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TRIBOLOGICAL STUDY OF NiCrBSi/FLYASH PLASMA SPRAYED COATINGS

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ABSTRACT
Plasma sprayed coatings are used for reducing the wear losses of many industrial components. It appears that few studies have considered the influence of the bulk temperature on the wear resistance of coatings. To study these effects in a Ni-based alloy reinforced with small quantities of fly ash, wear tests were carried out by using pin on disc tribometer. The specimens were tested at room temperature; the sliding speed was kept constant at 200 m/s, and the normal load 10N and 20N. The experimental programme reveals the coating behaviour and the wear rates of the material in terms of normal load and temperature. Considerable differences were found between the wear rates of the counter bodies. The analysis of the worn specimens by scanning electron microscopy (SEM) and energy dispersive X-rays spectroscopy (EDAX) provides information about the main mechanism associated with each condition.

Keywords*: Fly ash, Characterisation, Coating, Thermal Spray, Substrate.*

I. INTRODUCTION

The demands on performance and lifetime of parts are continuously increasing. As a consequence of the tribological requirements of thermally spray coatings for wear resistant applications, coating technologies have advanced a lot during the last decades. Thermal spraying is one of the most versatile process of deposition of coating materials to enhance the wear and corrosion performances. It is a process with almost no limitation of materials and with the ability to deposit coatings with thicknesses ranging from several micrometers to tens of millimetres. Additionally, it is suitable for a great variety of shapes and sizes and had the advantage of maintaining the substrate temperature relatively low. There are a lot of techniques to melt and propel the coating material. Among the most commonly applied are flame spraying and plasma spraying. The flame sprayed coatings exhibit a high porosity and a bad bonding strength in comparison to other thermal spraying process. Thus, sometimes the coating is subjected to a process of subsequent fusion. Flame spraying is widely used in industry for corrosion resistant coatings. Plasma spray is suitable for hard and thick coatings and it is used in applications requiring wear and corrosion resistant surfaces. The NiCrBSi alloys, subject of this study, present a high bonding strength and ex-cellent resistance to adhesive and abrasive wear at elevated temperatures. Usual applications are, for example, piston rings or rollers in steel making. (The industrial way to mea- sure wear losses in these components is hardly compared to laboratory tests, but as example 5 mg/h is an acceptable wear rate for piston rings. The wear of rollers is traditionally counted as millimetres loss per ton of steel rolled.) An- other remarkable aspects is the possibility of including very hard components such as WC in the powders to get harder coatings.

In this communication, an experimental programme has been carried out to analyse the influence on the wear behaviour of several factors such as load, temperature, presence of flyash in the powders and the type of thermal spray technique used. (Rodríguez, Martín, Fernández, & Fernández, 2003).

II. WEAR

It is defined as the loss of material takes place due to relative motion between the surface and contact surfaces.

Types of wear:

Abrasive wear
It is characterized as the kind of wear that happens when a hard surface slides or contuses to have relative movement with a milder surface. Hard materials or a roughness that cut forests amid this movement makes grating wear. The ill tempers are available in the tangling surface or any outside material. This kind of wear sections hurries the procedure of wear if not evacuated.

Adh$esive wear
The adhesive wear is caused due to the bonding between the contacting surfaces. The mutual transfer is in between the contacting surface. This real transfer depended on the two mating surfaces.

Erosive wear
The erosive wear is also one of the important kinds of wear. It is characterized as the procedure of metal evacuation because of impingement of strong particles on a surface. The important characteristics of erosive wear is

1) If angle of impingement is very small, the wear creates close to the analogous of abrasion.
2) If the impingement angle is small means the material will flows like a plastic.

Fatigue wear
The fatigue wear is also one of the important type wear. The fatigue will occurs when material undergoes a compression and tangential cyclic load at above threshold stress. The fatigue wear is begins with the development of smaller scale breaks and it is bit by bit spreads with rehashed stacking it really develops to the surface. The vibrations are important factor to origin the fretting fatigue wear.

III. FLY ASH

Fly ash is used as a coating material. The fly ash will reduce the wear and it gives good hardness to the coating material. The carbon percentage is more in the fly ash. The carbon will give the good hardness to the coating material. Fly ash is a waste material and it is a low grade material. The thermal power stations generate a huge amount of flyash due to combustion of coal that has great potential to apply as a coating material in the thermal spray coating process. The fly ash is a predominantly inorganic residue obtained from the flue gases of furnaces at pulverized coal power plants. The fly ash is produced when the burning of coal takes place in crushed boilers; the raw materials in the coal are thermally converted into chemical types reactive.

IV. COATING PROCESSES

The process used to apply the coatings and it consists of some coating materials. The coating processes are selected based on their applications, while selecting the coating processes some methods will be there to choose the coating process. The table 1 shows the typical coating process. Important factors controlling coating are coating thickness, coating material, and temperature are the main factors. Wear resistance, abrasion resistance, corrosion and oxidation resistance are some of the properties, coating has to exhibit for long service life of any component. Table below indicated the principal coating process and its characteristics.

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Table 1 principal coating processes and characteristics

Coating Process	Typical Coating Thickness	Coating Material	Characteristics	Examples
PVD	1 – 5 μm (40 – 200 μin)	Ti(C,N)	Wear resistance	Machine tools
CVD	1 – 50 μm (40 – 2000 μin)	SiC	Wear resistance	Fiber coatings
Baked Polymers	1 – 10 μm (40 – 400 μin)	Polymers	Corrosion resistance, aesthetics	Automobile
Thermal Spray	0.04 – 3 mm (0.0015 – 0.12 in)	Ceramic and metallic alloys	Wear resistance, corrosion resistance	Bearings
Hard Chromium Plate	10 – 100 μm (40 – 4000 μin)	Chrome	Wear resistance	Rolls
Weld Overlay	0.5 – 5 mm (0.02 – 0.2 in)	Steel, Stellite	Wear resistance	Valves
Galvanize	1 – 5 μm (40 – 200 μin)	Zinc	Corrosion resistance	Steel sheet
Braze Overlay	10 – 100 μm (40 – 4000 μin)	Ni-Cr-B-Si alloys	Very hard, dense surface	Shafts

V. THERMAL SPRAY COATINGS

The thermal coating consists of dissimilar kind of coating materials, thickness and possible coating features of thermal coating. Cost and performance ratio is only suitable for thermal coating. In the thermal coating process the Unique alloys and microstructures can be achieved are not likely with a formed material. This contains an always grouped composites and corrosion resistant shapeless phase on the component surface. Thermal spray coatings are being increasingly and successfully used for broad variety of high temperature wear, erosion and corrosion applications. On other hand, thermal spray coatings are a good option to repair components and prevent excessive wear because during the deposition process no significant changes to the microstructure of substrates or excessive deformation are promoted.

Thermal spray coating process is the type of coating process in which finely divided metallic or non-metallic materials are deposited in a molten or semi molten condition to form a coating process. By using some special devices for the coating process that will be melted at some high temperature and then propelled at a high speed on to the surface.

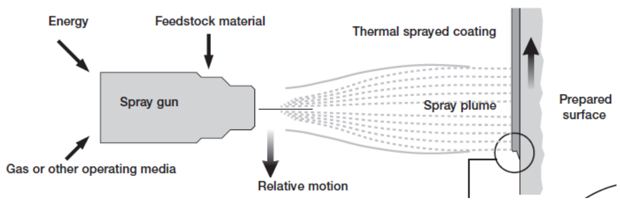


Fig 2 thermal spray coating

Figure 2 shows the principal of thermal spray. By using some thermal source to melt the feedstock material. After the heating of the feedstock material finally sprayed on to the substrate material.

VI. SUBSTRATE MATERIAL

Substrate is a material on which coating materials are sprayed in order to produce coatings. Substrate material acts as an important role in the thermal spray coating process. In the coating process substrates undergoes blasting operation to produce the rough surface, so it should consist of optimum hardness and adhesion strength. Wide variety of materials can be used as substrates in thermal spray coatings namely, metals, ceramics, plastics etc. Currently Ni based super alloys and super steels are being used in high temperature application as substrate materials.

In the present investigation super Ni76 [ASTM equivalent – Hastelloy X] is selected as a substrate material. Super Ni76 steel is used in petrochemical process and gas turbines in the hot combustor zone sections and it is also used in the structural components in industrial furnace applications because it has good oxidation resistance. The material is purchased from MIDHANI, Hyderabad who has supplied similar materials earlier and has proven credentials in terms of material quality. The specimens with appropriate 12mm x 12mm x 3mm are planned to be used for experiments. The actual composition of substrate materials are determined by spectroscopy is mentioned in the table

Table 2 chemical composition for Super Ni 76

Type of substrate	ASTM CODE	Composition	C	Mn	Si	S	P	Cr	Mo	Fe	Co	W	B	Ti	Ni
Super Ni 76	Hastelloy X	Nominal	0.08	-	2	-	-	18	-	Bal	-	-	-	0.4	11.5
		Actual	0.10	1.46	0.55	0.005	0.013	18.13	-	Bal	-	-	-	0.62	10.36

VII. COATING MATERIAL

In the thermal coating the coating material is used to coat the material. The coating material it does not decompose when it's melted that type of coating material is used as a coating material in thermal coating. The powder or wire type material is used as the coating material in thermal coating. The coating material must have good service environment. The coating material should some physical factors such as coefficient of expansion, heat conductivity, density and melting point.

VIII. COATING PROCESS

In the thermal coating process the surface properties acts as an important role in deciding the service life of a component. The surface requirements consist of some corrosive resistance, sufficient protection against wear, electrical insulation and thermal insulation. The surface coating helps during the extension of life time of the components against surface degradation. By the use of protective coatings it gives a protection against corrosion, oxidation, erosion and other degradation and thus results in maintaining the mechanical properties of the substrate. The thermal spray coatings are the one coating which is suitable for the turbine and any high temperature application. The thermal spray technique has very good flexibility for different coating materials and almost it has no limitation for coating materials. The thickness of the thermally sprayed hard metal coating is the range of 100µm to a few millimeters. This thermal spray enables the functionality of hard metals to be realized on the surface of large parts, and which cannot be produced by powder metallurgy for technical and economic reasons. It consists of some important properties such as wear and corrosion resistance, thermal or electrical insulation can be achieved using different coating techniques and coating materials.

IX. PLASMA SPRAY

Plasma spray process is the type of thermal spray techniques. It is defined as the process of finely divided metallic and non-metallic materials are deposited in a molten or semi molten state on the substrate by using thermal energy.
In the process the high energy spark produced between cathode and anode due to potential difference in the source of energy for plasma coating. In the dc plasma gun, arc is stuck in between the radial concentric copper anode and cylindrical tungsten cathode is also acts as the nozzle. The inert gases are as He, Ar, N are presented at the nozzle tip. The reactions are takes place inbetween the electrons from thegas molecules and the cathode, and finally it causes the ionization of the gas, and forms a plasma state. The gases are heated to some elevated temperature and they pass inbetween the arc, and also they expands axially and radially, and accelerate in between the nozzle outlet with a flow rate of 3.4 lts/minutes, the temperature reaches more than 10000K due to the heat released and radiation.

The arc temperature must be maintained between the range of 6000-11,000ºC separately of 1cm from the nozzle and decreases to 30000C separately of 9 CM towards the nozzle.

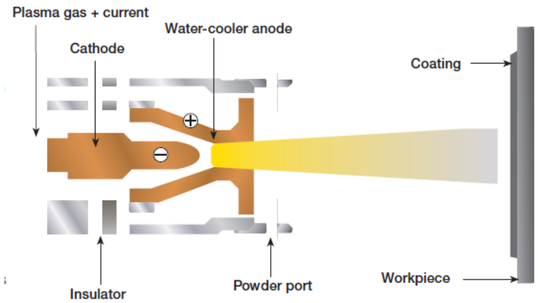


Figure 3 Schematic representation of plasma spray process

Applications of Thermal Spray Coatings

- Used as an alternative to hard chromium plating to enhance the wear and corrosion.
- Gas turbines.
- Automotive industry.
- Pump housings & Impellers.
- To enhance the wear and corrosion resistance of a surface

X. LITERATURE REVIEW

The wear rate is reduced by the coating process. In this paper the thermal spray coating is used as the coating process. Based on the requirements the different types of thermal coatings are used. The NiCrBSi is used as the coating material, along with flyash is used as the coating material. The fly ash gives good hardness and due to its abundant supply, the cost of the material is low. Therefore in this existing literature it is very clear that the environmental pollutant like fly ash has not exploited well before. The present work is to focus on studying the possibility of fly ash as coating material blend with NiCrBSi, for high temperature applications. Motivation for pursuing this topic is summarized as below
Waste utilization
Reduction in environmental pollution
Cost effective
Eco friendly processing
Use of an industrial process at real world scale

XI. MOTIVATION OF THE WORK

The Flyash is an unwanted material is produced plentifully by the burning of coal in furnace. Fly ash is the combination of Si, Fe, and AlO2. The fly ash requires huge area for dumping purpose. The use of fly ash as a coating material it is treated as a main for both the commercial and economic point of view. The fly ash is treated as the thermal spray coating as coating powder and will develop wear resistant coatings. Some of the studies give the excellent compatibility of fly ash as coating material in thermal spray coatings. The rapid production of high quality components is the key to cost reduction in many of these applications. The present work is focused on studying the possibility of fly ash as coating material blend with NiCrBSi.

XII. METHODOLOGY

Preparation of substrate material
The substrate to be sprayed on must be free from any dirt or grease or any other material that might prevent intimate contact of the splat and the substrate. For this purpose the substrate must be thoroughly cleaned (ultrasonically, if

possible) with a solvent before spraying. Spraying must be conducted immediately after shot blasting and cleaning. Otherwise on the nascent surfaces, oxide layers tend to grow quickly and moisture may also affect the surface. These factors deteriorate the coating quality drastically.

Substrate is a material on which coating materials are sprayed in order to produce coatings. In coating process substrates undergoes blasting operation to produce the rough surface, so it should consist of optimum hardness and adhesion strength. Currently Ni based super alloys and super steels are being used in high temperature application as substrate materials. In the present investigation super Ni76 is selected as a substrate material.

Grit blasting
In grit blasting the abrasive particles are made to impinge on a component to clean or modify its surface properties. There are various reasons to carry out the grit blasting but in coating process. The grit blasting is used to increase the adhesion things of the substrate materials to be coated. The different types of abrasive particles can be used depends on the application namely sand particles of silicon carbide, alumina, corundum etc. Various methods are available to carry out the grit blasting namely, Mechanical blasting, Air pressure method, Induction siphon method, Wet blasting etc. In the present investigation Air pressure method will be used to carry out the grit blasting. Alumina particles with 150µ grit size will be used as abrasive particles.

Coating material
The principle of plasma spray coating, any coating material it does not decompose by itself. The coating material consists of **Ni Cr B Si & fly ash** with a percentage of 60% & 40% as follows. Flyash particles are generally spherical in shape and range in size from 0.5 µm to 100 µm. They consist mostly of silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3), and are hence a suitable source of aluminum and silicon. Fly ash can be a cost effective substitute for conventional extenders in high performance industrial coatings [83]. It can be utilized to develop ceramic coatings on metal substrate. Good quality coating and homogeneously distributed phases are observed in the coatings made at power levels between 12 to 20 kW [84]. Fly ash with aluminium additions can be used to provide plasma spray ceramic composite coating on metal substrates and it is found that the coating quality and properties are improved with higher aluminium content in the feed material and are affected by the operating power level of the plasma.(Das, 2008)

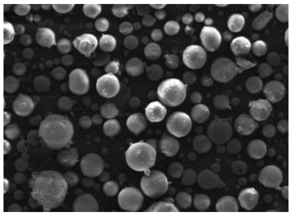


Fig 4 Mixture of NiCrBSi & fly ash powder

Deposition of coating
Plasma spray technique will be carried out using METCO USA 3MB equipment (Aum Technospray Pvt. Ltd. Bengaluru). The process utilizes the high energy spark produced due to the potential difference between cylindrical anode and cathode to generate plasma. The spray parameters employed during plasma spray is listed in table 4. All the process parameters, including the spray distance are constant throughout the coating process.

Table 3 Spray parameters of Plasma Spray Process

Argon	Pressure	100-110 psi
	Flow	150-160 lpm
Hydrogen	Pressure	45 psi
	Flow	6-7 lpm
Current		1250 amps
Voltage		50-70V
Powder feed		125-150 gm./min

XIII. PROPERTIES TO BE INVESTIGATED

Wear test

The Sliding wear test will be performed as per the ASTM G-99 with a high temperature pin on disc tribometer as shown in fig 9. Pin heating arrangement is used to maintain a required temperature. By using the acetone the contacting surfaces are ground with 1000 mesh grit sandpaper and finally it's dried.

Figure 5 pin-on-disc tribometer

The friction coefficient curves will automatically recorded in the computer connected to the wear tester. By using height loss method the wear volume loss will be measured. Wear rate is calculated using the formula as

W=V/LS

W= wear rate

V=wear volume loss in mm3, L is the normal load in N, S is the total sliding distance in mm. Wear test parameters and variables selected in the present investigation is given in the Table 4

Table 4 Wear test parameters

Test Parameters	Variables	
Load in N	10	20
Sliding Velocity in m/s	200	200
Temperature in ^{0}C	27	27
Track radius mm	130	130

Micro hardness measurement

Small specimens were sliced from the coated samples. Samples containing coating cross-sections were mounted and polished for the microhardness measurement. Microscopic observation under optical microscope of the polished section of the coatings exhibited three distinctly different regions/ phases namely grey, dark and spotted/mixed. Vickers Microhardness measurement was made on these optically distinguishable phases using Leitz Microhardness Tester equipped with a monitor and a microprocessor based controller, with a load of 0.245N and a loading time of 20 seconds. About twelve or more readings were taken on each sample and the average value is reported as the data point.

Scanning electron microscope and energy dispersive x-ray analysis

Plasma sprayed coated specimens and plasma processed powders were studied by JEOL JSM-6480 LV scanning electron microscope mostly using the secondary electron imaging. The surface as well as the interface morphology of all coatings was observed under the microscope. Small specimens were sliced from the coated samples and were mounted using thermosetting molding powders. Coating cross-sections was polished in three stages using SiC abrasive papers of reducing grit sizes and then with diamond pastes on a wheel for coating interface analysis under SEM. These specimens were also utilized for the microhardness measurement.

X-ray diffraction technique was used to identify the different (crystalline) phases present in the coatings. XRD analysis was done using Ni-filtered Cu-Kα radiation in a Philips X-ray diffractometer. The characteristic d-spacing of all possible values are taken from JCPDS cards and were compared with d-values obtained from XRD patterns to identify the various X-ray peaks obtained.

XIV. RESULT AND ANALYSIS

Microstructure of NICRBSI & fly ash by using sem process

Surface morphology of coating powder and tested samples can be investigated using scanning electron microscope of Modal-jSM-6380LA, and JEOL with an operating voltage of 30 KV with a magnification range of 300000. The elemental composition of different phases can be observed on surface and cross section using energy dispersive X-ray analysis, NiCrBSi

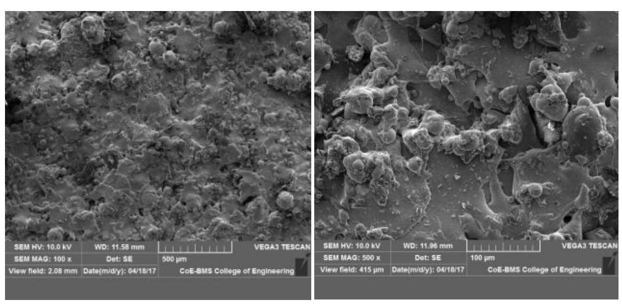


Fig 6 Microstructure of coated material

The figure 6 shows the electron microstructure of coated material. From these, microstructures we know the exact bonding of materials in the coating. Microstructures are obtained by using the scanning electron microscope. The above microstructures shows the how the coating material is spreads over the entire substrate material and its gives clearly how materials are bonded together.

Coating thickness

Thickness of the fly ash-illmenite coatings on different substrates were measured on the polished cross-sections of the samples, using an optical microscope. Five readings were taken on each specimen and the average value is reported as the mean coating thickness.

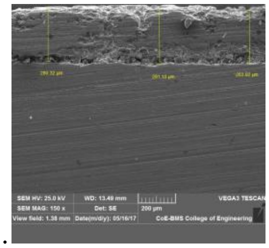


Fig 7 Sectioned view for coating thickness

Elemental analysis

Elemental analysis is a one of the technique is used to find the composition of the elements which are present in the coating material. The elemental analysis is carried at the time of SEM process only. The below figure shows the elemental pattern of the coated material

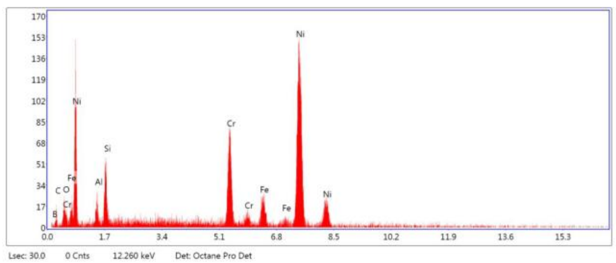
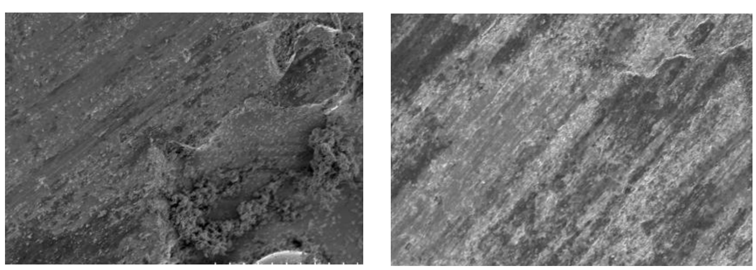


Fig 8 EDAX PATTERN

The fig 12 shows the elemental analysis of NiCrBSi& fly ash material to known the exact composition of the elements which are present in the coating process. From this elemental analysis we known the percentage of elements. In this graph the elements like Ni, Cr, Fe, Al, and Si & Cr are present in the coated material. The nickel percentage is more compared to other elements.

Worn surfaces

Surface morphology of NiCrBSi/flyash coating wear at different loads are shown in Fig.13.



(a) (b)

Fig 9 Micrographs of wear surfaces of coatings (a) 10N and (b) 20N

Composition of elements

The composition of the elements is obtained from the elemental analysis. The elemental analysis gives the total percentage of the elements which are present in the coating process. The composition of the all the elements which are present in the coated material are tabulated below.

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Table 8.1 elemental composition

Element	Weight %	Atomic %	Net Int.	Error %	Kratio
B K	12.26	29.08	0.66	38.88	0.0236
C K	13.84	29.55	4.72	19.89	0.0238
O K	4.28	6.86	6.02	21.45	0.0111
AlK	2.43	2.31	9.21	21.14	0.0075
SiK	4.45	4.06	23.51	15.55	0.0190
CrK	11.34	5.59	62.97	5.91	0.1188
FeK	4.99	2.29	23.31	10.90	0.0554
NiK	46.39	20.26	144.74	3.52	0.4307

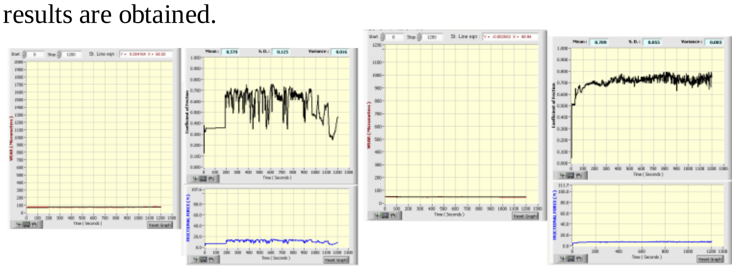
The figure shows the exact composition of elements which are present in the coated material. It gives the exact weight of the elements, atomic percentage of the elements. The elements like B, C, O, Al, Si, Cr, Fe, Ni are present this composition**.**

XV. WEAR TEST

The wear test is performed on the tribometer. The wear test is performed on two different materials with different loads and same speeds are as follows.

1) 10N for uncoated and coated material

The 10N load is used at room temperature with speed of 200 m/s and track radius 130mm. while performing the wear test, the following results are obtained.

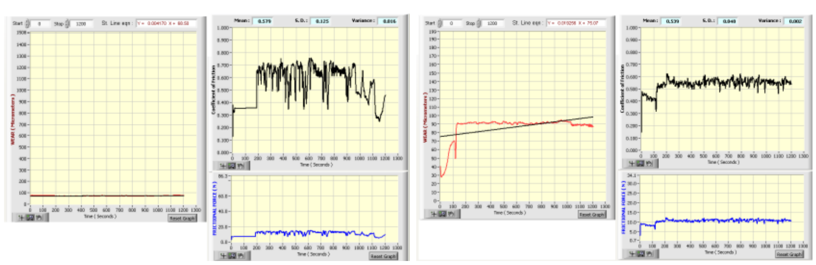


(a) (b)

Fig 10 Graph for 10N (a) uncoated material and (b) coated material

2) 20N for uncoated and coated material

The 20N load is used at room temperature with speed of 200 m/s and track radius 130mm. while performing the wear test, the following results are obtained.



(a) (b)

Fig 11 Graph for 20N (a) uncoated material and (b) coated material

It can be seen from the Fig.10 (a) and (b) and Fig.11 (a) and (b) that the wear and friction coefficient is more for the uncoated surface than for coated surface.

XVI. CONCLUSION

The different phases observed in XRD studies, corroborates to the observation of different hardness values for (different) optically distinguished phases.

Due to phase transformations and inter-oxide formation during plasma spraying at different power levels, changes in the coating characteristics such as hardness etc. are observed.

The microstructures of the coatings are dependent on operating power level of the plasma torch, the physical characteristics such as coating porosity, phase transformation of the raw material during spraying.

Initially the wear rate increases sharply with time of impact and after certain time length of impacting, the erosion rate becomes lower in magnitude and finally reaches a steady state.

Wear behavior is one of the main requirements of the coatings developed by plasma spraying for recommending specific application. In order to achieve tailored wear rate accurately and repeatedly, the influence of the process parameters are to be controlled accordingly. The coating sustains wear by pin on disc substantially and therefore NiCrBSi-fly ash can be considered as a potential coating material suitable for various tribological applications.

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