Journal of Materials Science & Surface Engineering Vol. 4 (2), 2016, pp 355-359

Contents lists available at http://www.jmsse.org/

Journal of Materials Science & Surface Engineering

Influence of HVOF parameters on the wear resistance of Cr_3C_2-NiCr coating

M. Shunmuga Priyan, A. Azad, S.Yasar Araffath

Department of Manufacturing Engineering, Anna University, Chennai-25, India.

Article history

Received: 05-Jan-2016
Revised: 27-Jan-2016
Available online: 29-Feb-2016

Keywords:
HVOF coating,
Microhardness test,
Wear test,
Pin-On-Disk,
Wear loss

Abstract

Grey Cast Iron is widely used in manufacture of many automobile applications due to its low cost and performance. The applications include piston rings, cylinder liner, brake discs, etc. As they undergo friction, wear happens on the surface. Because of this wear the life of the components gets reduced. In order to avoid the wear of the components due to friction the component should be coated using a proper wear resistant material. Thermally sprayed coatings that are based on Cr_3C_2-NiCr powders are widely used to improve properties such as the surface hardness and wear resistance of a variety of coated metal substrate materials. In this work Grey Cast Iron substrate will be coated with Cr_3C_2-NiCr powder to improve its performance. Coating is done by HVOF method because this process gives high adhesion of coating material over the substrate and low porosity of the coated surface. The microstructure and micro abrasive wear performance of both the uncoated substrates and the coated substrates would be characterized by optical microscopy as well as by Scanning Electron Microscope (SEM). In addition, X-ray Diffraction (XRD) has to be undertaken for the partial characterization of the coating. The wear performance test will be conducted for both coated and uncoated specimens using pin on disc apparatus.

Introduction

Coating technology can be tailored to suit certain environments. A variety of bulk materials, such as ferrous and non-ferrous metals, alloys, ceramics and cermets can be coated to achieve adequate resistance to wear, corrosion and friction. The WC-Co powders were used for many applications to improve the properties on steel bars using HVOF thermal spray process [1]. The efficiency of HVOF thermal spray coating of WC–Co powder on stainless steel and reported that the coating resulted in low porosity, better wear resistance, and superior hardness [2]. The structure of WC-12Co coating that is deposited on mild steel by high velocity oxy-fuel thermal spray process and reported that the coatings exhibit better abrasive resistance compared with conventional coating [3]. Nano-structured WC-18Co coatings on steel substrates by HVOF coating. In this thermally sprayed coating is associated with the coating microstructure, mechanical properties, physical properties, coating defects such as inclusion and porosity [4]. Microstructure and aqueous corrosion characteristics of HVOF sprayed coatings of the same generic NiCrSiB self-fluxing alloy have been investigated in the as-sprayed condition BS EN 10083-1 C40E carbon-steel [5]. The high bond strength was most influenced by higher current, longer spraying distance and lower pressure. It was performed the surface roughness produced by grit blasting [6] A36/1020 steel using different abrasives. Higher surface roughness and adhesion were produced by grit blasting under the spraying parameters. WC-Co thermally sprayed coatings on AISI 1020 steel substrates are often used for their high hardness and resistance to abrasion wear [7]. The Fe based alloy coating on mild steel substrate by HVOF process has been used to produce better mechanical properties of the substrate materials [8]. The spray coated WC-17Co and WC-10Co-4Cr on AISI 4340 steel and reported a reduction in the axial fatigue strength of coated steel in comparison to base metal [9]. **T**he microstructure of the coating surface properties depends on the stand-off distance and oxygen flow rates [10]. The wear tests were carried out in a pin-on-disc wear-testing machine, the pin being manufactured from friction material usually used in light truck brake pads [11]. Thermal spraying to improve the tribological and mechanical properties of aluminium alloys and aluminium matrix composites and it was observed CrC75–NiCr25 coated on Aluminium alloy A7022 had the COF values under lubricated/dry as 0.09/0.26 [12]. The NiCr coating also shows fine, uniform and layered microstructure [13] and also sliding wear conditions, the lubrication due to free carbon from decomposition of carbides and metal oxide debris formed during the sliding results in a decrease of friction coefficients. The Coatings of the WC-Co system generally have a high hardness and wear resistance [14-15]. The plasma sprayed ceramic coating Cr_2O_3, 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 Cr_3C_2–NiCr coating [16]. The as-sprayed coating consists of primary carbides, chromium oxide and a mixture of amorphous and Nano crystal line binder phases [17]. The microstructure and micro abrasive wear performance of both the uncoated substrates and the coated substrates were characterized by opticular Microscopy. The coating exhibited excellent wear resistance when subjected to the ball-cratering test method [18]. The Cr_3C_2-NiCr cermet are extensively used for wear and corrosion-resistant applications. Coatings of the WC-Co system generally have a high hardness and wear resistance and also identified the primary carbides, chromium oxide and a mixture of amorphous on coated surface [19, 20]. The goal of this project work is to do a comparative study and evaluate the coating performance in terms of the wear characteristics of

Corresponding author. Tel.: +91-9488888770
E-mail address: iampriyan25@gmail.com

Cr_3C_2-NiCr coating on Grey Cast Iron using HVOF coating method for validating better tribological factors amongst them.

Experimental

Materials

Substrate is the base material whose surface properties need to be enhanced for attaining better performance over the application. The substrate material identified is grey cast iron SAE G3500. Nominal Composition and Actual Composition of grey cast iron SAE G3500 is illustrated in Table 1.

Properties of SAE G3500

Melt Temperature	:1175 – 1290°C
Hardness, Rockwell 'C'	:56.0 - 61.0
Density	:7.15g/cc
Coefficient of Expansion	:10.5 µm/m-K

Specification of HVOF coating process

Gun-type	: DJ2600
Nozzle-type	: DJ2603

Table 1: Nominal and Actual Composition of Grey Cast Iron SAE G3500

Elements	%Nominal Composition	%Actual Composition
Carbon	3-3.4	3.40
Silicon	1.8-2.20	1.880
Manganese	0.6-0.9	0.540
Chromium	0.12 max	0.120
Sulphur	0.15 max	0.067
Phosphorous	0.18 max	0.181
Iron	Remaining	Remaining

Coating Material

Coating material is the material in the form of powder to be coated on the substrate material for altering the surface properties. The coating material identified is Cr_3C_2-NiCr whose properties are as follows:

Apparent Density	: 2.3 g/cm^3
Particle size	: 5.5 µm
Service Temperature	:800°C
Hardness (Vickers)	: 850 – 900 HV0.1

Specimen Preparation

Sectioning is a process in which the specimen is cut so that the cross-section of the specimen can be examined. The micro precise cutting process can be achieved by a diamond saw or electric discharge machine. Hand grinding is performed with a simple device in which four belts of abrasive paper (240-, 320-, 400- and 600-grit) are mounted in parallel. Running water needs to be supplied to cool specimen surfaces during hand grinding. Polishing is the last step in producing a flat, scratch-free surface. The specimen should be further polished to remove all visible scratches from Grinding .Polishing is commonly conducted by placing the specimen surface against a rotating wheel either by hand or by a motor-driven specimen holder. Abrasives for polishing are usually diamond paste, alumina or other metal oxide slurries.

Porosity Analysis

A percentage of the porosity in the coatings was evaluated using Stereographic image analysis system by analysing and averaging various optical micrographs taken at different areas of the coating, as per standard test method ASTM B276. The micrographs of stochastic cross sections of the coatings were taken to calculate the planar porosity by differentiating the contrast between lamellae and pores, and subsequently the average porosity of the whole coatings was calculated as an approximately statistic result.

Wear Study(Pin on Disc)

The pin-on-disk tribomete serves for the investigation and simulation of friction and wear processes under sliding conditions. It can be operated for solid friction without lubrication and for boundary lubrication with liquid lubricants. Thus both material and lubricant tests can be executed. According to the standard test (ASTM G99) principle a stationary test specimen (pin or ball) with a defined normal force is pressed against the surface of another test specimen placed on the rotary disk.

The normal force is applied over the pin or ball by means of a set of dead weights between no load and 60 N (other ranges under demand). This way of application allows a stable force during the test. The friction coefficient (µ) is determined during the test by measuring the friction force by means of the deflection of the elastic arm (strain gages bonded on the elastic body of the arm convert it in a force sensor and allow the direct measurement of the frictional force).

Tests are to be performed under Sliding Wear Conditions .It can be used to measure wear between metals, and also determine coefficient of friction. The specification of pin on disc apparatus is illustrated in Table 2.

Table 2: Specification of pin on disc apparatus

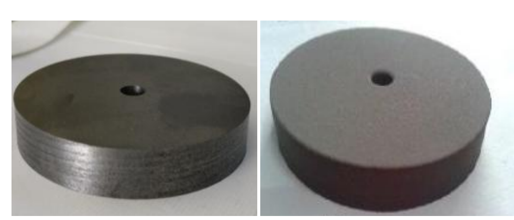
Parameter	Size	Unit
Pin size	3, 5, 10 & 12 diameter	mm
Disc Size	55Lx10T	mm
Disc Rotation Speed	0 –1450RPM	rpm
Wear Track dia. Mean	30to90	mm
Load	10	Kg
Frictional Force	0 – 10	Kg
Temperature	ambient to550	deg C
Power	415/50 /3	V/Hz/phase

Specimen preparation for coating

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. a specimen were fabricated from Grey cast iron 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 Figure 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.

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 above Table 3. The substrates material used was Grey cast iron material to the dimensions as per ASTM G99 standards.



(a) (b)

Figure 1: Uncoated (a) and coated (b) material of HVOF coating.

Table 3: The High-Velocity Oxygen Fuel (HVOF) spray parameters

Spray parameter	Parameter value	Unit
Oxygen flow rate	160-170	lpm
Fuel gas (hydrogen) flow rate	120-140	lpm
Powder feed	80-100	lpm
Spray distance	203-254	mm
Substrate velocity (horizontal plane)	1	m/s
Gun traverse speed (vertical plane)	5	mm/s
Number of passes	20	
Powder size	45-90	µm

Results and Discussion

Optical emission spectrometer test

Extensive Literature survey was carried out about the weakness of cylinder liner pi and piston ring materials Grey Cast Iron SAE G3500 and the methodology of project was formulated. Suitable coating material was selected considering its good wear resistant and better antifriction properties even at higher temperature and the appropriate coating method was selected so that the wear properties can be increased. To find the chemical composition of Grey Cast Iron optical emission spectroscopy apparatus is used.

SEM analysis of HVOF coating

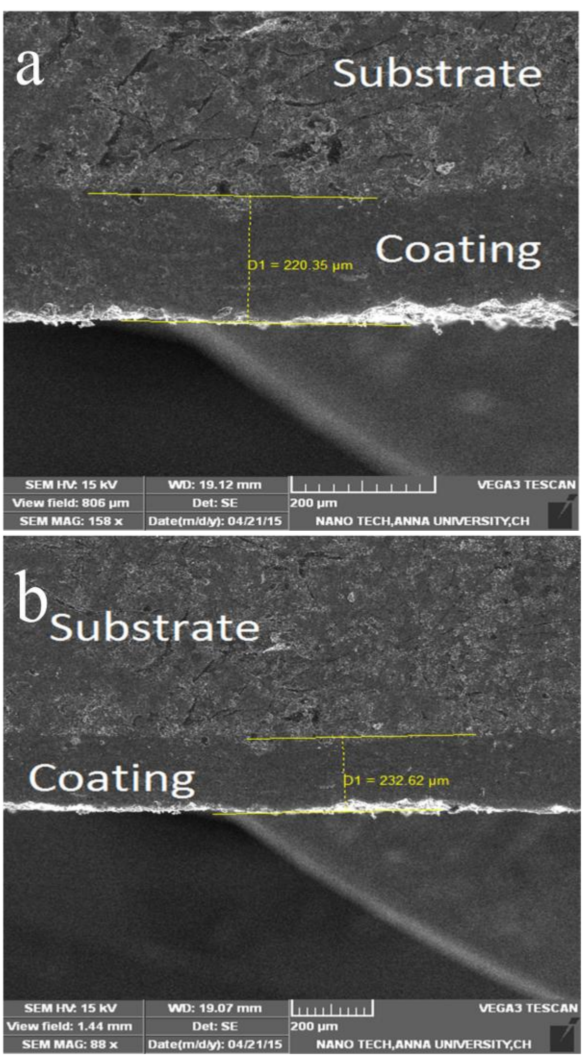


Figure 2: SEM image of HVOF coating (a) 80%Cr_3C_2+20%NiCr; (b) 75%Cr_3C_2+25%NiCr (Magnification - 200X)

From the Figure 2 shows SEM image, the thickness of the HVOF was found to be 200µm. The coating thickness was comparatively uniform.

EDX analysis of coatings

Energy Dispersive X-ray analysis was carried out on the coated surface to found out the composition of elements present in HVOF coating. And the results are given in Table 4.

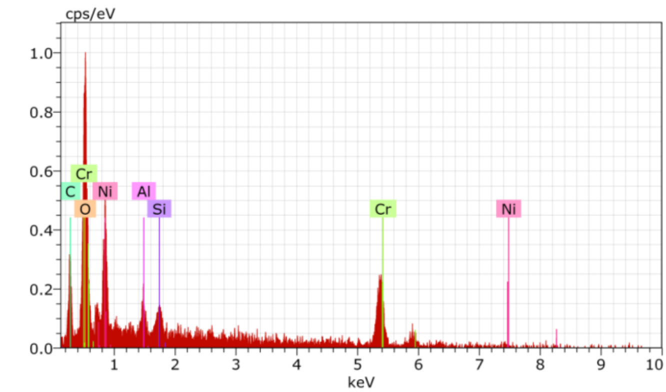


Figure 3: EDX analysis of the HVOF coating on (80%Cr_3C_2+20%NiCr).

Table 4: Chemical % of EDX analysis of (80%Cr_3C_2+20%NiCr) Coated material

Element	Weight Composition
Cr	45.81
O	10.69
Ni	20
C	19.13
Si	2.50
Al	1.87

From the Figure 3 it was observed that, the coated (80%Cr_3C_2+20%NiCr)contains 45% of chromium and 20% of Nickel and 10% Oxygen, carbon 19% and silicon 2%.Al is 1%.

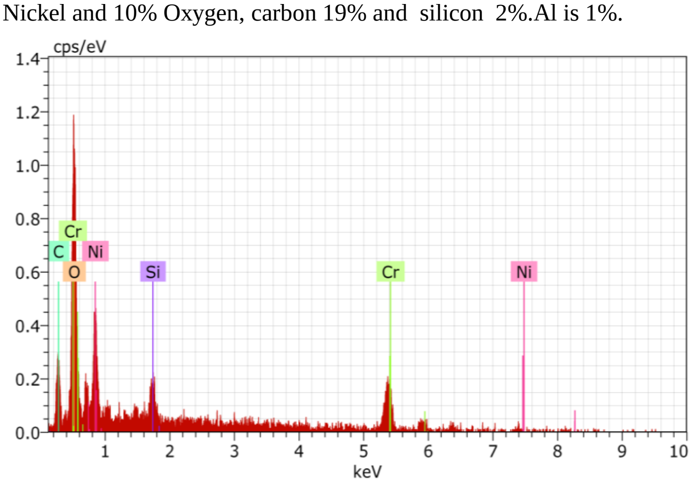


Figure 4: EDX analysis of the HVOF coating on (75%Cr_3C_2+25%NiCr).

Table 5: Chemical % of EDX analysis of (75%Cr_3C_2+25%NiCr) Coated material.

Element	Weight Composition
Cr	38.37
Ni	23.01
O	16.88
C	17.78
Si	3.96

From the Figure 4 it was observed that, the coated (75%Cr_3C_2+25%NiCr)contains 38% of chromium and 23% of Nickel and 16% of Oxygen. carbon 17% and silicon 3%.

Hardness test

Hardness at the surface of the coated and the uncoated Grey cast iron material was found out by using Micro-Vickers hardness tester. Load applied was 100 grams and the dwell time was 15 Sec. The hardness was found to be as 412HV0.3 for the Grey cast iron coated material and1410 HV0.3 for the coated one (Table 6). Hardness was increased upto 3 times for the HVOF coated specimen, because of the presence of very high carbon content.

Table 6: Micro hardness (Hv)value on uncoated and coating material

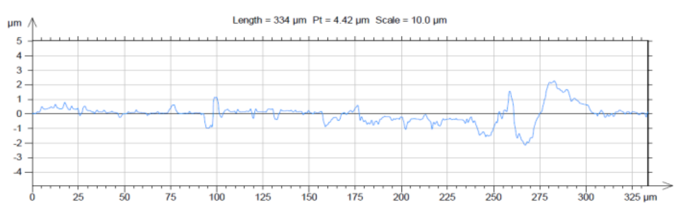
Material Type	Micro Hardness Value (Hv)
Uncoated Grey cast iron material	412
Coated Material (80%Cr_3C_2+20%NiCr)	1410
Coated Material (75%Cr_3C_2+25%NiCr)	1350

Surface roughness

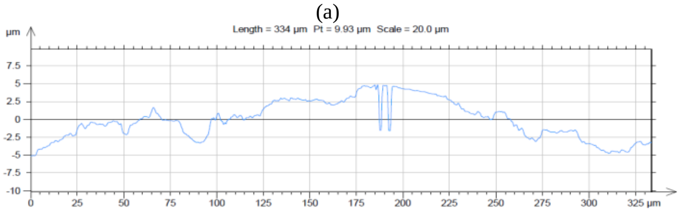
Surface Roughness of the HVOF coated surface was found out by using Taylor Hobson surface roughness tester. The roughness (Ra) was found to be around. The surface-roughness-3D analysis tests were performed on coated samples. Completely different worn surfaces were developed in order to establish specific characteristics from which conclusions relating to the wear process could be drawn. Another objective was to explain the wear phenomena that were generated in the surface, as indicated in the profile values in the coating depicted in table 7. The maximum depth of the wear track was 0.868µm , measuring the mass loss that is determined from the profile. It shows figure 5 (a), (b) and (c) the profile traces for the coated materials of different initial surface roughness. Only the distance between the predominant peaks rather than the average roughness has a significant effect on the percentage of contact between the metal surface and the coating.

Table 7: Surface Roughness (Ra) value on uncoated and coating material

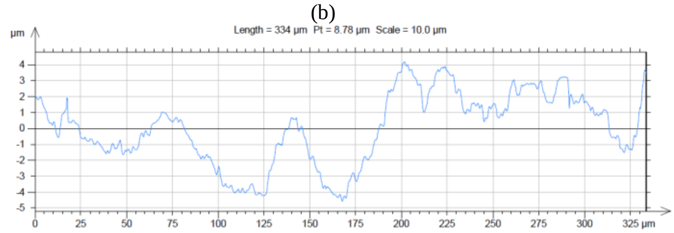
Material	Surface Roughness(Ra) Value
Uncoated Grey cast iron material	0.309 µm
(80%Cr_3C_2+20%NiCr) Coated Material	0.868µm
(75%Cr_3C_2+25%NiCr) Coated Material	0.681 µm



(a)



(b)



(c)

Figure 5: Surface roughness value patterns (a) Uncoated; (b) (80%Cr_3C_2+20%NiCr) Coated; (c) (75%Cr_3C_2+25%NiCr) Coated Material

Adhesive wear testing for uncoated and coated specimen

Adhesive wear test was carried out by using Pin-on-Disc apparatus. The test conditions are as follows: Speed – 500rpm, Load applied – 10N,20N,30N, Track Diameter – 30mm, Velocity – 1m/s, Sliding distance – 180m.

Coefficient of friction for adhesive wear

The data obtained for the coefficient of friction for coated and uncoated material was given in Table 8. Coefficient of friction versus uncoated/coated material for adhesive wear.

Table 8: Coefficient of friction versus uncoated/coated material for adhesive wear

Load (N)	Uncoated	Coated (80%Cr_3C_2+20%NiCr)	Coated (75%Cr_3C_2+25%NiCr)
10	0.2294	0.2018	0.2161
20	0.2587	0.2155	0.2341
30	0.2751	0.2346	0.2516

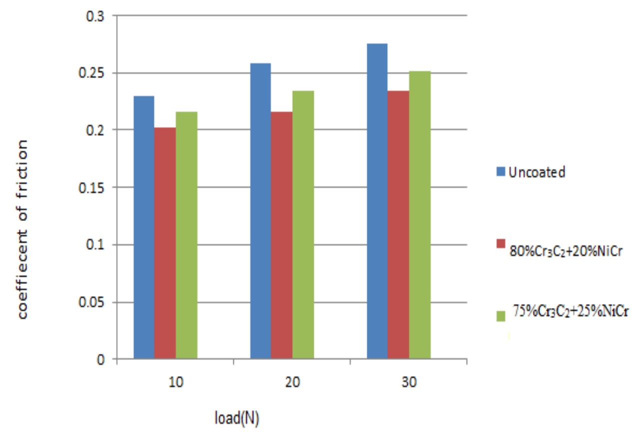


Figure 6: Coefficient of friction versus uncoated/coated material for adhesive wear

The figure 6 shows that, coefficient of friction increases with increase in load at constant speed for the uncoated material. The same condition prevails for the coated material too. When comparing the uncoated material with the coated material, for the 10N,20N,30N load and 500 rpm. Out of the uncoated and coated materials (80%Cr_3C_2+20%NiCr and 75%Cr_3C_2+25%NiCr), 80%Cr_3C_2+20%NiCr has the least Coefficient of friction.

Adhesive wear rate

The data obtained for the abrasive wear for the uncoated and coated material was given in Table 10. Weight loss due to wear for the coated and the uncoated material for adhesive wear.

Table 10: Weight loss due to wear for the coated and the uncoated material for adhesive wear

Load (N)	Uncoated	Coated (80%Cr_3C_2+20%NiCr)	Coated (75%Cr_3C_2+25%NiCr)
10	0.18	0.009	0.016
20	0.025	0.019	0.021
30	0.032	0.026	0.029

The figure 7 shows the comparison of weight loss due to adhesive wear for the coated and the uncoated specimen. It implies that the wear rate increase with increase in load for constant speed for both the coated and the uncoated material. For 10N, 20N,30N load and 500rpm. Out of the uncoated and coated materials (80%Cr_3C_2+20%NiCr and 75%Cr_3C_2+25%NiCr), 80%Cr_3C_2+20%NiCr has the least wear rate.

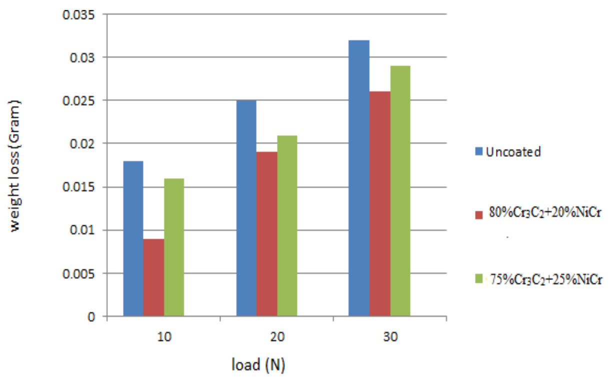


Figure 7: Comparison of weight loss due wear for the coated uncoated material for adhesive wear

Conclusions

A study was under taken to establish the wear behavior of HVOF coating of Cr_3C_2 and NiCr on Grey cast iron substrate. Two compositions of Cr_3C_2 and NiCr were used and the results were compared. The first composition was 80%Cr_3C_2 and 20%NiCr; the second composition was 75%Cr_3C_2 and 25%NiCr.

1. The hardness of the uncoated specimen is 410Hv and for the coated (80%Cr_3C_2+20%NiCr) specimen is 1410Hv. When compared to the Grey cast iron material, there is an increase in hardness upto 3.5 times.
2. The hardness of coated (80%Cr_3C_2+20%NiCr) specimen is 1410Hv and for the coated (75%Cr_3C_2+25%NiCr) specimen is 1350 Hv. When compared to the Grey cast iron material, there is an increase in hardness (80%Cr_3C_2+20%NiCr) of coating.
3. Adhesive wear was measured by Pin-on-Disc apparatus. The results suggest that the coefficient of friction and wear rate decrease with increase in applied loads at constant speed testing for both coated (80%Cr_3C_2+20%NiCr,75%Cr_3C_2+25%NiCr)and uncoated materials Grey cast iron.
4. Grey cast iron Coated with (80%Cr_3C_2+20%NiCr) shows low coefficient of friction because it has a high carbide content.
5. It is finally concluded that (80%Cr_3C_2+20%NiCr) HVOF coating of Grey cast iron can be used to reduce coefficient of friction and wear rate of moving parts.

References

1. Cueva A., Sinatora W.L., Guesser A.P. and TschiptschinA., "Wear resistance of cast irons used in brake disc rotors", Wear, Vol. 255, PP. 1256-1260,2003.
2. DurgaV., RaoN., BoyerB.A., CikanekH.A. and Kabat D.M.,"Influence of surface characteristics and oil viscosity on friction behaviour of rubbing surfaces in reciprocating engines". Fall Technical Conference ASME-ICE, Vol. 31–2,Paper No. 98-ICE-131, PP. 23-35,1998.
3. Fang W., Cho T.Y., Yoona J.H., SongK.O.,HurS.K., YounbS.J. and Chunc H.G.,"Processing optimization, surface properties and wear behavior of HVOF spraying WC–CrC–Ni coating",materials processing technology,Vol. 209, PP. 3561-3567,2009.
4. Fleury E., Lee S.M., Kima J.S., Kima W.T., Kimc D.H. and Ahnd H.S., "Tribological properties of Al–Ni–Co–Si quasicrystalline Coating against Cr-coated cast iron disc",Wear, Vol. 253, PP.1057-1069, 2002.
5. Flor S., Beitrag Z. and Gerard B., "Application of thermal spraying in the automobile industry", Surface and Coatings Technology, Vol. 201, No. 8, PP. 2028-2031, 2003.
6. Sidhu H.S., Sidhu B.S. and Prakash S.,"Solid particle erosion of HVOF sprayed NiCr and Stellite-6 coatings", Surface and Coatings Technology,Vol.202, PP.232-238, 2007.
7. HouQ.Y., GaoJ.S., Lewis R.,Gallardo E.A. and ZhouF., "Microstructure and wear characteristics ofcobalt-based alloy deposited by plasma transferred arc weld surfacing", Surface and Coatings Technology, Vol.194, PP. 238-243, 2005.
8. Houdkova S., Zahalka F., Kasparova M. and Berger L.M., "Comparative Study of Thermally Sprayed Coatings Under Different Types of Wear Conditions for Hard Chromium Replacement", Tribology, Vol. 43, No. 4, PP. 139-154, 2011.
9. Ishikawa Y., Kuroda S., Kawakita J., Sakamoto Y. and TakayaM.,"Sliding wear properties of HVOF sprayed WC–20%Cr_3C_2–7%Ni cermet coatings", Surface and Coatings Technology, Vol. 201, PP. 4718-4727,2007.
10. Johansson S., Frennfelt C., Killinger A., Nilsson P.H., Ohlsson R. and Rosen B.G., "Frictional evaluation of thermally sprayed coatings applied on the cylinder liner of a heavy duty diesel engine: Pilot tribometer analysis and full scale engine test", Wear, Vol. 273, No. 1, PP. 82-92, 2011.
11. Picas J.A., Forn A. and Matthaus G., "HVOF coatings as an Alternative to Hard Chrome for pistons and valves",Wear,Vol. 261,PP.477-484,2006.
12. Priyan M.S. and Hariharan P., "Micro abrasive wear resistance of FeSiNiCr alloy coating deposited by HVOF coating", Surface Science and Engineering, Vol. 7, No. 3, PP.250-268, 2013.
13. PriyanM.S., Hariharan P., Azad A. and Kumar K.S., "Microstructure and Wear Analysis of FeBCr BasedCoating Deposited by HVOF Method", Tribology in industries, Vol. 36, No. 2, PP.134-143, 2014.
14. Prudenziati M., Gazzadi G.C., Medici M., Dalbagni G. and Caliari M. "Cr_3C_2-NiCr HVOF-Sprayed Coatings Microstructure and Properties versus Powder Characteristics and Process Parameters", Surface and Coatings Technology, Vol. 19, PP. 540-556, 2010.
15. Samur R. and Demir A., **"**Wear and corrosion performances of new friction materials for automotive industry" Metalurgija, Vol. 51, No 1, PP.94-96, 2012.
16. Hong S., Wu Y., Wang Q., Ying G., Li G., Gao W., Wang W.and Guo W., "Microstructure and cavitation–silt erosion behavior of high-velocity oxygen–fuel (HVOF) sprayed Cr_3C_2–NiCr coating", Surface and Coatings Technology, PP.85-89, 2013.
17. Skopp A., Kelling N., Woydt M. and Berger L.M., "Thermally sprayed titanium suboxide coatings for piston ring/cylinder liners under mixed lubrication and dry-running", Wear, Vol. 262, No. 8, PP. 1061-1070, 2007.
18. Zhou Z., Wang L., Wang F.C., ZhangH.F., Liu Y.B.and Xu S.H., "Formation and corrosion behavior of Fe-based amorphous metallic coatings by HVOF thermal spraying", Surface and Coatings Technology, Vol. 204,PP. 563-570,2009.
19. Ji, GC, Li, CJ, Wang, YY & Li, WY 2006, 'Micro structural characterization and abrasive wear performance of HVOF sprayed Cr3C2-NiCr coating', Surface Coatings & Technology, vol. 200, pp. 6749-6757.
20. Lih, WC, Yang, SH, Su, CY, Huang, SC, Hsu, IC & Leu, MS 2000, 'Effects of process parameters on molten particle speed and surface temperature and the properties of HVOF CrC-NiCr coatings', Surface and Coatings Technology, vol. 133-134, no. 1, pp. 54-60.

