Middle-East Journal of Scientific Research 23 (6): 1237-1242, 2015
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2015.23.06.22302

An Experimental Investigation on Abrasive Wear Behaviour of Different Ceramics Coating on AISI 1040 Steel by Plasma Process

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Abstract: This study analyzes by the plasma technique, the microstructure and abrasive wear performance of AISI1040 steel surface coated with 85% Al_2O_3, 15% TiO_2, 55% TiO_2, 45% Cr_2O_3, 40% Cr_2O_3, 60% TiO_2 and 99% Cr_2O_3 ceramic materials. To the present finish, the surface of AISI 1040 steel was covered with the ceramic materials of 85% Al_2O_3, 15%TiO_2,55% TiO_2, 45% Cr_2O_3, 40%Cr_2O_3,60%TiO_2 and 99% Cr_2O_3, using the plasma technique. Following the coating method, the abrasive wear behaviour of every sample was tested by the pin-on-disc technique. ZrO_2 grating paper was utilized as abrasive. The best wear behaviour was obtained with the ceramic coating containing 85% Al_2O_3 that was trailed by 60% TiO_2, 55% TiO_2 and 45% Cr_2O_3 respectively. All time low wear resistance was ascertained in 99% Cr_2O_3 ceramic coating. Wear resistance of the samples enhanced with increasing micro hardness value. Micro cracking is that the main wear mechanism within the samples with high micro hardness values, whereas micro scratching-type wear method was detected within the samples with low hardness values.

Key words: AISI 1040 · Plasma Technique · Abrasive Wear · Ceramic · Pin-on-Disc · Micro-Structure

INTRODUCTION

Wear involves the physical removal of material from a solid object. Wear rates are less affected by temperature than the corrosion. However, as the wear surface temperature approaches the softening temperature of the substrate, wear rates increase dramatically. Wear can be classified into three general categories: abrasive, adhesive and fatigue wear. Abrasive wear can result from two surfaces rubbing together, with the harder surface grinding away the softer surface many corrosion resistant coatings that are not considered to be "Hard" are quite effective when wear is not a concern.

AISI 1040 carbon steel has high carbon content and can be hardened by heat treatment followed by quenching and tempering to achieve 150 to 250 ksi tensile strength. C1040 is a medium carbon, medium tensile steel supplied as forged or normalized. This steel shows good vigour and wear resistance. C1040 is good for flame or induction hardening. It is a multifaceted forging material with mechanical properties that are appropriate for a full range of applications. This grade of steel is utilized for forged parts where the strength and toughness of the material are appropriate. C1040 may be employed for the manufacture of forged crankshafts, roller shaft and couplings, along with a range of parts where the properties of heat-treated C1040 are suited to the application.

Tahar Sahraousi [1] in his article describes wear resistance and potentials of HVOF sprayed Cr_3C_2 -NiCr and WC-Co coatings for a possible replacement of hard chromium plating in gas turbine components repair and that the coatings exhibit high hardness with a high volume fraction of carbides being preserved during the spraying and have different wear behaviour.

D.N. Hanlon [2] in his paper he illustrated the response of spray forming on the wear properties of 1.2C-3.4W-8.9Cr-4.3V-2.7Mo high speed steel. The microstructure, fracture behaviour and wear response

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of the spray cast materials were compared with those of conventionally cast material of the same composition. The wear rate of the traditional material was momentously higher than that of the spray cast material at all temperatures.

A. Pardoa [3] investigated the corrosion protection of Mg-Al alloys by flame thermal spraying of Al/Sic particles (SiCp) composite coatings was evaluated by electrochemical impedance spectroscopy in 3.5 wt. % NaCl solutions. They concluded that the electro chemical results in Sodium Chloride at 3.5%, the incorporation of Silicon Carbide particulate reduces the corrosion resistance of the coatings compared with the aluminium coatings without reinforcing particles carried out via heat spraying. This effect is more apparent when the proportion of reinforcement in the coating is very high (Al/Sic/30p), where as it is practically insignificant when the proportion of reinforcement is low and the coating has been consolidated via cold pressing (Al/Sic/5p-(PT þ PF).

M. Senthil Kumar [4] investigated the AISI 1040 steel substrate by coating with WC-12%CO and Al_2O_3-3%TiO_2 through HVOF spraying technique. The surface morphology, composition and phase structure analysis are done with the help of scanning electron microscopy (SEM) and X-ray diffraction analysis (XRD), respectively. They observed that the wear rate at room temperatures of the WC-12%CO and Al_2O_3M-13%TiO_2 are almost equivalent. While at 600°C, the wear failure mechanism turns from plastic deformation to fracture resulting from crack propagation.

M. Jalali Azizpour [5] studied the application of thermal spray coatings in high speed shafts by a revolution up to 23000 RPM. He identified the wear mechanism of gas compressor shafts at the contact zone with journal surface. The worn surface was coated by hard WC-Co cermets using high velocity oxy fuel (HVOF) after formation. The shafts were in adequate service in 8000h period.

Dimitar Karastoyanov [6] in his article he described the chrome coating which having high mechanical wear-resistance and surface smoothness for renovation of the working area of shafts for extruding sheet material like PVC, Plexiglas, other plastics by laying and polishing of new types of highly wear-resistant coatings based on ultra disperse nickel coatings with nano dispersiods and/or nano-particles included.

Adnan Al-Bashir [7] studied the effect of varies process parameters of HVOF spray process on the substrate material 4140 alloy steel of 8mm diameter. The iron-based coating (Eutalloy RW 19400) produced by Castolin Eutectic used as coating material. Spray parameters investigated in this study included fuel gas (acetylene gas) pressure; standoff distance and rotational speed of shafts (pins) during the coating process. The Pin-on-Disc test was used to estimate the wear resistance of the different material coating-parameters combinations. He concluded that the wear resistance of HVOF coating (represented by mass loss) is affected by the respective process parameters such as, fuel gas pressure (flow rate), standoff distance and speed. The effect of the gas pressure appears to be the greatest, followed by the interaction between the gas pressure and the standoff distance. The rotational speed did not show a significant level of effect on the average mass loss.

T. Sahraoui [8] inquired into and compared the friction behaviour of High-Velocity Oxy-Fuel (HVOF) sprayed Tribaloy-400, Cr_3C-25%$NiCr_2$, WC-12%Co coatings and electroplated hard chromium, using a sturdy implicit formulation for a feasible replacement of electrodeposited hard chromium in gas turbine shaft repair. He found that the friction coefficient was decrease with the applied load due to the effect of the ‘‘third body’’ acting as solid lubricant and not sensitive to low-sliding velocities. However, for higher parameter values, predicted results showed an increase of the friction coefficient due to a change in the friction mode.

Jerzy Haduchet [9] in his article TIG pad welding technology was applied to a steel shaft with a thin single-layer coating of bronze CuSn6. Cylindrical samples of steel 45 with a length of 180 and 33.8 mm in diameter were used. He examined the effect of various TIG welding parameters to avoid the welding imperfections.

Many studies on the ceramic coatings were carried over by many researchers So, in the present study, the wear behaviour of ceramic materials with different composition rates towards ZrO_2 abrasive were examined and a relationship was tried to be established between load, path and ceramic materials.

Experimental Work: This study utilized AISI 1040 circular pins with 8 mm diameter and 30 mm length were selected as substrate material for coating. This cylindrical shaped specimen was with coated layer. The ceramic powders with four separate substances with different mixture rates were utilized as coating materials are shown in Table 1. The composition of AISI 1040 steel is given in Table 2. First, by spraying Al_2O_3 powders on the substrate surface material prepared in the mentioned

Table 1: Chemical compositions (wt. %) of ceramics for surface coating.

Specimen No.	Al_2O_3	TiO_2	Cr_2O_3
S1	85	15	-
S2	-	55	45
S3	-	60	40
S4	-	-	99

Table 2: Chemical compositions of (wt. %) AISI1040 forged steel shaft.

S.No	Constituent	Percentage
1	Carbon	0.37-0.44
2	Manganese	0.5-0.8
3	Silicon	0.4 max
4	Nickel	0.4 max
5	Phosphorus	0.045max
6	Sulphur	0.045 max
7	Molybdenum	0.1 max
8	Chromium	0.4 max

Table 3: Guidelines of Plasma spray process.

Gun	METCO 3MB
Nozzle	GH
Arc flow rate	80-90 l/min
Arc pressure	100-120 psi
Auxiliary gas flow rate	20-35 l/min
Auxiliary gas pressure	100 psi
Spray rate	2.6 - 6.5 kg/h
Arc voltage	60-70V
Arc current	490-590A
Spray distance	3-5 inches
Powder feed	40-50 grams/min

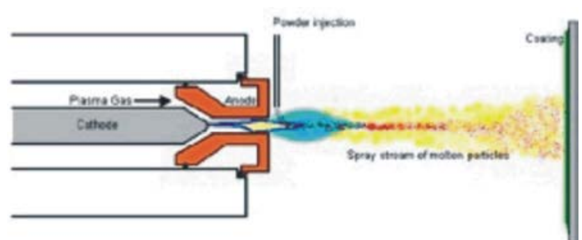

Fig. 1: Plasma spray process

dimensions with the help of compressed air, the surface was cleaned off unwanted residue (oil, dust and residual metals) to achieve a certain roughness value. Following this process, powders with a composite rate of 80% Cr and 20% Ni baked at 100°C were coated on the substrate surface material so as to form an intermediate surface in 30 µm thickness. The aim of this process is to ensure that a stronger bond is established between the substrate surface material and the ceramic coating material. Finally, ceramic powders were coated on the surfaces using the plasma method shown in figure 1. The coating thickness was 102 µm and process parameters are shown in Table 3.

Wear Testing: The dry wear tests were performed on coated specimens using pin-on-disc wear testing machine as shown in figure 5 according to ASTM G99-04 standards. The cylindrical pins of 8mm diameter and 30mm length coated with 85%Al_2O_3-15%TiO_2 and 55%TiO_2-45%Cr_2O_3 oxides of same coating thickness were used as test material. Hardened ground steel was used as disk. Abrasive wear tests were carried out under constant dry sliding conditions under the loads 2N, 6N, 8N and 10 N on grade 80 ZrO_2 abrasive paper stuck to the grinding disk, which rotated at 100 rpm. The test was performed with a fresh abrasive paper. Wear losses were obtained by determining the masses of the samples. For determination of the wear behaviour of the ceramics, the worn surfaces were examined by scanning electron microscopy (SEM).

RESULTS AND DISCUSSION

Composition and Microstructure: Figure 2 shows the uncoated surfaces of AISI 1040 steel and figure 3 shows the coated surface of the specimens after the coating process as completed. Figure 4 present the photographs taken on the surfaces of uncoated specimen using an Scanning Electron Microscope (SEM) before wear test on AISI 1040 substrate. Figures 6 and 7 shows the microstructure photographs taken on the ceramic coated surface areas of the specimens 1 and 2 using SEM. An examination of these images revealed that the substrate surface layer and the ceramic coating layer were homogenously fused and there were no pores, cracks and spaces on the coating area.

Experimental Results

Characterization of Coatings: Figure 10, 11 and 12 shows the SEM images of coating powder samples at 200x magnification and the SEM images of the coated specimens before wear test on AISI 1040 substrate are shown in figure 8 and 9 of the specimens 3 and 4 that is 40% Cr_2O_3-60% TiO_2 and 99% Cr_2O_3 with a little porosity present on surface of the samples.

Hardness Measurement: The micro hardness values received from totally different ceramic coating powders of the specimens are bestowed within the figure 13.

Fig. 2: Photograph of uncoated surfaces of AISI 1040 steel

Fig. 3: Photograph of coated surfaces of specimens 1, 2, 3 and 4.

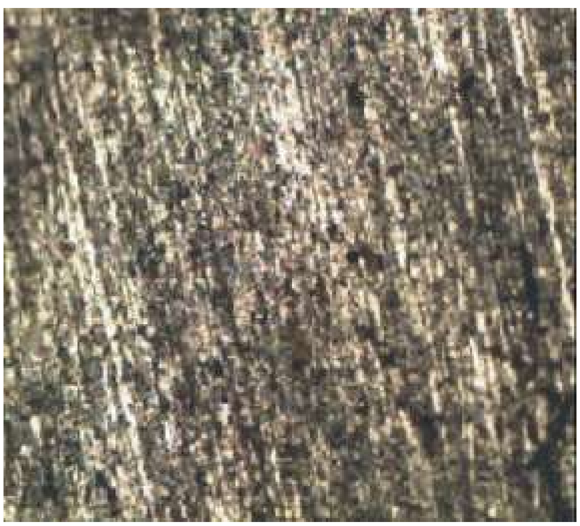

Fig. 4: Micro structure of AISI1040 Forged Steel – Before coating

Fig. 5: Pin on disc machine

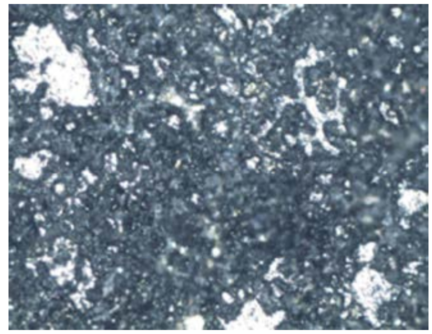

Fig. 6: SEM image of 85%Al_2O_3-15%TiO_2 coated specimen

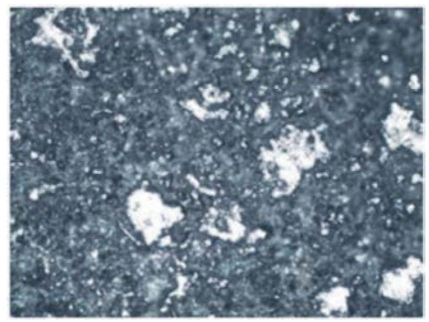

Fig. 7: SEM image of 55%TiO_2-45%Cr_2O_3 coated specimen

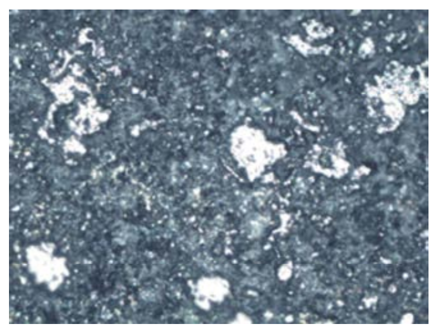

Fig. 8: SEM image of 40% Cr_2O_3-60% TiO_2 coated specimen

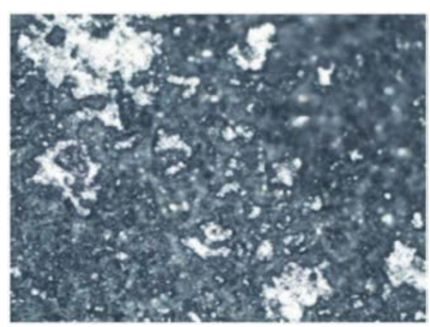

Fig. 9: SEM image of 99% Cr_2O_3 coated specimen

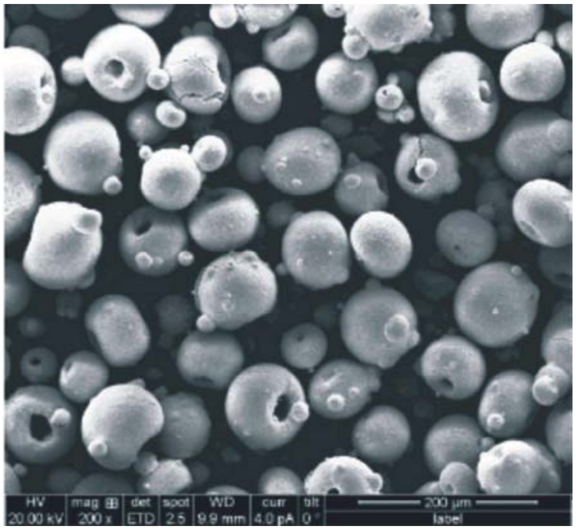

Fig. 10: SEM image of TiO_2 at 200x magnification

Fig. 11: SEM image of Al_2O_3 at 200x magnification

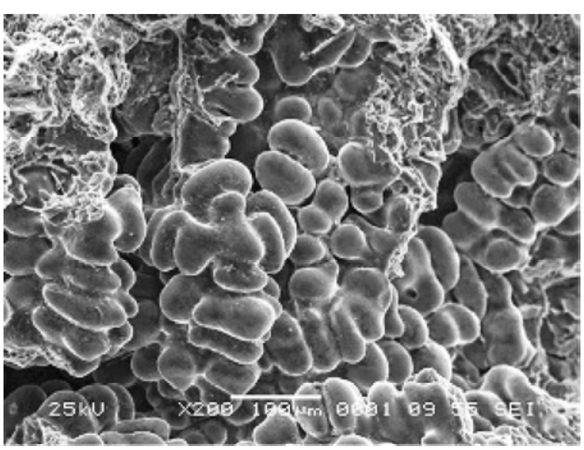

Fig. 12: SEM image of Cr_2O_3 at 200x magnification

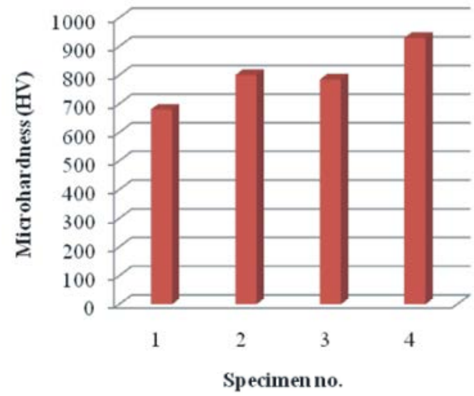

Fig. 13: Hardness values of coated specimens

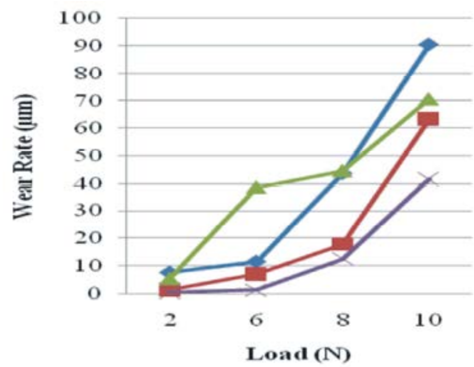

Fig. 14: Effect of Load on Wear rate

An observation of these gives knowledge of that the highest hardness values was observed in the specimen 4, which could be connected with 99 % Cr_2O_3 ceramic phase since the highest hardness value among the ceramic materials used belongs to Cr_2O_3 ceramic. The second highest hardness value was obtained in specimen 2, whose surface was coated with 55%TiO_2-45%Cr_2O_3. The ceramic material 85%Al_2O_3-15%TiO_2 includes a lower hardness value and a higher toughness value when made a comparison to other ceramics. As an result of that the very small hardness values dropped with increasing the TiO_2 rate in Al_2O_3. Thus, all-time low hardness value was observed in specimen 1.

Wear Analysis: According to ASTM G99-04 standards a Pin-on-Disc wear test was performed to simulate sliding wear of the coatings. Figure 14 shows the effect of constant sliding distance on wear rate of coated specimens under different load 2N, 6N, 8N and 10N for different coating powders. There is a decrease in wear rate at a load of 2N and slowly wear rate increased by increases in load on the coated surfaces of the substrate material. This is due to the abraded material comes into contact with abrasive particles under a normal load applied. Shear forces are generated on the abraded material surfaces along with a normal load due to relative motion of the abrasive particles. The abrasive particles tend to penetrate into the surface of the specimens due to normal load. Grooves and scratches are formed on the surface of the specimens with the help of shear forces. That's the reason for the will be increased as the forces developed on the specimen's surface will raised with increasing load.

CONCLUSIONS

In this study, the abrasive wear behaviour of different types of ceramic materials coated on AISI 1040 forged steel towards ZrO_2 abrasive wear tested and the following results were obtained;

- Alumina-Titania, Titania-Chromium (III) Oxide and pure Chromium (III) Oxide coatings are deposited on AISI 1040 steel substrates with an intermediate bond coat of NiCr by atmospheric plasma spraying technique and these bond coatings exhibit desirable coating characteristics like adhesion strength is an important factor in thermal barriers applications.
- Among the specimens the highest micro hardness value was observed in ceramic coating of pure Chromium (III) Oxide than that of 55%TiO_2-45%Cr_2O_3 which was followed by 40%Cr_2O_3-60%TiO_2. Also the combination of 40%Cr_2O_3-60%TiO_2 gives better result when compared to 85%Al_2O_3-15%TiO_2.
- If the percentage rate of TiO_2 in Al_2O_3 ceramic materials increases the micro hardness of the specimen has been decreased.
- The wear rate increased with decreasing micro hardness values of the specimens hence, their abrasive wear resistance property increased.
- The pure Chromium (III) Oxide coated on AISI 1040 forged steel specimen showed excellent wear property when compared to other coating materials due to the proper adhesion of 99% Cr_2O_3 than that of Alumina-Titania and Titania-Chromium (III) Oxide.

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