and 6 shows the thickness of WC based coating on AlSi alloy and Grey Cast Iron. The thickness of the coating varies from 413 to 421 µm for the AlSi alloy substrate material and the thickness for the Grey cast iron varies from 456 to 464 µm. The average thickness for AlSi alloy and Grey Cast Iron was found to be 416 µm and 459µm.It is observed that in the case of AlSi alloy the interface is clearly visible and the substrate is fused with coating material due to its inheritance as soft metal.

In case of HVOF coating the temperature and pressure is so high that the substrate is fused with coating material as shown in Fig.5. Therefore, when WC based coating impinges on AlSi substrate it forms a good adhesion bonding between them and it initially need 2 to 3 torch scans to improve the surface near the interface.

So, the thickness of the coating reduces when compared to coating Grey cast iron. In case of Grey cast Iron as substrate material, the interface is not visible as in the case of AlSi alloy. A good layer of coating can be formed by single torch scan in HVOF coating. The substrate material fuses with coating material but not to extend of AlSi alloy. It is observed that in this case, some unmelted particles are found in the coating as shown in Fig 6.

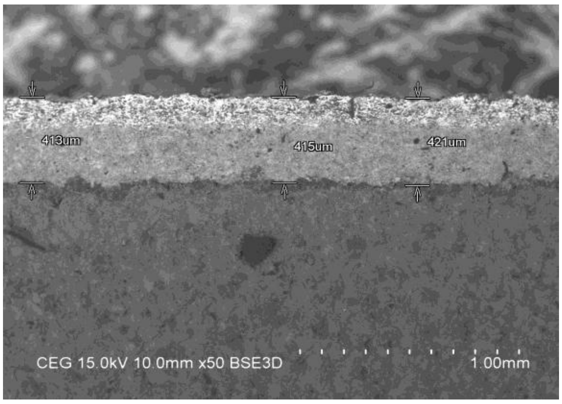

Fig. 5 SEM image of WC based coating on AlSi alloy as substrate material

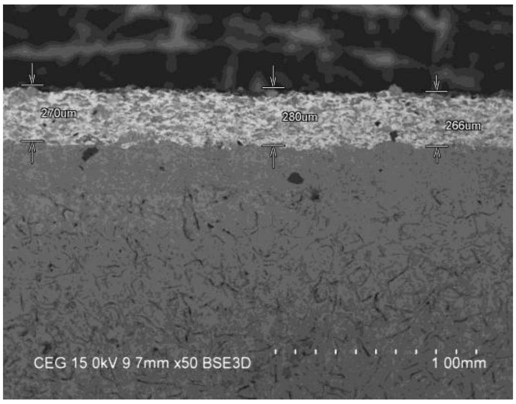

Fig. 6 SEM image of WC based coating on Grey Cast Iron as substrate material

3.3 MICRO HARDNESS

Micro hardness tests were performed on the coated samples using a Leco M-400 machine with a 500 g load and a dwell time of 15 sec using a Vickers micro indenter. Micro hardness was taken along the cross section of the coating. Hardness test was performed for a series of positions starting from the coating edge to substrate material through the interface. In case of Grey cast iron as substrate material it is observed that at the coating edge it is 408.5 $HV_{0.5}$ and gradually increases as the positions shift from edge towards interface as shown in Fig. 7 and Table V. It is observed that at 100 µm distance from interface it is recorded as highest hardness value of 599 $HV_{0.5}$. At the interface it reduces to 283.2 $HV_{0.5}$ and subsequently reduces further in substrate material to 167.1 $HV_{0.5}$.

TABLE V
MICRO VICKERS HARDNESS TEST ON GREY CAST IRON AS SUBSTRATE MATERIAL

Distance from the coated edge	**$HV_{0.5}$**
0.10 (Coating)	408.5
0.20 (Coating)	445.7
0.30 (Coating)	470.2
0.40 (Coating)	599.0
0.50 (interface)	283.2
Substrate	167.1

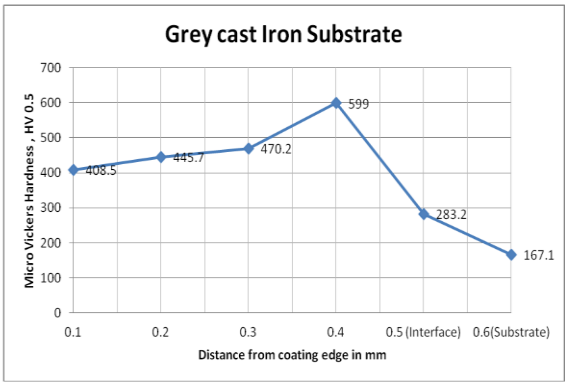

Fig. 7 Micro Vickers Hardness vs Distance from coating edge in case of Grey cast iron as substrate material.

In case of AlSi alloy as substrate material, the hardness value as shown in Fig.8 and Table VI is 606.6 $HV_{0.5}$ at 100µm from coating edge and it maintains a significant value and reaches the highest hardness observed at 300 µm from coating edge as 658.8 $HV_{0.5}$.

TABLE VI

MICRO VICKERS HARDNESS TEST ON AlSi ALLOY AS SUBSTRATE MATERIAL

Distance from the coated edge	**$HV_{0.5}$**
0.10 (Coating)	606.6
0.20 (Coating)	557.3
0.30 (Coating)	658.8
0.40 (Coating-interface)	304.6
0.50 (interface)	275.6
Substrate	85.3

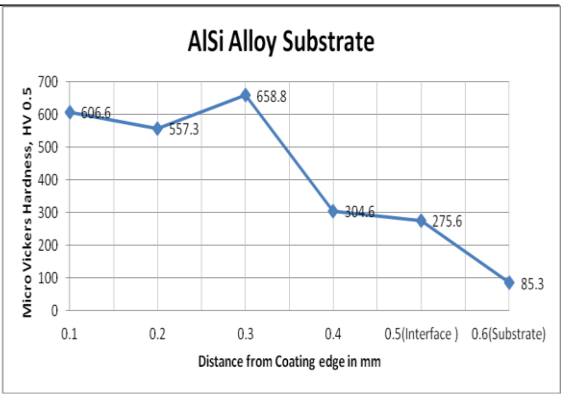

Fig. 8 Micro Vickers Hardness vs Distance from coating edge in case of AlSi alloy as substrate material.

Micro Vickers hardness gradually decreases at the interface to 275.6 $HV_{0.5}$ and the substrate material to 85.3 $HV_{0.5}$.It is observed that in case of AlSi alloy as substrate material the hardness is maintained 607 $HV_{0.5}$ across the coating thickness whereas in case of Grey cast iron the hardness decreases as the thickness increases.

III. CONCLUSIONS

In this work, two substrate materials AlSi alloy and Grey cast iron was coated with WC based coating and the changes in the surface properties and the changes in the surface flattening behaviour were noted. The WC based coating was noted with 8.74% of oxidation levels. The metallic bonding between WC based coating and substrate material was found to better in case of AlSi alloy than Grey Cast Iron as substrate material. The subsequent increase in micro hardness was noted in case of AlSi alloy than Grey cast iron as substrate material. It shows a seven fold increase in hardness in case of AlSi Alloy as substrate material and four fold increase in hardness in case of Grey cast iron as substrate material. Thus, the better improvement in surface properties in case of AlSi Alloy as substrate material could provide a replacement of Grey cast iron in engine application. Further investigation is to be done to study the microstructure changes and wear behavior to find out the potential of WC based coating.

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