Study the Effects of Coating on Slurry-Erosive Wear of INCONEL718 on Copper

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***Abstract*— Machine components are exposed to different types of damages over their lifetime. These components are subjected to wear due to variety of loads and different kinds of environments. These damages reduce durability of the component. Hence high resistance to wear is desirable to achieve high durability and reduce maintenance costs.**

Slurry-erosive wear is the kind of wear where there is loss of surface material by the action of particles entertained in a fluid. The wear is due to the hard particles which are forced and moved relative to the solid surface. These wear can be restricted by coating the solid components with proper components.

There are various ways of surface coating of material, Out of many surface modification techniques, plasma spraying stands out as one of the most versatile and technologically sophisticated thermal spraying technique. Plasma spraying is gaining extensive attention in the research fraternity as it has the advantage of applying coatings using different materials such as ceramic, metallic and composite coatings with possibility of controlling the thickness from few microns to few millimeters. Thus produced coatings improve hardness and hence reduce wear.

Keywords—Wear, INCONEL 718, Plasma Spray Coating, Slurry erosive wear.

I. INTRODUCTION

Copper and its alloys are finding enormous applications in the field of automobile engineering for manufacturing of axles, crankshafts, steering, steering shaft, levers, turbines, aircrafts and heavy vehicle components and building constructions. During working, there is always a relative motion and friction between the metal parts resulting in wear and tear. Due to this many adverse effects will be encountered by the specimen which renders loss of material, excess consumption of power during working, shift in the tolerances, wiping of lubrication etc. To make these alloys of copper further versatile and flexible for various application, and to provide a long life under different environments coatings are applied which provide better service and better quality to the metal pieces.

Since all the manufacturing and fabrication processes involve the use of copper as the metal removal agent a method has to be adopted to minimize the wear of the copper to a possible extent in working conditions, by which its life should be increased.

In order to enhance life of these parts, their mechanical properties and tribological properties should be improved. This can be done by reinforcing the metal parts with metal composites or by coating these surfaces with other hard substrates. If we go for reinforcement it changes the material property itself as it is mixed with the base metal and in case if only surface property has to be improved its better to go for coating as it improves property only at surface. And also to avoid excessive cost incurred for reinforcing the metal it is feasible to go for coatings since friction is a surface phenomenon.

Therefore in the present investigation, a comparative study had been conducted to evaluate the various tribological properties such as wear. To enhance the tribological properties of copper, it was decided to apply INCONEL718 coating on copper by plasma spray coating and study its wear behavior by conducting slurry erosive tests.

II. METHODOLOGY

A. Test specimen will be first prepared to the given dimensions by various machining process.

B. The prepared specimen is to be coated with INCONEL718 by plasma spraying machine.

C. To carry out slurry erosive tests to assess their tribological properties and behavior under working conditions in slurry erosive wear tester.

D. Presentation of the test results in the form of tabular columns and graphs with inference and conclusion.

III. LITERATURE SURVEY

COATINGS

Coating is a covering that is applied to the surface of an object, usually referred to as the substrate. In many cases coatings are applied to improve surface properties of the substrate, such as appearance, adhesion, wetability, corrosion resistance, wear resistance, and scratch resistance. In other cases, in particular in printing processes and semiconductor device fabrication (where the substrate is a wafer), the coating forms an essential part of the finished product.

PLASMA SPRAY COATINGS

The Plasma Spray Process is basically the spraying of molten or heat softened material onto a surface to provide a coating. Material in the form of powder is injected into a very high temperature plasma flame, where it is rapidly heated and accelerated to a high velocity. The hot material impacts on the substrate surface and rapidly cools forming a coating. This plasma spray process carried out correctly is called a "cold process" (relative to the substrate material being coated) as the substrate temperature can be kept low during processing avoiding damage, metallurgical changes and distortion to the substrate material. The plasma spray gun comprises a copper anode and tungsten cathode, both of which are water cooled. Plasma gas (argon, nitrogen, hydrogen, helium) flows around the cathode and through the anode which is shaped as a constricting nozzle. The plasma is initiated by a high voltage discharge which causes localized ionization and a conductive path for a DC arc to form between cathode and anode. The resistance heating from the arc causes the gas to reach extreme temperatures dissociates and ionises to form plasma. The plasma exits the anode nozzle as a free or neutral plasma flame which is quite different to the Plasma Transferred Arc coating process where the arc extends to the surface to be coated. When the plasma is stabilized ready for spraying the electric arc extends down the nozzle, instead of shorting out to the nearest edge of the anode nozzle. This stretching of the arc is due to a thermal pinch effect. Cold gas around the surface of the water cooled anode nozzle being electrically non-conductive constricts the plasma arc, raising its temperature and velocity. Powder is fed into the plasma flame most commonly via an external powder port mounted near the anode nozzle exit. The powder is so rapidly heated and accelerated that spray distances can be in the order of 25 to 150 mm.

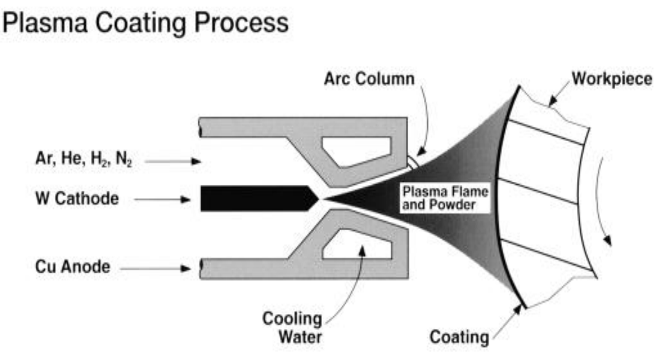

Fig. I Plasma Coating Schematic diagram

A plasma torch is shown schematically in Figure. Gas, usually argon and/or nitrogen, with hydrogen or helium admixed in some cases, flows through a cylindrical copper anode which forms a constricting nozzle. A direct current arc is maintained between an axially placed tungsten cathode and the outer or expanding portion of the anode. Gas plasma (ionized gas) is generated with a core temperature of about 50,000°F (30,000°C). Powder, with a particle size ranging up to about 100 microns, is fed into the plasma stream in a variety of ways and locations. The powder is heated and accelerated by the plasma stream, usually to temperatures above its melting point, and to velocities ranging from 400 to almost 2,000 ft/sec. The actual powder temperature distribution and velocity are strongly a function of the torch design. The gases chosen for plasma do not usually react significantly with the powder particles; however, reaction with the external environment, normally air, may lead to significant changes in the coating. The most significant reaction with metallic and carbide coatings is oxidation. The unique design of Praxair Surface Technologies' torches results in less oxidation than occurs with most other plasma torches. To reduce degradation during deposition even further, coatings may be produced using either an inert gas shield surrounding the effluent or by spraying in a vacuum chamber under a low pressure of inert gas. Argon is usually used in both cases as the inert gas. A proprietary Praxair gas shroud is extremely efficient in inhibiting oxidation and is less costly than spraying in low pressure chambers. Plasma deposition is a line-of-sight process. However, because of the relatively small size of the torch, the inside surface of hollow cylinders (and some other more complex shapes) can frequently be coated with appropriate traversing equipment. Torches have been produced which can coat inside cylinders to substantial depths. The as-deposited surface roughness of Praxair plasma coatings vary with the type of coating from about 60 to over 300 micro inches Ra. Although for many applications the coating is used as deposited, some are ground or ground and lapped to 1 to 10 micro inches, Ra. Typical coating thicknesses range from about 0.002 to 0.020 inch, but both thicker and thinner coatings are used on occasion.

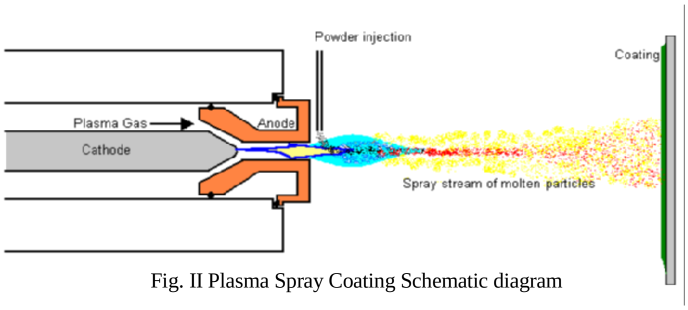

Fig. II Plasma Spray Coating Schematic diagram

SLURRY EROSIVE WEAR

SLURRY can be described as a mixture of solid particles in a liquid (usually water) of such a consistency that it can be readily pumped. The term "slurry erosion" is strictly defined as that type of wear, or loss of mass, that is experienced by a material exposed to a high-velocity stream of slurry. This erosion occurs either when the material moves at a certain velocity through the slurry or when the slurry moves past the material at a certain velocity. Typical pump able slurries possess inherent "apparent abrasivity," which must be determined by testing to enable cost predictions for pump replacement parts or other equipment used for slurries. Material in certain slurry does not indicate how that material would respond to another slurry. Slurry is a mixture of solids and liquids. Its physical characteristics are dependent on many factors such as size and distribution of particles, concentration of solids in the liquid phase, size of the conduit, level of turbulence, temperature, and absolute (or dynamic) viscosity of the carrier. Nature offers examples of slurry flows such as seasonal floods that carry silt and gravel. A slurry mixture is a mixture of a carrying fluid and solid particles held in suspension. The most commonly used fluid is water, however in some cases air is also used such as in pneumatic conveying.

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INCONEL 718

INCONEL 718 is a precipitation-hardenable nickel-chromium alloy also containing significant amounts of iron, niobium, and molybdenum along with lesser amounts of aluminum and titanium. It combines corrosion resistance and high strength with out-standing weldability including resistance to post-weld cracking. The alloy has excellent creep-rupture strength at temperatures to 1300°F (700°C).Used in gas turbines, rocket motors, spacecraft, nuclear reactors, pumps, and tooling. INCONEL alloy 718SPF is a special version of INCONEL alloy 718, designed for super plastic forming.

The compositions and various other properties of INCONEL 718 is as given below

INCONEL 718 Chemical composition

Alloy	%	Ni	Cr	Fe	Mo	Nb	Co	C	Mn	Si	S	Cu	Al	Ti
718	Min.	50	17	balance	2.8	4.75							0.2	0.7
	Max.	55	21		3.3	5.5	1	0.08	0.35	0.35	0.01	0.3	0.8	1.15

INCONEL 718 Physical properties

Density	**8.2 g/cm³**
Melting point	**1260-1340 ℃**

INCONEL 718 Alloy minimum mechanical properties in the room temperature

Alloy	Tensile strength Rm N/mm²	Yield strength R P0. 2N/mm²	Elongation A 5 %	Brinell hardness HB
Solution treatment	965	550	30	≤363

INCONEL 718 characteristics are as below:

- Workability
- High tensile strength, endurance strength, creep strength, and rupture strength at 700*C
- Steady mechanical performance at low temperature
- Good welding performance

INCONEL 718 metallurgical structure

INCONEL 718 alloy is Austenitic structure, precipitation hardening generate "γ" made it excellent mechanical performance. Grain boundary generate "δ" made it the best plasticity in the heat treatment.

INCONEL 718 corrosion resistance

718 alloy with extremely resistance to stress corrosion cracking and pitting ability in high temperature or low temperature environments, especially the inoxidability in the high temperature

INCONEL 718 application field

The elevated temperature strength, excellent corrosion resistance and workability at 700*C properties made it to be used in a wide range applications

Steam turbine

Liquid fuel rocket

Cryogenic engineering

Acid environment

Nuclear engineering

IV. EXPERIMENTAL DETAILS

Base metal : COPPER

Coating material: INCONEL718

Stage 1

Preparation of specimen by firstly cutting, then subsequently by milling, drilling and then finishing by filing process in workshop.

Stage 2

Specimens are prepared to size to the following sizes

Flat specimen: 25mm*25mm*10mm

Stage 3

The coating material was plasma sprayed on to the base metal to a thickness of 100µm at Spray met Coatings Industries Pvt. ltd.

Specification of plasma spray coatings

VOLTAGE 60-70V

CURRENT 495amps

INNERT GASES

Primary gas HYDROGEN (flow rate-100m3/min)

Secondary gas ARGON (flow rate -100m3/min)

TiO_2 POWDER 100gm/min

SPECIMEN PREPARATION

- Cleaning with Trichloroethylene
- 24 mesh Al_2O_3 grit blasting

COATING

Bond coating - Ni, Cr

Coating thickness – INCONEL718 (100-120microns)

DISTANCE OF SPRAY GUN FROM SPECIMEN – 6 inches

Stage 4

Before the start of the actual test, initial weights of the coated and uncoated specimen are found. Details of the following tests were collected

- Slurry erosive wear test
- Test parameters
  a. Effect of slurry concentration
  b. Effect of particle size
  c. Effect of speed

Stage 5

During each test the specimens will be held in the holder of the slurry erosive machine and will be made to run in the slurry concentration by varying the parameters.

Stage **6**

After each test the specimens will be cleaned in water, dried, washed with acetone solution and their final weights will be tabulated and results will be tabulated and graphs will be plotted.

Fig. III: Slurry erosive wear setup.

V. RESULTS AND DISCUSSIONS

MEASUREMENT OF WEAR RATE USING SLURRY EROSION TESTER

EFFECT OF PARTICLE SIZE

TABLE I: Effect of Particle Size on Coated Specimen and Uncoated Specimen for grain size of 212µ

Time (min)	Speed (rpm)	Grain Size (µ)	Sand Concen-tration	Coated Specimen Masses (grams)			Uncoated Specimen Masses (grams)		
				Initial	Final	Mass loss	Initial	Final	Mass loss
0	1000	212	100	-	419371		-	410363	
30	1000	212	100	419371	419355	0.0016	410363	410355	0.0008
60	1000	212	100	419355	419349	0.0006	410355	410346	0.0009
90	1000	212	100	419349	419345	0.0004	410346	410337	0.0009
120	1000	212	100	419345	419338	0.0007	410337	410325	0.0012
150	1000	212	100	419338	419332	0.0006	410325	410308	0.0017
180	1000	212	100	419332	419325	0.0007	410308	410302	0.0006
210	1000	212	100	419325	419315	0.001	410302	410295	0.0007
240	1000	212	100	419315	419303	0.0012	410295	41029	0.0005
270	1000	212	100	419303	419298	0.0005	41029	410279	0.0011
300	1000	212	100	419298	419293	0.0005	410279	410275	0.0004

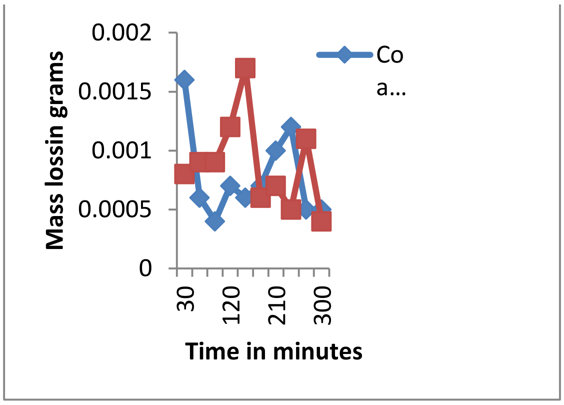
Overall Mass Loss (g):

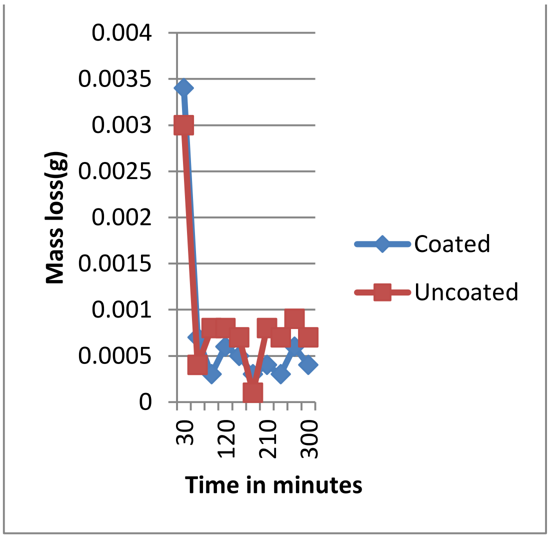
Coated Specimen - 0.0078

Uncoated Specimen -0.0088

TABLE II: Effect of Particle Size on Coated Specimen and Uncoated Specimen for grain size of 425µ

Time (min)	Speed (rpm)	Grain Size (µ)	Sand Concen-tration	Coated Specimen Masses (grams)			Uncoated Specimen Masses (grams)		
				Initial	Final	Mass loss	Initial	Final	Mass Loss
0	1000	425	100	-	415223	-	-	39.579	-
30	1000	425	100	41522	415189	0.0034	39.58	39.576	0.003
60	1000	425	100	41519	415182	0.0007	39.58	39.5756	0.0004
90	1000	425	100	41518	415179	0.0003	39.58	39.5748	0.0008
120	1000	425	100	41518	415173	0.0006	39.57	39.574	0.0008
150	1000	425	100	41517	415168	0.0005	39.57	39.5733	0.0007
180	1000	425	100	41517	415165	0.0003	39.57	39.5732	0.0001
210	1000	425	100	41517	415161	0.0004	39.57	39.5724	0.0008
240	1000	425	100	41516	415158	0.0003	39.57	39.5717	0.0007
270	1000	425	100	41516	415152	0.0006	39.57	39.5708	0.0009
300	1000	425	100	41515	415148	0.0004	39.57	39.5701	0.0007





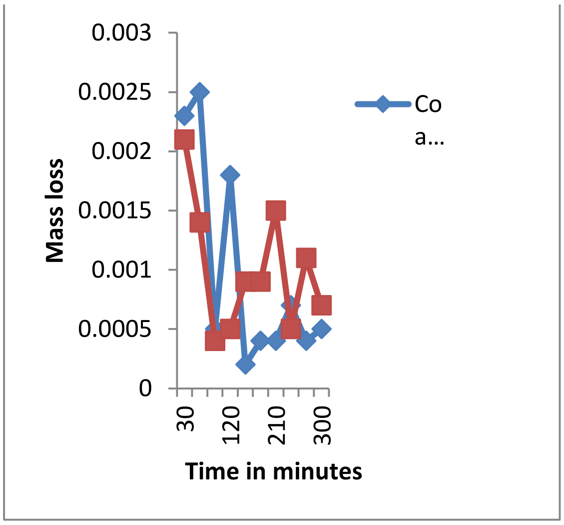
Overall Mass Loss (g):

Coated Specimen - 0.0079

Uncoated Specimen - 0.0089

TABLE III: Effect of Particle Size on Coated Specimen and Uncoated Specimen for grain size of 600µ

Time (min)	Speed (rpm)	Grain Size (µ)	Sand Concen-tration	Coated Specimen Masses (grams)			Uncoated Specimen Masses (grams)		
				Initial	Final	Mass loss	Initial	Final	Mass loss
0	1000	600	100	-	41.6561		-	52.0257	
30	1000	600	100	41.656	41.6538	0.0023	52.0257	52.0236	0.0021
60	1000	600	100	41.654	41.6513	0.0025	52.0236	52.0222	0.0014
90	1000	600	100	41.651	41.6508	0.0005	52.0222	52.0218	0.0004
120	1000	600	100	41.651	41.649	0.0018	52.0218	52.0213	0.0005
150	1000	600	100	41.649	41.6488	0.0002	52.0213	52.0204	0.0009
180	1000	600	100	41.649	41.6484	0.0004	52.0204	52.0195	0.0009
210	1000	600	100	41.648	41.648	0.0004	52.0195	52.018	0.0015
240	1000	600	100	41.648	41.6473	0.0007	52.018	52.0175	0.0005
270	1000	600	100	41.647	41.6469	0.0004	52.0175	52.0164	0.0011
300	1000	600	100	41.647	41.6464	0.0005	52.0164	52.0157	0.0007



Overall Mass Loss (g):

Coated Specimen - 0.0097

Uncoated Specimen - 0.010

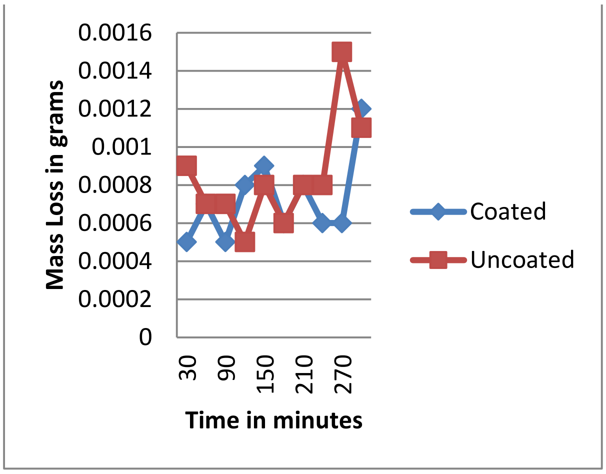
EFFECT OF PARTICLE SIZE

From the above graph we can conclude that as size of the sand particle increases wear rate of the specimen also increases but when compared to the coated specimen, uncoated specimen wears out more.

EFFECT OF SAND CONCENTRATION

TABLE IV: Effect of Sand Concentration on Coated Specimen and on Uncoated Specimen for concentration of 50 g/l

Time (min)	Speed (rpm)	Grain Size (µ)	Sand Concen-tration	Coated Specimen Masses (grams)			Uncoated Specimen Masses (grams)		
				Initial	Final	Mass loss	Initial	Final	Mass loss
0	1000	425	50	-	41.368	-	-	52.0385	-
30	1000	425	50	41.37	41.367	0.0005	52.04	52.0376	0.0009
60	1000	425	50	41.37	41.366	0.0007	52.04	52.0369	0.0007
90	1000	425	50	41.37	41.366	0.0005	52.04	52.0362	0.0007
120	1000	425	50	41.37	41.365	0.0008	52.04	52.0357	0.0005
150	1000	425	50	41.37	41.364	0.0009	52.04	52.0349	0.0008
180	1000	425	50	41.36	41.364	0.0006	52.03	52.0343	0.0006
210	1000	425	50	41.36	41.363	0.0008	52.03	52.0335	0.0008
240	1000	425	50	41.36	41.362	0.0006	52.03	52.0327	0.0008
270	1000	425	50	41.36	41.362	0.0006	52.03	52.0312	0.0015
300	1000	425	50	41.36	41.36	0.0012	52.03	52.0301	0.0011



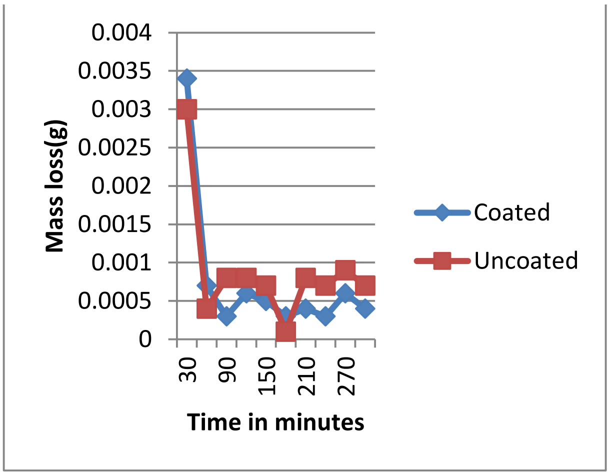
Overall Mass Loss (g):

Coated Specimen - 0.0072

Uncoated Specimen - 0.0084

TABLE V: Effect of Sand Concentration on Coated Specimen and on Uncoated Specimen for concentration of 100 g/l

Time (min)	Speed (rpm)	Grain Size (μ)	Sand Concen-tration	Coated Specimen Masses (grams)			Uncoated Specimen Masses (grams)		
				Initial	Final	Mass loss	Initial	Final	Mass Loss
0	1000	425	100	-	41.522	-	-	39.579	-
30	1000	425	100	41.52	41.519	0.0034	39.58	39.576	0.003
60	1000	425	100	41.52	41.518	0.0007	39.58	39.576	0.0004
90	1000	425	100	41.52	41.518	0.0003	39.58	39.575	0.0008
120	1000	425	100	41.52	41.517	0.0006	39.57	39.574	0.0008
150	1000	425	100	41.52	41.517	0.0005	39.57	39.573	0.0007
180	1000	425	100	41.52	41.517	0.0003	39.57	39.573	0.0001
210	1000	425	100	41.52	41.516	0.0004	39.57	39.572	0.0008
240	1000	425	100	41.52	41.516	0.0003	39.57	39.572	0.0007
270	1000	425	100	41.52	41.515	0.0006	39.57	39.571	0.0009
300	1000	425	100	41.52	41.515	0.0004	39.57	39.57	0.0007



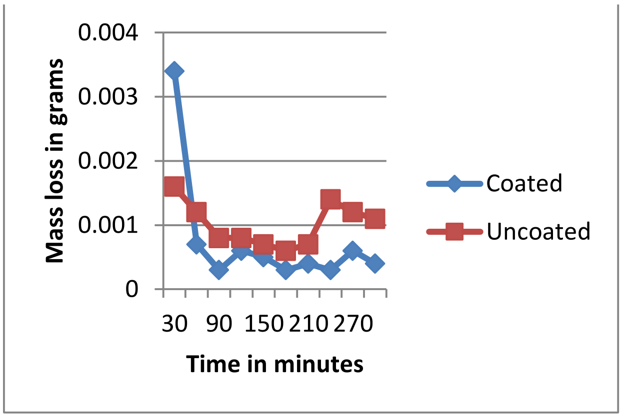
Overall Mass Loss (g):

Coated Specimen - 0.0075

Uncoated Specimen - 0.0089

TABLE VI: Effect of Sand Concentration on Coated Specimen and on Uncoated Specimen for concentration of 150 g/l

Time (min)	Speed (rpm)	Grain Size (μ)	Sand Concen-tration	Coated Specimen Masses (grams)			Uncoated Specimen Masses (grams)		
				Initial	Final	Mass loss	Initial	Final	Mass loss
0	1000	425	150	-	41.522	-	-	51.0253	-
30	1000	425	150	41.52	41.519	0.0034	51.03	51.0237	0.0016
60	1000	425	150	41.52	41.518	0.0007	51.02	51.0225	0.0012
90	1000	425	150	41.52	41.518	0.0003	51.02	51.0217	0.0008
120	1000	425	150	41.52	41.517	0.0006	51.02	51.0209	0.0008
150	1000	425	150	41.52	41.517	0.0005	51.02	51.0202	0.0007
180	1000	425	150	41.52	41.517	0.0003	51.02	51.0196	0.0006
210	1000	425	150	41.52	41.516	0.0004	51.02	51.0189	0.0007
240	1000	425	150	41.52	41.516	0.0003	51.02	51.0175	0.0014
270	1000	425	150	41.52	41.515	0.0006	51.02	51.0163	0.0012
300	1000	425	150	41.52	41.515	0.0004	51.02	51.0152	0.0011



Overall Mass Loss (g):

Coated Specimen - 0.0079

Uncoated Specimen - 0.0101

EFFECT OF SLURRY CONCENTRATION

From the above graph we can conclude that as the concentration of the sand in the water increases, wear rate of the specimen also increases because more sand grains hit against the surface and the wear of the specimen increases but when compared to the coated specimen, uncoated specimen wears out more.

EFFECT OF SPEED

TABLE VII: Effect of Speed on Coated Specimen and on Uncoated Specimen for speed of 500 rpm

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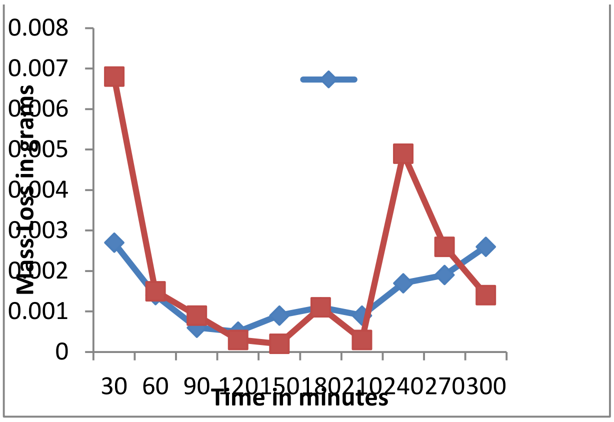
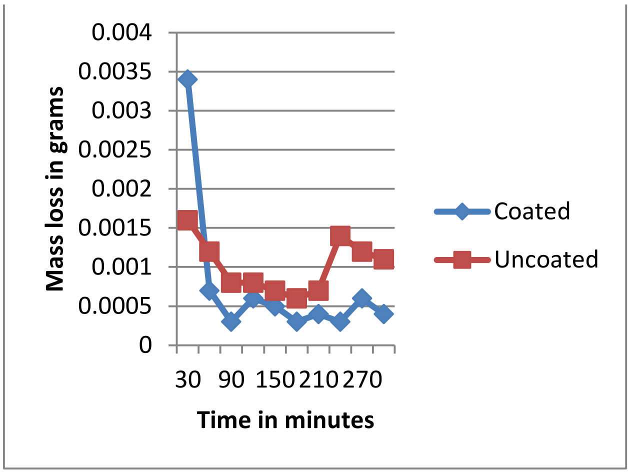


Overall Mass Loss (g):

Coated Specimen - 0.0073

Uncoated Specimen - 0.0084



Overall Mass Loss (g):

Coated Specimen - 0.0075

Uncoated Specimen - 0.0089

TABLE VIII: Effect of Speed on Coated Specimen and on Uncoated Specimen for speed of 1000 rpm

Time (min)	Speed (rpm)	Grain Size (μ)	Sand Concen-tration	Coated Specimen Masses (grams)			Uncoated Specimen Masses (grams)		
				Initial	Final	Mass loss	Initial	Final	Mass loss
0	1000	425	150	-	41.5223	-	-	51.0253	-
30	1000	425	150	41.52	41.5189	0.0034	51.03	51.0237	0.0016
60	1000	425	150	41.52	41.5182	0.0007	51.02	51.0225	0.0012
90	1000	425	150	41.52	41.5179	0.0003	51.02	51.0217	0.0008
120	1000	425	150	41.52	41.5173	0.0006	51.02	51.0209	0.0008
150	1000	425	150	41.52	41.5168	0.0005	51.02	51.0202	0.0007
180	1000	425	150	41.52	41.5165	0.0003	51.02	51.0196	0.0006
210	1000	425	150	41.52	41.5161	0.0004	51.02	51.0189	0.0007
240	1000	425	150	41.52	41.5158	0.0003	51.02	51.0175	0.0014
270	1000	425	150	41.52	41.5152	0.0006	51.02	51.0163	0.0012
300	1000	425	150	41.52	41.5148	0.0004	51.02	51.0152	0.0011

TABLE IX: Effect of Speed on Coated Specimen and on Uncoated Specimen for speed of 1500 rpm

Time (min)	Speed (rpm)	Grain Size (μ)	Sand Concen-tration	Coated Specimen Masses (grams)			Uncoated Specimen Masses (grams)		
				Initial	Final	Mass loss	Initial	Final	Mass loss
0	1500	425	100	-	41.517	-	-	52.0257	-
30	1500	425	100	41.52	41.512	0.0048	52.026	52.0224	0.0033
60	1500	425	100	41.51	41.511	0.0007	52.022	52.0214	0.001
90	1500	425	100	41.51	41.511	0.0004	52.021	52.0204	0.001
120	1500	425	100	41.51	41.51	0.0005	52.02	52.0197	0.0007
150	1500	425	100	41.51	41.51	0.0006	52.02	52.0189	0.0008
180	1500	425	100	41.51	41.509	0.0006	52.019	52.018	0.0009
210	1500	425	100	41.51	41.509	0.0007	52.018	52.0172	0.0008
240	1500	425	100	41.51	41.508	0.0005	52.017	52.0161	0.0011
270	1500	425	100	41.51	41.507	0.0008	52.016	52.0152	0.0009
300	1500	425	100	41.51	41.507	0.0006	52.015	52.014	0.0012

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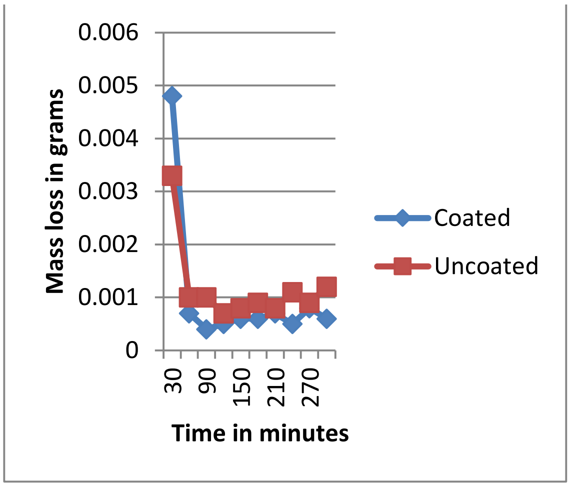

Overall Mass Loss (g):

Coated Specimen - 0.0102

Uncoated Specimen - 0.0117

EFFECT OF SPEED

From the above graphs, we can conclude that as the speed of rotation increases, more no. of sand particles hits the specimen hence the wear of the specimen increases but when compared to the coated specimen uncoated specimen wears out more.

VI. CONCLUSIONS

Based on the tests carried out to study the effect of wear of INCONEL 718 coated on copper as explained in the previous chapter and within the scope this investigation, the following conclusions have been drawn.

1. Plasma spray coating of INCONEL 718 on copper is effectively done for required thickness.

2. With increase in sand grain size, wear rate of test specimen increases.

3. With increase in sand concentration, wear rate of test specimen increases.

4. With increase in speed, wear rate of test specimen increases.

5. On the basis of comparison between the results obtained of both uncoated and coated specimens, it is clear that coating increases the wear resisting property of the base metal.

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