Investigation of tribological behaviour of 88WC-12Co coating

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Abstract. High velocity oxy-fuel (HVOF) is a coating technique of thermal spray process usually employed for protecting the substrate, where high velocity is used instead of high temperature for coating the substrate. In this paper, the wear behaviour of tungsten carbide-cobalt (88WC-12Co) coating was studied experimentally. The coating of 0.3 mm was deposited by HVOF technique on SS202 substrate. The dry abrasive wear experiments were carried out using pin-on-disc test rig at fixed sliding velocity 0.603 m/s, and 20, 40, 60 N load for 1000 m distance. The weight loss was measured at each 250 m distance. For the preparation of abrasive surface 80 grit SiC (silicon carbide) emery paper was used. Results show that at initial stage wear rate of coated substrate was high which reduces with increase in sliding distance and linear increment in coefficient of friction with increase in load.

1. Introduction
In many engineering areas, the mechanical components are subjected to extreme operating conditions like force, speed, temperature and chemical environment. The surface of the components for such application needed to be modified to prevent them from various types of degradation. For achieving a goal of high production rate, low break down time and low maintenance cost in industries, it is necessary to reduce wear in machine. There are several methods suggested for controlling wear and applying protective coating is widely used technique. Coating is a layer of protection, which isolate substrate from effect of high temperature, corrosion and wear [1-4].

Tungsten carbide (WC) is used for components subjected to wear and corrosion due to its excellent hardness properties. This can be added with alloying metals such as cobalt which will improve its toughness and overall performance. The high velocity oxy-fuel (HVOF) spraying process is used for tungsten carbide cermet powder spraying, by using high velocity oxy-fuel (HVOF) spraying processes. The coating obtained by this method have high hardness and small porosity and good adhesion to substrate. Literature showed that coating from HVOF has better properties compared to other thermal spraying methods. Components in relative motion, coating with high hardness compared to counter surface is required to minimize abrasive wear [2, 4-6].

Cemented carbides are widely used in industrial application compared to other products obtained from powder metallurgy due to excellent wear resistance. It is used in application like mining tools, agriculture machineries, metalworking accessories and application where high wear resistant required. Its application includes tool bits and drill bits, gas, oil and mining drilling, earthmoving and heavy construction machinery, metal working and agriculture machinery [1]. Pin-on-disk test is broadly used...
method to characterize the tribological properties of material. It is preferred due to simplicity, ease to control operating parameters and cost effectiveness.

Many studies are available for characterization of thermal spray coatings. Umale et al. [7] studied abrasive wear behaviour of two reinforced copper matrix composites. The silicon carbide (SiC, 12%) and silica particles (SiO₂, 9%) were used as reinforced particles and prepared by powder metallurgy. The two composites were analyzed for metallography, abrasive wear experiment, surface imaging and surface hardness. They reported that copper-SiC (12%) composites showed high abrasive wear resistance. The SEM analysis demonstrated that the wear mechanism is a function of test conditions. Khan et al. [8] investigated aluminium (Al6082-T6) and Al-6082T6 coated by plasma spray technique. The coating of Alumina (Al₂O₃), Titania (TiO₂) and Alumina-Titania (Al₂O₃+40% TiO₂) ceramic with different coating thicknesses of 100 μm, 150 μm and 200 μm were deposited on Al6082-T6 substrate. These coating were studied for tribological and microstructural properties. The results showed excellent wear resistance by alumina coating compare to other coatings (Titania and Alumina-Titania coating). The imaging by SEM of the wear out surfaces of coated specimen shows better properties than that of bare substrate Al 6082-T6. Guilemany et al. [9] work was focused on WC-Co cermets. They studied two coatings of conventional and nanostructured cermets, sprayed by high-velocity oxy-fuel (HVOF). The coating deposited by nanostructured cermets showed better properties between two, however under dry abrasion test wear results are more or less same. Tavoosi et al. [10] worked on experimental and numerical simulation of wear in nanostructured NiAl coating. The coating were put on substrate of mild steel through HVOF. Mechanical characterization was carried out by nano-indentation test. The test results indicate high wear-rate initially, which reduces gradually. The results of experiment and simulation shows good agreement of wear rate (volume losses rate) obtained from simulation and experimental results.

2. Material and experiment

2.1. High velocity oxy-fuel (HVOF) coating

The SS 202 circular pins of diameter 10 m and length 30 mm were chosen as substrate material for coating. WC-Co powder is used as coating materials, percentage of coating material are shown in table 1. In this investigation 0.3 mm thick WC-Co coating was developed on the top surface of the substrate by High Velocity Oxy Fuel (HVOF) coating technique. The Coating parameter are given in table 2.

| Table 1. Composition (%) of coating material |
|---------------------------------------------|
| Coating Material   | Percentage |
| Tungsten Carbide (WC) | 88         |
| Cobalt            | 12         |

| Table 2. Coating parameters |
|-----------------------------|
| Parameters                  | Value       |
| Fuel gas flow rate          | ~60 lpm     |
| Compressed air flow rate    | ~650 lpm    |
| Spray distance              | ~7 inches   |
| Spray rate                  | ~38 gm/min  |
| Coating thickness           | ~0.3 mm     |
2.2. Sliding wear test apparatus
Pin on disc (POD) apparatus used for characterizing the wear behavior of coating material in present work. In POD test, pin is arranged perpendicular to a disc. The disc is circular and flat and rotated through a motor in machine at fixed speed. The pin specimen is stationary with respect to disc and pressed at constant load against the disc. The loading is applied by a lever arm as shown in Fig. The data of wear loss of specimen are measured as volume loss in cubic mm. The wear results were measured at regular interval of sliding distance at selected value of load and speed. Figure 1 shows the Pin on Disc setup used for conducting the sliding wear test available in the laboratory.

Figure 1. Pin on disc experimental set-up

2.3. Abrasive wear test
The abrasive wear tests were conducted on pin on disc tribometer working at constant sliding velocity and fixed wear path diameter and the specific wear rate (k) is calculated, the specific wear rate helps in determining wear resistance offered by the metal under running conditions. By fixing various parameters of test, wear rate of 88WC-12Co was calculated. Coating of WC-Co is performed by HVOF (High Velocity Oxy-Fuel) process and the thickness of the coating was 0.3 mm, SS202 was substrate material for coating. For creating abrasive conditions in pin on disc wear test a waterproof silicon carbide (SiC) emery paper was used, which was properly glued with the surface of disc. Working parameters used present work wear experiment are shown in table 3

| Parameter               | Value                  |
|-------------------------|------------------------|
| Sliding Distance        | 1000 m (in interval of 250 m) |
| Sliding Velocity        | 0.6 m/sec              |
| Load                    | 20, 40, 60 N           |
| Wear Track Diameter     | 80 mm                  |

Table 3. Wear test parameters
In this tribological testing, coated WC-Co pin run for 1000 m at each load condition, and weight loss of each pin was measured at interval of 250 m. Wear track diameter, sliding velocity and time was fixed for each experiment. Tests were repeat for different load conditions [11]. Specific wear rate was calculated using expression.

\[
K = \frac{\text{Volume of Wear}}{(\text{Applied Load}) \times (\text{Sliding Distance})} \frac{mm^3}{N \cdot m}
\]  

(1)

3. Results and discussion

In this work dry abrasive wear test was performed for different load of 20 N, 40 N and 60 N, constant sliding distance of 1000 m by using pin-on-disc. The results incurred from the above experimental work are plotted in figure 2, 3, 4 and 5 given below.

- Volume loss of any specimen can be calculated by dividing mass loss during test by density of softer material. Mathematically it is expressed as

\[
\text{Volume Loss} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Density of material}}
\]

![Graph showing volume loss vs. sliding distance at different loads](image)

**Figure 2.** Loss vs. sliding distance at different Load

Graph in figure 2 is plotted in between of volume loss and various sliding distance. Graph shows that volume loss showing same pattern in each load condition (i.e. 20, 40, 60 N). With increase in sliding distance firstly it is increasing and there after decrement in volume loss is taking place.

- A coefficient of friction is a value that shows the relationship between the force of friction between two objects and the normal force between the objects. Graph is plotted in between coefficient of friction (C.O.F) and load; change in value of coefficient of friction relatively to load is shown in figure 3. Coefficient of friction is showing linear increment with respect to load.

![Graph showing coefficient of friction vs. load](image)

**Figure 3.** Coefficient of Friction vs. Load

- Weight loss is loss in material of wearing surface, which can be measured by cleaning and weighing sample before and after wear test. Weight loss i.e reduction in weight is a difference between initial weight of sample and final weight of sample. Change in weight loss with time at different different load condition is shown in figure 4. Graph is showing that at the starting
of experiment weight loss is increasing but after some time it is showing decrement in weight loss.

**Figure 4.** Graph between weight loss and time

**Figure 5.** Graph Between wear rate and sliding distance

- The wear rate is defined as the wear volume of the pin specimen corresponding to the unit sliding distance under the application of a unit vertical load. The weight loss is divided by the density and converted into the wear volume. The graph is showing same behaviour as other above in this graph wear rate at 40N load condition is high then 60N load conditions and it is also incremental at the start of test and decreasing after a certain sliding distance as shown in figure 5.

In each graph wear volume, wear rate and weight loss corresponding to time and sliding distance initially high but with the increase of time and distance it gradually reduces. The high wear rate at beginning due to low area of contact between disc and coated pin due to surface roughness of coated surface, however with sliding it decrease with smoothening of surface [11-13].

4. Conclusion

In this investigation, coating of cemented carbide (88WC-12Co) with thickness 0.3mm deposited on SS202 substrate through High Velocity Oxy Fuel (HVOF) technique. To identify the wear characteristics of the cemented carbide (88WC-12Co) coating, pin-on-disc dry abrasive wear test was performed. For the preparation of abrasive surface 80 grit SiC (silicon carbide) emery paper was used. Test was performed by applying 20, 40 and 60 N normal loads on pin and the tests were continued for a distance of 1000 m. The reduction of mass at different sliding distances (i.e. 250 m, 500 m, 750 m and 1000 m) was determined. The results indicated an increased wear-rate at beginning, which slowly decreases [11]. At beginning of the experiment, surface roughness of newly coated pin results into small actual area contact with disc which increases with increase in sliding distance.

5. References

[1] Barbezat G 2005 Advanced thermal spray technology and coating for lightweight engine blocks for the automotive industry *Surface and Coatings Technology* **200** 1990-3

[2] Meng R, Deng J, Liu Y, Duan R and Zhang G 2018 Improving tribological performance of cemented carbides by combining laser surface texturing and WSC solid lubricant coating *International Journal of Refractory Metals and Hard Materials* **72** 163-71
[3] Domínguez-Meister S, Rojas T C, Brizuela M and Sánchez-López J C 2017 Solid lubricant behavior of MoS2 and WSe2-based nanocomposite coatings Science and Technology of advanced Materials 18 122-33

[4] de Villiers Lovelock H 1998 Powder/processing/structure relationships in WC-Co thermal spray coatings: A review of the published literature Journal of thermal spray technology 7 357-73

[5] de Villiers Lovelock H, Richter P, Benson J and Young P 1998 Parameter study of HP/HVOF deposited WC-Co coatings Journal of thermal spray technology 7 97-107

[6] Yao Z, Stiglich J J and Sudarshan T 1999 Nano-grained tungsten carbide–cobalt (WC/Co) Mater. Modif 1-27

[7] Umale T, Singh A, Reddy Y, Khatitrkar R and Sapate S International Journal of Modern Physics: Conference Series, 2013), vol. Series 22): World Scientific) pp 416-23

[8] Kumar A and Suresh P 2014 Tribological Behaviour of Plasma Sprayed Al2O3-TiO2 Coating on Al-6082T6 Substrate behaviour 3

[9] Guilemany J, Dosta S, Nin J and Miguel J 2005 Study of the properties of WC-Co nanostructured coatings sprayed by high-velocity oxyfuel Journal of thermal spray technology 14 405-13

[10] Tavoosi H, Ziaei-Rad S, Karimzadeh F and Akbarzadeh S 2015 Experimental and finite element simulation of wear in nanostructured NiAl coating Journal of Tribology 137 041601

[11] Sharma A, Singh N and Rohatgi P 2013 Study of Wear Pattern Behavior of Aluminum and Mild Steel Discs Using Pin on Disc Tribometer European Journal of Applied Engineering and Scientific Research 2 37-43

[12] Sahraoui T, Fenineche N-E, Montavon G and Coddet C 2003 Structure and wear behaviour of HVOF sprayed Cr3C2–NiCr and WC–Co coatings Materials & design 24 309-13

[13] Hajare A S and Gogte C 2018 Comparative study of wear behaviour of Thermal Spray HVOF coating on 304 SS Materials Today: Proceedings 5 6924-33