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Friction and Sliding Wear Behaviour of Bare and Thermal Sprayed Tool Steels

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Abstract - Several hot forming processes are bound with severe problem of sliding wear resulting in failure of die. The surfaces of the tools get damaged severely due to the application of repeated cyclic contact between the hot work-piece and the tool. Therefore, the present research work aims to experimentally analyze the sliding wear behavior of bare and High Velocity Oxy-fuel (HVOF) sprayed hot forming tool steels under dry conditions at room temperature. AISI H11 and AISI H13 tool steels were selected in the study. NiCrFeSiBC - (WC-Co) coating was deposited by HVOF spray process on tool steels. The as-sprayed coatings were characterized by X-ray diffraction (XRD) analysis and Scanning Electron Microscopy (SEM) and Energy Dispersive Spectrometry (EDS) analysis. Wear performance of the uncoated and the coated tool steels was evaluated on the pin-on-disc tribometer in laboratory so as to ascertain the usefulness of the developed coating composition. The variations of wear rate with the sliding distance for all the specimens studied were plotted. Based on the observations, it was found that H13 showed the least wear rate at 20N load and at a load of 40N H11 showed the least wear rate.

Keywords: Hot forming, Sliding Wear, High Velocity Oxy-fuel, Characterization, wear rates

I. INTRODUCTION

The recent years have witnessed an increasing usage of high-strength steels as structural reinforcements and in energy-absorbing systems in automobile applications due to their favorable high-strength-to-weight ratios. Owing to poor formability, complex-shaped high-strength steel components are invariably produced through hot-metal forming [1]. Several hot forming processes are bound with severe problem of sliding wear resulting in failure of die. The surfaces of the tools get damaged severely due to the application of repeated cyclic contact between the hot work-piece and the tool. There are many ways to protect the surface of the tools from wear and one possible way of controlling friction and reducing wear is to utilize the latest developments in surface engineering and modify or coat the tool surface with some thermally stable layer. The use of High Velocity Oxy-fuel (HVOF) coatings for numerous wear resistant applications in a variety of industrial environments was reported by number of authors [2-8]. HVOF coating process is a thermal spray coating process used to improve or restore a component's surface properties or dimensions, thus extending equipment life by significantly increasing its resistance to wear, corrosion and erosion. The objective of this research work is to study the sliding wear behavior of 65%NiCrBSiCFe – 35%(WC-Co) composite coating deposited by HVOF spray process on the selected tool steels, In-depth characterization of the as-sprayed coatings was done by X-ray diffraction (XRD) analysis and Scanning Electron Microscopy (SEM) and Energy Dispersive Spectrometry (EDS) analysis. Sliding wear bahaviour was studied according to ASTM, Standard G99-03 on a Pin-on-Disc Wear Test Rig. Cumulative wear volume loss, wear rate and coefficient of friction (μ) were calculated for all the specimens for 20 N and 40 N normal loads. The variations of wear rate with the sliding distance for all the specimens studied were plotted and analyzed.

II. EXPERIMENTAL DETAILS

2.1. Substrate Materials

The substrate materials selected for the study were hot forming chromium tool steel AISI H11 (H11) and AISI H13 (H13) with the nominal and actual chemical composition as shown in Table 1. The workpiece material 20MnCr5 was also procured in consultation with the actual hot press forging industry. The steel is a high strength alloy steel being used these days for preparing pinions by hot press forging. The tool steel samples were cut to form pins of diameter 8mm and length 50mm for the wear tests. The specimens were polished and grit-blasted with Al_2O_3 (grit 45) prior to the application of HVOF spray coating.

2.2. Formulation of Coating

The coatings were developed at Metallizing Equipment Co. Jodhpur (India) on their commercial HIPOJET-2700 apparatus operating with oxygen and liquid petroleum gas (LPG) as fuel gases and nitrogen as powder carrier gas. The robotic arm for automatic spray was of make KUKA, made in Germany. It was decided to mechanical blend the two commercially available powders in the ratio 65:35 by wt.%. The NiCrFeSiBC and WC-Co coating powders were commercially available. The powders were procured from M/s H.C. Starck, Germany. Flame Temperature in this process was 5000°C and maximum powder feed rate was 55gms/min. The fuel gas (LPG) flow rate was 70 SLPM, whereas the particle impact velocity was measured as 450-500m/s and stream velocity as 1300 m/s. The coating powder characteristics as supplied by the manufacturer are given in Table 2. The spraying parameters adopted for the process are given in Table 3. The coating thickness for the coating was kept in the range 150±25 μm. The substrate steel was cooled with compressed air jets during and after spraying to reduce the formation of oxides.

TABLE 1 NOMINAL AND ACTUAL CHEMICAL COMPOSITION (WT%) FOR THE SUBSTRATE MATERIAL

Substrate material	AISI H11		AISI H13	
Elements	Nominal wt%	Actual wt%	Nominal wt%	Actual wt%
C	0.30-0.40	0.375	0.32-0.45	0.389
Si	0.80-1.20	0.98	0.80-1.20	0.894
Mn	0.20-0.40	0.364	0.20-0.50	0.344
P	0.03 Max	0.02	0.03Max	0.0276
S	0.03 Max	0.014	0.03 Max	0.0099
Cr	4.75-5.50	4.75	4.75-5.50	5.23
Mo	1.25-1.75	1.75	1.10-1.75	1.26
Al	---	0.071	---	0.0278
B	---	0	---	0.00083
Co	---	0.02	---	0.0183
Cu	---	0.091	0.25 Max	0.0495
Pb	---	0	---	0
Ti	---	0.266	---	0.00064
V	0.30-0.50	0.379	0.8-1.2	0.87
W	---	0.049	---	0.05
Fe	---	90.65	---	90.7

TABLE 2 CHEMICAL COMPOSITION AND PARTICLE SIZE OF ALLOY POWDER

Powder	Nominal Chemical Composition (wt%)	Particle size
NiCrFeSiBC	Ni-71.7, Cr-15.7, Si-4.27, Fe-4.17, B-3.35, C-0.81 (65%)	-45+15μm
WC-Co	(88WC-12Co) 35%	-45+15μm

TABLE 3 SPRAY PARAMETERS EMPLOYED DURING HVOF SPRAY PROCESS

Oxygen flow rate (SLPM)	300
Fuel (LPG) flow rate (SLPM)	70
N_2 flow rate (SLPM)	15-20
Spray distance (mm)	250
Powder feed rate (gm/min)	55
Particle velocity (m/s)	450-500

*SLPM - Standard liters per minute

2.3 Characterization of the As-sprayed Coating

The as-coated samples were characterized by XRD and FE-SEM/EDS analyses to investigate their surface and cross-sectional microstructures and compositions. Surface roughness of each coating has been evaluated with Talysurf at Baba Banda Singh Bahadur Engineering College, Fatehgarh Sahib, Punjab. Initial coating thickness on the substrate was evaluated by using a digital vernier caliper with least count of .001mm. For final thickness of the coating the coated specimens were sectioned using Electron Discharge Machine (EDM) at IIT, Ropar. Thereafter, the cut sections were hot mounted in BAINMOUNT-H (Hydraulic Mounting Press, Chennai Metco Pvt. Ltd., Chennai, India) with transparent acrylic powder so as to show their cross-sectional details. This was followed by polishing of the mounted specimens by a belt sanding machine having emery belt (180 grit). The specimens were then polished manually down to 1000 grit using SiC emery papers. Final polishing was carried out using cloth wheel polishing machine with 1μm levitated alumina powder suspension.

2.4 Sliding Wear Tests

To study the sliding wear behavior of tool-workpiece materials, both should be equally hard. To increase the hardness of the 20MnCr5 workpiece (disc) materials, the disc samples were heat treated and plasma nitrided. Sliding wear studies were performed on pin-on-disc wear test rig (TR-20E, Ducom, India) at Baba Banda Singh Bahadur Engineering College, Fatehgarh Sahib, Punjab. The teas were performed according to ASTM wear testing standard G99-04. The surface roughness was brought down to below 1 μm prior to wear tests by polishing the pin surface using sand papers of different grit size. The material was pressed against the disc to carry out the tests at nominal normal force of 20N and 40N. The total test duration was 26 minutes and the total distance covered was 780 meters. The total test duration was distributed in 13 steps of 120 sec each covering 60 meters in each run. The test velocity of .5m/s was selected for each run. The test was carried out at ambient temperature. During the wear test, the disc rotated horizontally and the sliding velocity was set to 213 rpm at a radius of rotation of 45 mm. The tests were performed in ordinary laboratory environment at RH 70% and 38-42^oC. The coefficient of friction was obtained by means of a torque transducer. The variation in height of the contact between the disc and the composite was registered using a LVDT with ±1μm of precision. Both, friction coefficient and wear rate, were continuously recorded during the test. The wear rate (mm^3/m) was calculated as the volume loss per sliding distance.

III. RESULTS AND DISCUSSION

3.1 SEM Analysis of Coating Powders

The SEM morphology of NiCrFeSiBC powder is shown in [Fig. 1 (a)]. The coating powder particles were found to be spherical in shape. The WC-Co powder particles are found in the form of lumps of irregular sized particles [Fig. 1 (b)]. These powder particles have a porous appearance. For the case of [{65% (NiCrFeSiBC) + 35% (WC-Co)}] powder mixer of all the two types of particles mentioned above which include lumps and spherical particles dispersed into it [Fig. 1 (c)].

3.2 SEM/EDS Analysis of As-sprayed H11 and H13 tool steel

The surface morphology of as-sprayed H11 and H13 tool steel has been shown in Fig. 2 (a) and (b) respectively. The as-sprayed NiCrFeSiBC - (WC-Co) coating is found to have splats on the substrate. The EDS analysis of the coating indicates the presence of mainly Nickel (Ni) and Carbon (C) on two positions alongwith significant amount of Chromium (Cr) in its composition, and Tungsten (W) and Oxygen (O) on another alongwith significant amounts of Cr. The compositions at the points 2 and 3 do not differ significantly as is evident from Fig. 8. Moreover, the presence of small amounts of O at both the points indicates the possibility of formation of oxides in the microstructure of the coating.

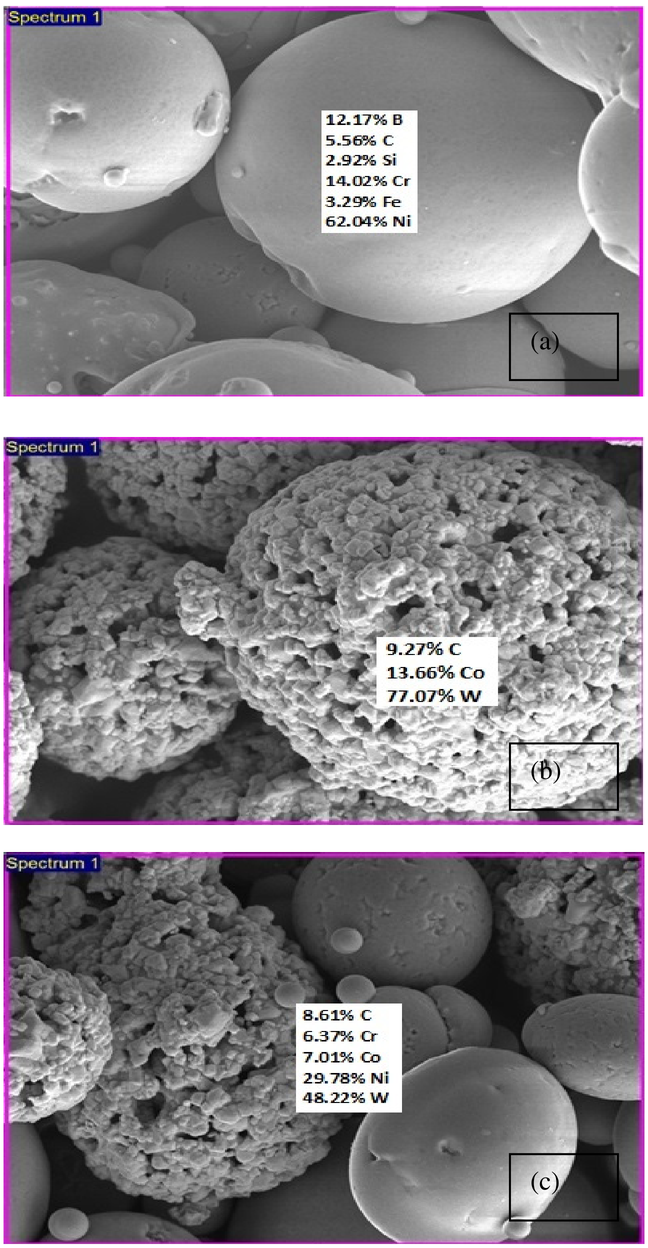


Fig. 1: The SEM morphology and EDS analysis of
(a) NiCrFeSiBC particles (b) WC-Co particles (c) [{65%(NiCrFeSiBC)-35%(WC-Co)}] powder.

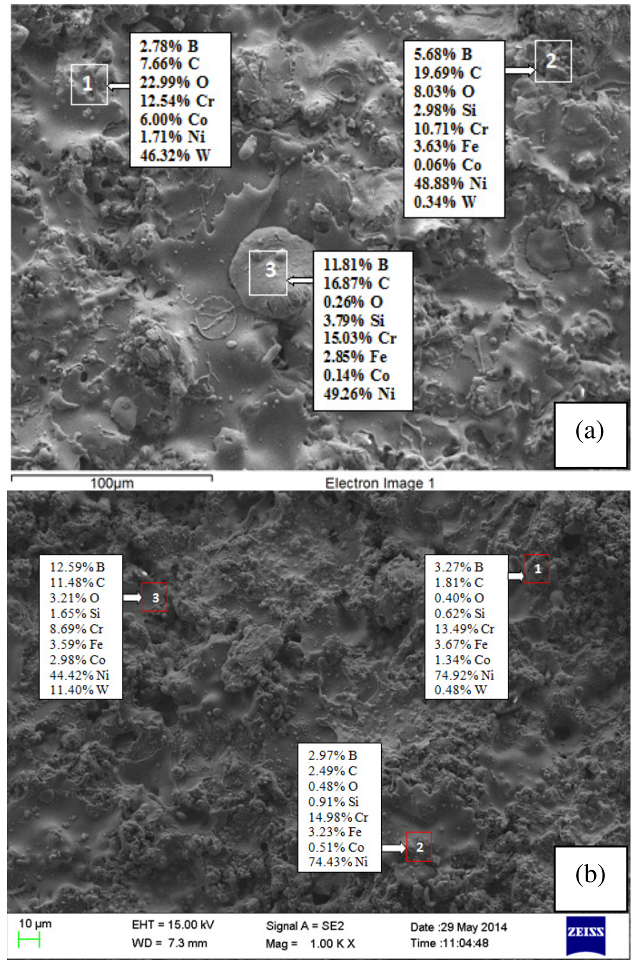


Fig. 2 : Surface morphology and EDS analysis of the HVOF as-sprayed NiCrFeSiBC+(WC-Co) coated (a) H11 and (b)H13 tool steel.

3.3 XRD of As-sprayed H11 and H13 tool steels

The XRD analysis of HVOF as-sprayed H11 and H13 have been compiled in Fig. 3. The XRD peaks of NiCrFeSiBC + (WC-Co) coatings revealed the presence of WCas a very strong phase WC and Si_2W, CrB_2 and Ni had medium intensity. W and W_2C peaks were also present in smaller intensities. It was also found from the XRD patterns of coatings that they also had the strong intensity of WC and medium intensity of Ni. And other phases were found in smaller intensities on the coatings Figure 3. It is also clear that there are no new phases formed in the coating during the thermal spray process. Similar peaks have also been observed by Gruzdys et al [10]. The XRD results were further supported by the EDS analysis.

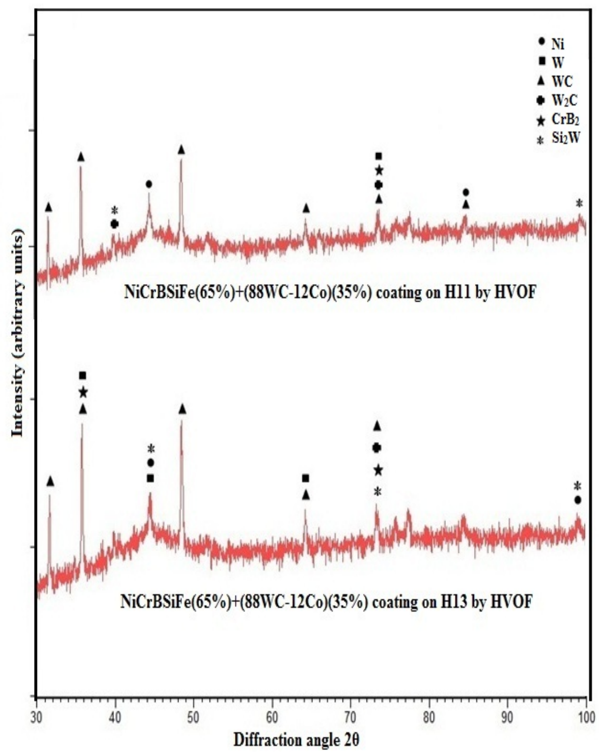


Fig. 3 Consolidated XRD pattern showing phases of NiCrBSiCFe+(WC-Co) as-sprayed AISI H11 and H13 substrates.

3.4 Cross-sectional Analysis of the As-sprayed Coatings on H11 and H13 substrates

Average thickness of the coating is measured from the SEM Image for the NiCrBSiCFe - (WC-Co) coating on H11 steel shown in Fig. 4 (a). In the micrograph, three regions namely substrate, coating and epoxy are shown for this particular type of coating. Average thickness of the coating measured was 103 µm. The cross-sectional SEM image of the HVOF sprayed NiCrBSiCFe - (WC-Co) coating on H13 steel substrate has been shown in Fig. 4 (b). Average thickness of the coating measured was 240µm. The coating in general has a dense appearance. The coating seems to have a proper coalescence with the substrate steel such that the coating substrate interface is not even easily distinguishable from the substrate steel. This predicts the existence of a good adherence between the coating and the substrate.

3.5 Surface Roughness of As-Sprayed Coatings

The initial surface roughness of as-sprayed samples was measured and average of five readings was taken that comes out to be 5.433 for H11 and 5.263 in case of H13. Further the samples were polished down to average surface roughness value 0.913 and 0.853 for H11 and H13 respectively (Table 4) in order to perform wear test as per the literature studied.

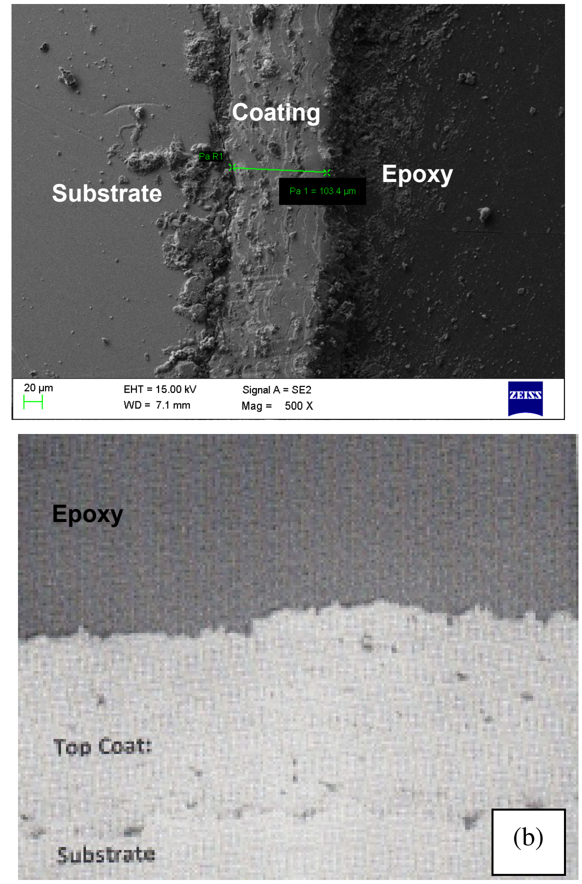


Fig. 4: SEM micrographs showing cross-sectional morphology of HVOF sprayed NiCrFeSiBC - (WC-Co) coated (a) H11 and (b)H13 tool steel.

TABLE 4 ROUGHNESS VALUES OF THE COATINGS BEFORE AND AFTER POLISHING

Substrate	Roughness	Roughness after polishing
H11	5.433	0.913
H13	5.263	0.853

3.6 Physical Characteristics

The macrographs of the worn out surface of the as-sprayed H11 and H13 steels subjected to sliding wear test at room temperature at 20N load are shown through Fig. 5 (a) and (b) respectively. These micrographs clearly indicate the presence of wear tracks on all the exposed surface.

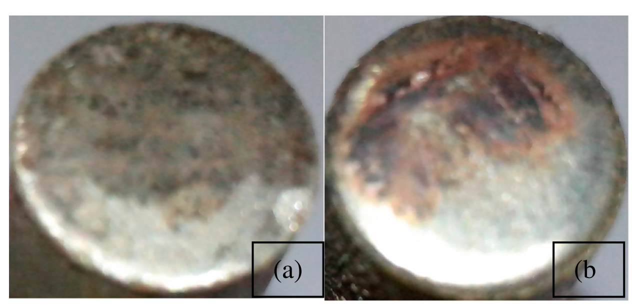


Fig. 5: Macrographs of the coated tool steels subjected to sliding wear tests at room temperature at 20 N loads (a) H11 (b) H13 steel

3.7 Wear Rate

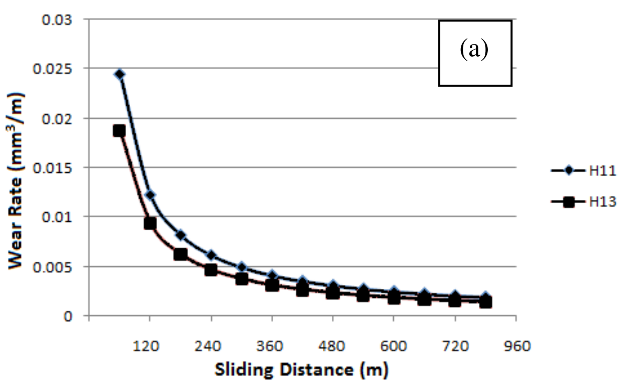
The variation of wear rate with the sliding distance for H11 and H13 at 20 N and 40 N normal loads is plotted in Figure 6.

3.7.1 Wear Rate at a Normal Load of 20 N

At 20 N normal load the wear rate of both the coated tool steels decrease linearly with the sliding distance, as shown in [Figure 6 (a)]. Both the tool steels at 20N load showed higher values of wear rate during the initial stages of the run. But in the later stages (after 180 m) wear rate goes on decreasing and tends to become uniform towards the end of run. Comparing both the substrates H13 showed the lower wear rates than H11 for same coating powder and for same process used. The wear rate keep on decreasing upto 600m and after that wear rate was steady till the end run. H13 showed the least wear rate at 20N load.

3.7.2 Wear Rate at a Normal Load of 40 N

At a normal load of 40 N, the wear rate of both the coated tool steels was also decreasing linearly with the sliding distance, as shown in [Figure 6 (b)]. But at a load of 40N H11 showed the least wear rate.



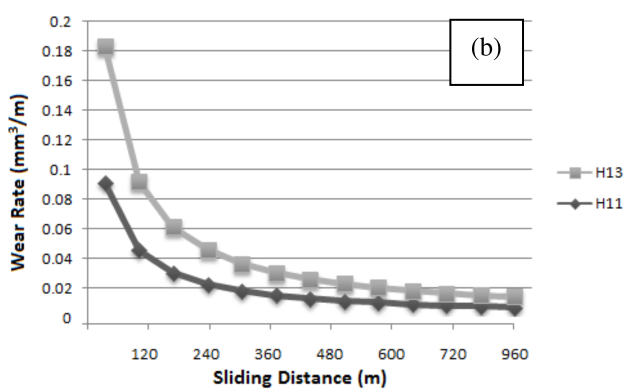


Fig. 6 Variation of sliding wear rate with sliding distance for as-sprayed H11 and H13 at (a) 20N load (b) 40N load

IV.CONCLUSIONS

1. The 65%NiCrBSiCFe – 35%(WC-Co) coatings were successfully deposited on hot forming tool steels by HVOF spray process.
2. The SEM analysis showed the splat like morphology of the coatings.
3. The coating deposited in H13 showed lesser wear rate at small loads of 20N, whereas the coated H11 steel showed lesser wear rates at 40 N loads.

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