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CHARACTERISTIC EVALUATION OF MECHANICAL PROPERTIES OF PLASMA SPRAYED CERAMIC COATING

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ABSTRACT
Solid Surface Coatings are used in the mitigation of many tribological problems that range from controlling friction and limiting wear to accommodate hostile environments and sustaining thermal and mechanical stresses. Ceramic Coatings by plasma spraying belongs to the family of surface treatment technologies called thermal spray coating. Plasma, flame serves as a heat source to melt the ceramic powder, which are then propelled onto substrate to form the coating. Plasma spraying is one of the widely used technique to deposit coatings on industrial components for precision applications. Satisfactory functioning of the plasma sprayed ceramic coated material depends on quality of the coating. Evaluation of coating properties are undertaken to assess the basic quality of coating and to determine, if the properties of a particular coating are suitable for required function. To assess the life and functional efficiency of plasma sprayed ceramic coating some of the mechanical properties are evaluated.

Key Words: Plasma Spray, Wear strength, bond strength

1. INTRODUCTION
Solid surface coatings are primarily used to enhance the durability and/or performance of components employed in adverse operating conditions. Typically, these coatings are aimed at modifying the surface properties of critical components to provide enhanced resistance against deterioration due to mechanism such as corrosion, oxidation, wear, or failure under an excessive heat load. In recent years, considerable advances in the field of coatings technology have accompanied the growing realization of the immense potential of surface engineering in the modern industrial world. Consequently, there are now available a number of methods for developing a wide variety of protective coatings. Of all the coating methods, the thermal spray technique has gained by far the most widespread industrial acceptance to date [1]. Among the various thermal spray techniques, plasma spraying is gradually finding wide application.

Plasma spraying, originally a surface technology used for ceramic coating on metal and non-metal substrates. Plasma partially ionized state of gas can be generated by imparting a sufficient amount of energy to strip off electrons from the gas molecules. Generally, a plasma is produced either by passing a plasma-generating gas through a high intensity arc struck between two electrodes (arc plasma) or by high radio frequency excitation of the plasma gas (RF plasma). The plasma flame basically serves as a heat source to melt the injected powder particles, which are then propelled onto the substrate where they deposit and form the coating .A schematic diagram of a plasma gas is shown in fig.1.

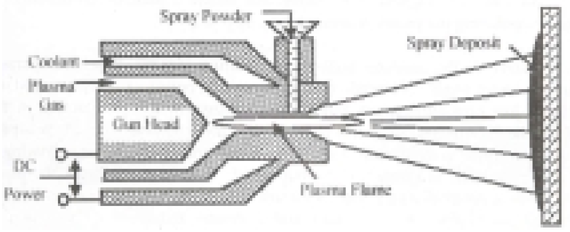

Fig.1 Schematic sketch of Plasma Spray system

Development of high quality ceramic coating by plasma spraying demands consideration of various materials, process and evaluation related issues. The life and functional efficiency of ceramic coatings made by plasma spraying method are influenced by the coating properties among which the wear resistance, fatigue strength, bond strength, hardness etc., of the coatings play a dominant role. Evaluation of these of the coating is discussed in the present paper.

2. DESCRIPTION OF EXPERIMENTS

For the characteristic evaluation of mechanical properties of the ceramic sprayed plasma coating, coating of ceramic material like alumina/chrome oxide on substrate of mild steel was done. Extensive tests were conducted to evaluate wear resistance, fatigue strength, bond strength, hardness etc.

2.1 Wear Test

Oxide ceramics with improved wear resistance, toughness etc., are labeled as 'triboceramics'.[2]. Hence, for effective application, it is necessary to assess the tribological characteristics of coatings. Sliding is a very common form of interaction between surfaces in service. To study the adhesive friction and wear characteristics of the ceramic coated surfaces, experiments were carried out on pin-on-wear test rig (Fig.2). Both the pin and disc made of mild steel were coated with Alumina and chrome oxide ceramics to form ceramic-ceramic sliding pair of same ceramic material. The pin was of diameter 10 mm, and the disc of diameter 300 mm (Fig.3). The experiments were carried out in dry conditions at room temperature. The pins were mated against a rotating disc with normal contact pressure ranging from 20-50 MPa. The loss of mass of pin due to wear is measured by electronic balance after cleaning with CCl_4. wear test was also carried out on plain mild steel (uncoated specimen) for the comparison of wear of coated and uncoated specimen.

Fig.2 A typical pin-on-disc machine for wear testing

2.2 Fatigue test

The development of toughened ceramics can be considered as a real breakthrough in material technology. This has brightened up the application of ceramics. Though ceramics have been considered for many structural applications, simultaneously considerable reservation has been created in the minds of designers owing to the ceramics being susceptible to degradation under cyclic fatigue loading. The crack growth rate under cyclic loading is much greater than that under cyclic loading.[3].

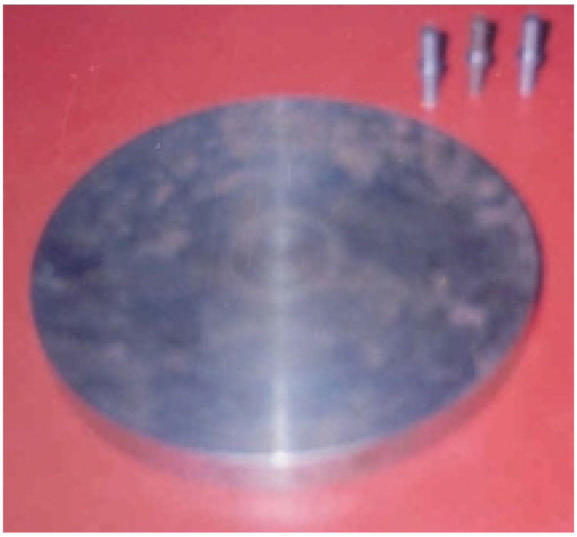

Fig.3 Wear Test Specimen (a) Disc (b) Pins

The bright drawn mild steel substrates were prepared according to the dimensions mentioned in Indian Standard (IS: 5649-1970) and then were grit blasted for about 4-5 minutes and ultrasonically cleaned in CCl_4 medium for about 5 minutes. Then they were plasma sprayed immediately and air cooled. During the spraying required thickness of ceramic coating was built by multi-pass spraying. The sprayed samples (Fig.4) were taken out of the spray booth, cooled and kept in dessicator until tested. The rotating cantilever fatigue testing machine (Fig.5) is used for determining the fatigue strength under reversed bending stresses according to the Woohler stress cycle diagram.

Fig.4 Sprayed samples for Fatigue test

Fig.5 A typical rotating cantilever Fatigue Test Machine

2.3 Hardness test

The micro hardness values of the ceramic coatings were measured to determine local variations. The coated surface of 400 microns was prepared metallographically and the micro hardness (Hv 200) of the coatings was measured in Vicker's scale. The load in the range of 1g-2000g is applied for about 10-15 seconds and size of impression is measured for measurement of micro hardness. Vicker's indentor is tetrahedral pyramidal diamond indentor, having angle of 136° between opposite faces. A square impression is formed upon indentation, for which average diagonal length is measured optically and hardness is calculated by the following relation

$Hv=1.854\ P/L^2$ …………(1)

Fig.6 shows a Schematic of a Vickers indentation showing the diagonal (L) of hardness impression.

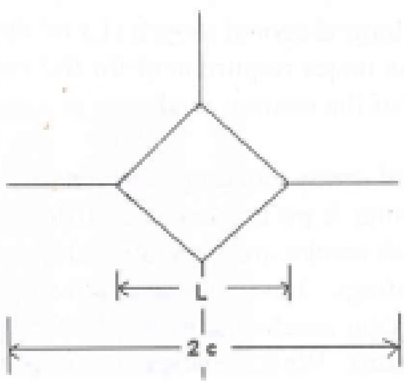

Fig.6 Schematic of a Vickers indentation

2.4 Adhesion Test:

The specimen for adhesion test is prepared for testing according to ASTM C633-79, the standard test method for adhesive or cohesive strength of flame sprayed coatings. The coating for which the adhesion strength is to be evaluated is coated on a flat end of a cylindrical specimen. The coating is glued on to another cylindrical sample with cynamid FM73 adhesive. The pair is uniaxially aligned with pull off bar and cured. The specimen assembly so prepared (Fig.7) is mounted on a tensile testing machine and pulled. The samples were tested with UTM-40 tonne capacity (Fig.8).

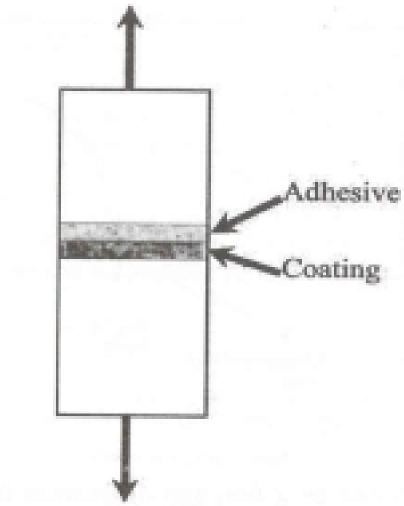

Fig. 7 Schematic sketch of tensile bond strength test specimen

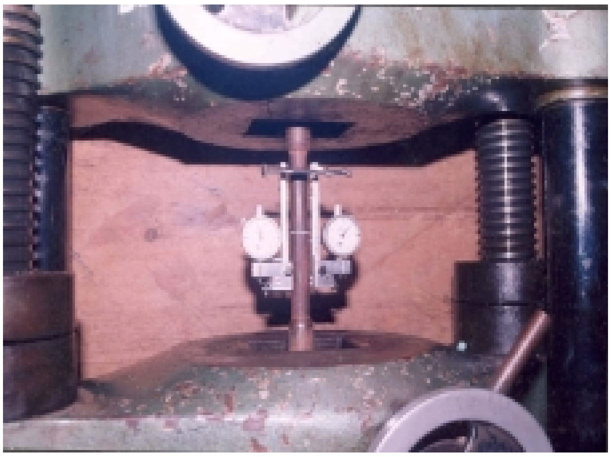

Fig.8 A typical tensile testing machine (UTM-40 tonne capacity) for Adhesion Test

3. RESULTS AND DISCUSSIONS

The successful utilization of plasma technology, to solve industrial problems, requires high quality coatings. Ceramic coated components offer a wide range of thermal, chemical and mechanical properties with applications from engines to ball tipped pens. Alumina/Chrome oxide ceramic deposited by plasma technique on Mild steel substrate were evaluated through different tests. Responses are presented in the following sections.

3.1 Wear characteristics

Sliding wear characteristics of uncoated mild steel, mild steel coated with alumina and mild steel coated with chrome oxide for variation in pressure and velocity is illustrated in Fig.9 and Fig.10 respectively.

Fig.9 shows the effect of pressure on the wear rate of mild steel (uncoated), Alumina coated and chrome oxide coated specimen sliding pair for sliding distance of 0.34 Km at constant velocity of 3.14 m/s. Wear generally increases with increase in pressure. It is observed that the wear rate of chrome oxide coating is less compared to alumina coated part and alumina coated part wear is less compared to uncoated specimen.

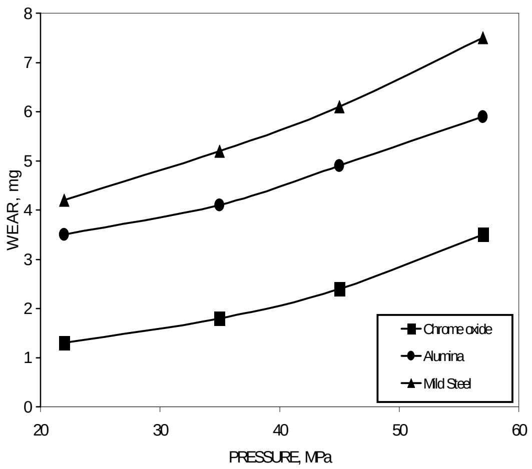

Fig 9: Influence of applied pressure on wear

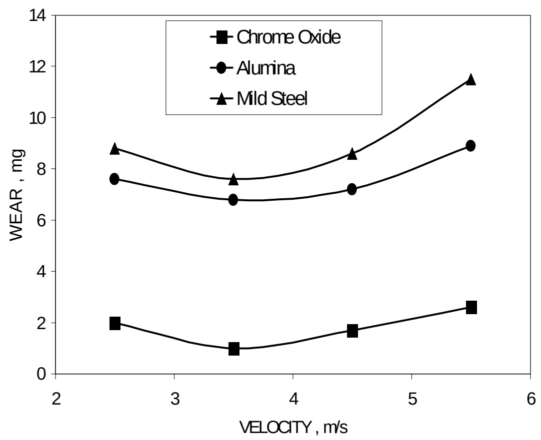

Fig 10: Influence of sliding velocity on wear

Apart from contact pressure, sliding velocity can also influence wear.Fig.10 illustrates that the wear is marginally dropped down with increasing velocity in the range of 3 to 4 m/s. For most of the cases increase in wear propagation around 5 to 6 m/s is noticed. This is attributed to higher order spalling of deposits. Wear rate of chrome oxide coating is better compared to alumina coating and wear rate of alumina coating is better compared to uncoated Mild Steel.

3.2 Fatigue characteristics

Fig.11 illustrates the fatigue characteristics for the range of stress applied on Mild Steel (uncoated), Mild Steel coated with Alumina and Mild Steel coated with Chrome oxide. With increase in stress applied, the fatigue strength of the substrate material generally decreases. Above a critical stress of approximately 1000 MPa, the coatings reduce the fatigue strength of the substrate and below it , the fatigue strength was improved slightly. For thermal spraying of harder material, the surface of the substrate would be grit blasted, maintaining apt asperity/valley geometry to facilitate effective keying of the coating on to the substrate. The rough surface produced by grit blasting is supposed to reduce the fatigue strength.[4]. As the coatings were very thin compared to the thickness of the substrate, the surface of the substrate adjacent to the coating was stressed largely and below the surface the induced stress decreased with depth below the surface. The stress gradient can result in cracking of the coating during coating. At higher stress levels(above 1000 MPa) the mechanical bond could not arrest crack initiation, whereas at lower stress conditions, the ceramic coatings spread over the substrate firmly and mechanical bonding between the substrate and the coating as a barrier prevented/slowed down the crack initiation and growth. Hence fatigue life was marginally improved at lower stress levels.[5]. It is observed that fatigue strength is slightly improved due to coating at lower stress levels.

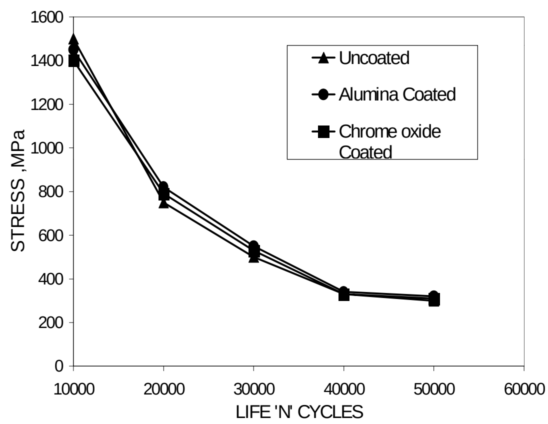

Fig.11: Fatigue characteristics

3.3 Hardness characteristics

Hardness of sprayed coating is an important characteristic. Usually the hardness and related properties of a sprayed material will be smaller than those for the same in the sintered/monolithic state. This is attributed to the presence of large scale porosity, inferior cohesion between different layers of a multi-layered sprayed coating and also due to environmental influences such as oxidation etc.[5].Typical values are presented in Table 1.

Table 1: Micro hardness Values

Ceramic	Coating (Hv)	Monolithic (Hv)
Alumina	1000	2100-2300
Chrome oxide	650	1400-1600

3.4 Adhesion Strength Characteristics:

Adhesion Strength is influenced by direct parameters such as porosity and hardness and indirect parameters such as stand-off, power input and other parameters such as surface preparation etc. Thermal sprayed coatings are usually thicker, with large porosity content. When sprayed on a relatively weaker substrate like mild steel, the bond strength will be considerably influenced by the substrate deformation characteristics; in that the retention of the sprayed coating without being spalled-off largely depends on the ability of coating to follow the deforming substrate.[3].Hence bond coat is applied. The result of the bond strength test is illustrated in table 2.

Table 2:Bond Strength

Ceramic	Coating (MPa)
Alumina	15
Chrome oxide	10

4. CONCLUSIONS

Protective coatings of alumina/chrome oxide ceramic material on mild steel substrate have been developed. Coatings were evaluated for mechanical properties. The following major conclusions are drawn from the study.

1. Wear rate increases with contact pressure, sliding velocity and distance of sliding.
2. Fatigue strength increases for lower loads in case of ceramic coated specimen compared to uncoated specimen.
3. The micro hardness of sprayed coated material is smaller than those for monolithic material.
4. The coating thickness significantly influences the bond strength of ceramic coating. Direct parameters such as porosity and hardness and indirect parameters such as stand off distance, power input and other parameters such as surface characteristics influence bond strength.

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6. NOMENCLATURE

Symbol	Meaning	Unit
F	Force	N
L	Average diagonal length	μm
H_v	Hardness	GPa