

HVOF Sprayed Coating's (WC-CoNiCrSi) to Conduct the Erosion Test

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ABSTRACT: It is a well-known fact that materials that consist of both brittle and ductile constituents can show erosion behavior in either a ductile or a brittle manner. The high velocity oxy-fuel(HVOF) sprayed WC-CoNiCrSi coatings on GrA1 boiler tube steal exhibit composite ductile and brittle modes of erosion under angular silica sand erodent of size 125-180 μ m impacted at 40m/s. The HVOF spraying leads to a high retention of WC in the coating matrix accompanied with lower porosity. The as-sprayed as well as eroded coatings have been characterized using scanning electron microscope and optical profilometer.

KEYWORDS: HVOF process, erosion test, coating composition, and 306-SS

I. INRODUCTION

Erosive wear is caused in the solid bodies by the action of sliding or impact of solids, liquids, gases or a combination of these [1]. Manifestations of solid particle erosion in service usually include thinning of components, a macroscopic scooping appearance following the gas particle flow field, surface roughening, lack of the directional grooving characteristic of abrasion and in some but not all cases, the formation of ripple patterns on metals [2]. Solid particle erosion is an important material degradation mechanism encountered in a number of engineering systems such as thermal power plants, aircraft gas turbine engines, pneumatic bulk transport systems, coal liquefaction/gasification plants and ore or coal slurry pipe lines [3,4].

Power plants are one of the major industries suffering from severe corrosion and erosion problems resulting in the substantial losses. Erosion results from impact of particulates, such as coal ash, dolomite and unburned carbon particles o the surface of heated boiler tubes. It is generally believed that the most erosive species in the fly ash are quartz, which is a crystalline from of SiO₂ and mullite. More than one quarter of all the boiler tube failures worldwide are caused by fly ash erosion [5,6].



Fig 1.1 Erosion on Metal Surface

Generally speaking, coatings can be regarded as materials with greater resistance to the significant surface degradation process. Coatings provide of extending the limits of use of materials at the upper end of their performance capabilities,

by allowing the mechanical properties of the substrate material to be maintained while protecting them against wear or corrosion. An advantage of coating is that are relatively cheap and they can be applied insitu. There are many coating deposition techniques intended, level of adhesion required (size, shape, and metallurgy of the substrate), and availability and cost of the equipment. In general, widely used techniques to obtain coatings on boiler tubes or weld overly, diffusion coating, thermal spraying and laser cladding. The most important drawbacks diffusing coatings are that they are thin and cannot be produced on sight or repaired. In compression with diffusion coatings, thermal spray coatings do not require such a high temperature of the base metal that would impair the mechanical or micro structural properties in the case of weld overly there is increase in corner that repeated weld overlay application to the same tube area may result in embrittlement of the old overlay and lead to cracks that could propagates in to the overlaid tube. Because of the mentioned short coming in diffusion and weld overlay coatings, attention is increasingly being forced on thermal sprayed coating.[1],[2],[3],[4],[5],[10].

II. LITERATURE REVIEW

- Fire side corrosion and erosion of metallic structural materials at elevated temperature in complex multicomponent gas environments that include particulates are potential problems in many fossil energy systems, especially those using coal as a feedstock (Natesan 1993).
- Demand for metallic materials with higher strength and special properties are on the increase with the advancement of technology. However, a drawback of metallic material is the deterioration in properties originating from their interaction with the environments. This leads to a premature failure of metallic components with the hazards of plant shutdown and loss of economy, environmental pollution and risk to human lives (Chatterjee et al. 2001).
- In a case study of a coal fired boiler of a power plant in north western region of India, Prakash et al (2001) have reported that out of 89 failures occurring in one year duration, 50 failures were found to be due to hot corrosion and erosion by ash. Moreover fly ash content of the Indian coal is very high and causes severe erosion-corrosion of the materials in the power plants.
- Present materials being capable of resisting erosive and corrosive environments are highly alloyed, and thus expensive. In search for cost-effective solutions for E-C problems, various coatings like thermal sprayed coatings have become attractive. For E-C resistance at elevated temperatures, thermal sprayed coatings must be hard, dense, (Uusitalo et al. 2002A, Vicenzi et al. 2006)
- Coatings provide a way of extending the limits of use of materials at the upper end of their performance capabilities, by allowing the mechanical properties of the substrate materials to be maintained while protecting them against wear or corrosion (Sidky and Hocking, 1999, Stringer 1987, and Stroosnijder et al, 1994).
- Wang and Luer (1994) reported the recent use of coatings to protect the heat exchanger tubes of fluidized bed combustor from E-C problems and Hocking (1993) also suggested the use of corrosion resistant alloys as coatings to protect substrate alloys having good mechanical properties.
- Meadowcroft (1987), Tani et al. (1998), and Wang (1997) reported that Conventional coating processes such as flame spraying were tested unsuccessfully in earlier years, but recent advances and ready availability of plasma spraying or HVOF equipments, including portable systems, has prompted an examination of these processes in the last few years. HVOF spraying is a competitive method for producing high quality coatings. HVOF coatings are homogeneous and dense coatings compared to the other thermal sprayed coatings (Moskowitz 1993 and Uusitalo et al., 2002B).
- Uusitalo et al. (2002B) and Warren (1992) also suggest that coatings for combined erosion-corrosion protection, complex formulations containing Ni, Al, Cr, Mo, Si, borides and other minor elements may also be used.

III. HIGH VELOCITY OXY-FUEL PROCESS (HVOF)

3.1 Explanation on HVOF Process

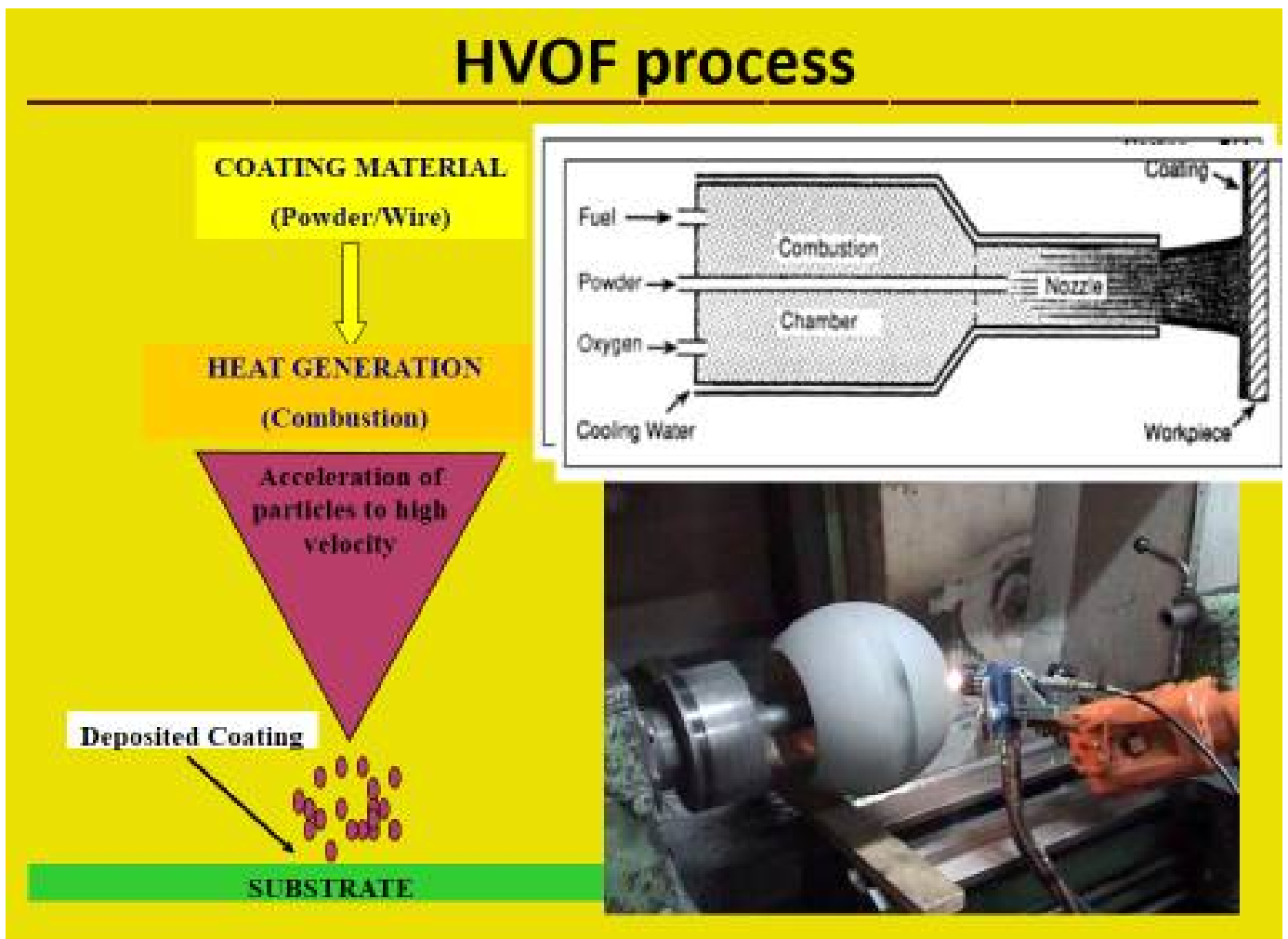


Fig 3.1 Block Diagram of HVOF Process

- HVOF is a method of propelling molten particles on to work surfaces for each coating. As an essential feature of thermal spray coatings, sprayed particles – upon and after impact – deform so as to interlock with the impact surface’s profile. While the initial thermal spray technology focused on guaranteed deformation through excessive heating, a new method is introduced with the high velocity of HVOF.
- A small chamber is used to create supersonic velocity of exhaust. The focused exhaust stream receives the powder material at a velocity that the resultant impact forges adequate bonding. In fact, the impact from the kinetic energy is so great that most of the porosity is eliminated. As such, the less porous coating provides the best wear resistance and densest coatings available. The HVOF thermal spray process uses the combustion gases such as propane, propylene hydrogen or a liquid fuel such as a kerosene fuel and oxygen.[1],[2],[3],[5]

3.2 HVOF Process Parameters

Oxygen flow rate	200 l/mm
Fuel (LPG) flow rate	50 l/mm
Air flow rate	750 l/mm
Spray distance	100mm
Powder feed rate	36g/min
Fuel pressure	500kpa
Oxygen pressure	750kpa
Air pressure	535kpa
Model no of the gun	5220
Diameter of the gun	11mm

3.3 Coating Compositions

WC	Co	Ni	Cr	Si
66.4	13.6	8.67	7.82	1.557

In this coating, 80% of coating contains WC Co and 20% of Ni Cr Fe Si.
The percentage of WC - 66.4, Co - 13.6, Ni - 8.67, Cr- 9.82, and that of Si - 1.557.

IV. EXPERIMENTAL PROCEDURE

4.1 Substrate material and development of coating

Low carbon steel ASTM-SA201 grade A1(GrA1) which is used as material for boiler tubes in some coal fired thermal power plants in northern part of India has been used as substrate in the study. The specimens with approximate dimensions of 30mm*30mm*5mm were cut from the tubes for erosion studies. Samples were grinded with SiC papers down to 180 grit and grit blasted with Al₂O₃ (grit45) before being HVOF sprayed to develop better adhesion between the substrate and the coating. [8],[9],[10]

The composite coating powder of 80%WC CO-NiCrFeSi was used to spray to deposit coatings using HVOF Process.

4.2 Powder and Coating Characterization Techniques

The surface and cross section of coated samples with were wheel cloth polished for metallurgical examination. Zeiss Axiovert 200 MAT inverted optical microscope, fitted with analyzing software zeiss Axiovision release 4.1 used for optical microscopy. porosity and average coating thickness was measured with image analyzing software. surface roughness of the coating was recorded with WYKO NT1100 optical profilometer using veco version 32 software Vickers microhardness measurements (leitz's hardness tester) using 2.94N were performed in order to access the hardness across the coating and to ascertain substrate plastic strain hardening promoted by the high velocity projection

4.3 Erosion Studies

Room temperature erosion test was carried out using air jet erosion test as per ASTM G76-02 standard at the defense metallurgical research laboratory, Hyderabad, India the erosion studies were performed on uncoated as well as coated samples for the purpose of comparison. The erosion test conditions utilized in the present study are listed in table 2 the velocity of the eroding particles was determined by a rotating double disk method Ruff and Ives [18]. The sample was first cleaned in acetone using an ultrasonic cleaner, dried and then weighed using an electronic balance with least count of 0.01mg. The samples were then removed, cleaned in acetone and dried and weighed to determine the weight loss. The above procedure was repeated till the incremental erosion rate attained a constant value independent of the erodent particles or, equivalently, of testing time. This constant value of the incremental erosion rate was defined as the steady state erosion rate. The incremental erosion rate was converted into volume wear rate to take into account the different densities.[4],[7],[8],[11].

4.4 Erosion Test Equipment and Setup

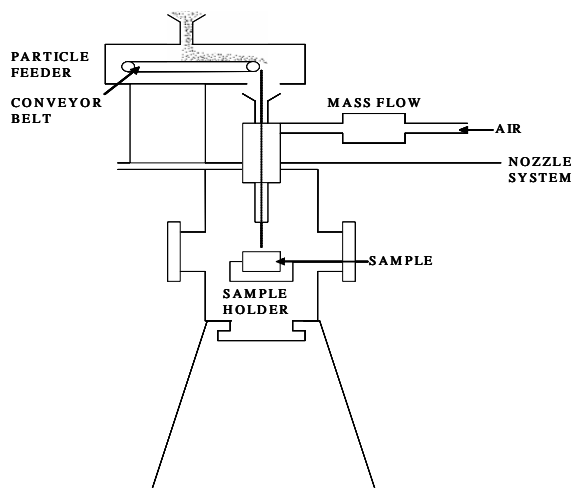


Fig 4.1 Block Diagram of Erosion Test Equipment



Fig 4.2 Air Jet Erosion Test Machine

Erosion Test Procedure:

- Before conducting the test, the specimen surface was cleaned properly.
- The sample is clamped at the fixture. The required angle and standoff distance was adjusted.
- The air at required pressure is mixed with the erosive particle and is directed to a specimen for specified time duration.
- The initial mass and the mass of the specimen after erosion were found out using the weighing machine.
- The above steps are repeated for different parameters mentioned.

1) **Experimental set-up**

The electronics controller controls erodent discharge, air flow and duration of the test in ambient temperature. Eroder discharge is controlled by a motor and control parameters are displayed on the front panel of the instrument. The inlet air pressure regulates the erodent velocity and can be adjusted by the user. A timer allows users to set test duration.

In instruments equipped with high temperature modules, integrated heaters heat the air and sample to the desired temperature. The sample temperature can be adjusted by the user between ambient and the maximum temperature limit of the tester. An integrated PC is used to enter test parameters.

Erosion resistance of samples is determined by measuring the initial weight and final weight of the specimen. Materials that exhibit lower loss are said to be more resistant to erosion.[5]

4.5 Erosion Test for Substrate (306-SS)

Its compositions are listed below:

Element	Percent by Weight 306-SS
Carbon	0.08
Manganese	2.00
Silicon	0.75
Chromium	16.00 18.00
Nickel	10.00 14.00

Molybdenum	2.00 3.00
Phosphorus	0.045
Sulfur	0.030
Nitrogen	0.10
Iron	Bal.

1.6 Tables for Impingement Angles (30°, 60°, 90°)

30°Table

Cycle	Initial	Final
5	15.6445	15.6440
10	15.6440	15.6395
15	15.6395	15.6393
20	15.6393	15.6392
25	15.6392	15.6392

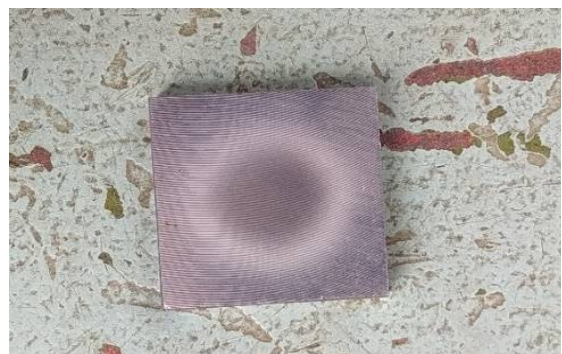


Fig 4.2 Erosion Test for 30°

60° Table

Cycle	Initial	Final
5	19.6329	19.6326
10	19.6326	19.6324
15	19.6324	19.6323
20	19.6323	19.6323

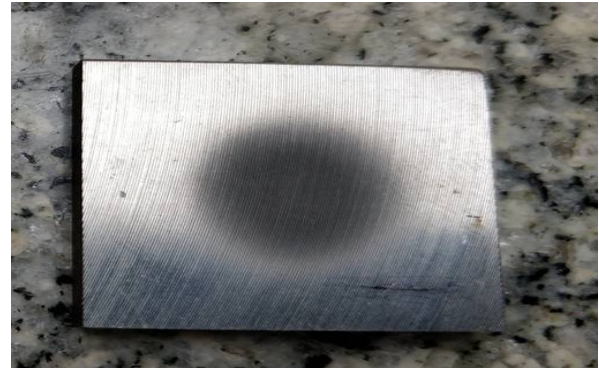


Fig 4.3 Erosion Test for 60

90° Table

Cycle	Initial	Final
5	19.6335	19.6332
10	19.6332	19.6330
15	19.6330	19.6329
20	19.6329	19.6329



Fig 4.4 Erosion Test for 90°

4.6 Erosion Test for Coating Components (30°, 60°, 90°)
Coating Compositions – WC Co-NiCrSi (80%-20%)

30° Table

Cycle	Initial	Final
5	16.2802	16.2773
10	16.2773	16.2760
15	16.2760	16.2743
20	16.2743	16.2736
25	16.2736	16.2730
30	16.2730	16.2730



Fig 4.5 Erosion Test at 30°

60° Table

Cycle	Initial	Final
5	21.2661	21.2652
10	21.2652	21.2633
15	21.2633	21.2617
20	21.2617	21.261
25	21.261	21.260
30	21.260	21.260



Fig 4.6 Erosion Test at 60°

90° Table

Cycle	Initial	Final
5	21.2723	21.2707
10	21.2707	21.2696
15	21.2696	21.2689
20	21.2689	21.2668
25	21.2668	21.2661
30	21.2661	21.2661

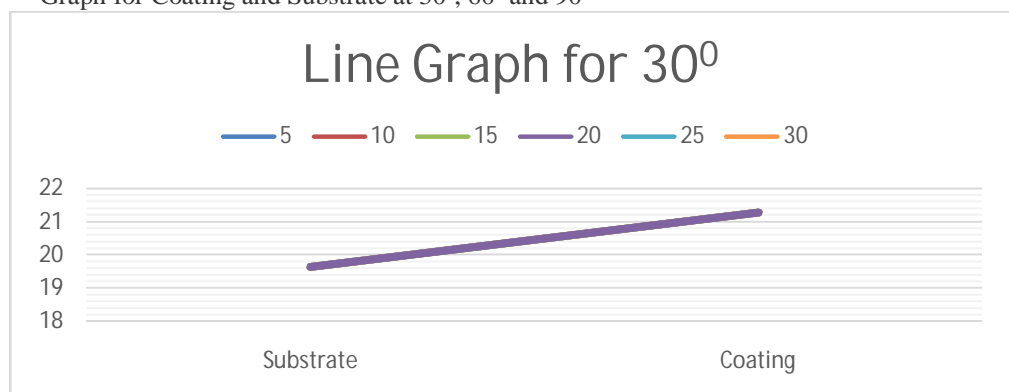


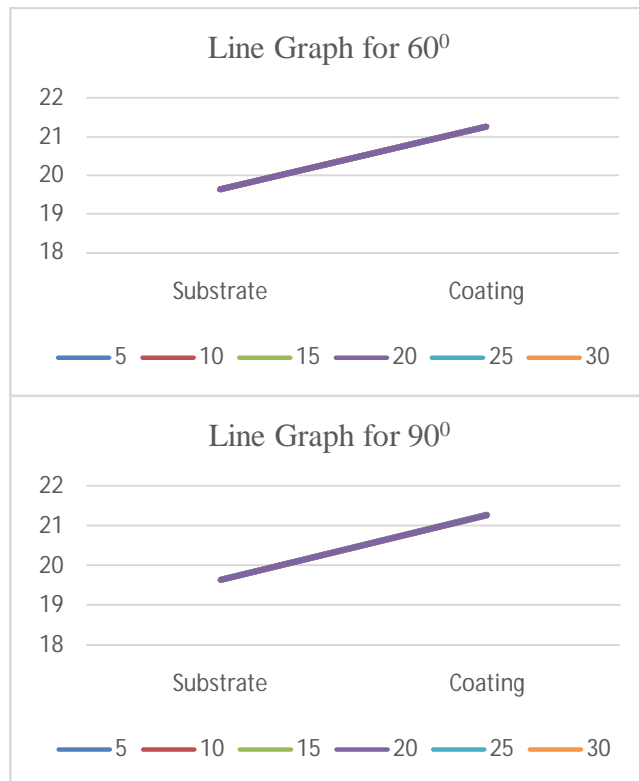
Fig 4.7 Erosion Test at 90°

V. RESULT AND DISCUSSION

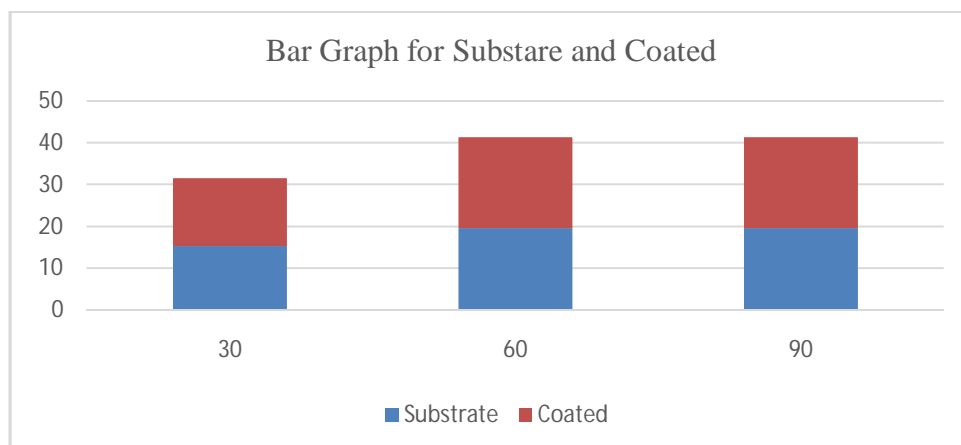
5.1 Comparison Between Substrate and Coating

5.1.1 Graph for Coating and Substrate at 30°, 60° and 90°





Explanation: From the above graph the erosion rate increased in coating compared to substrate at 60° and 90°



Explanation: Bar Graph shows the erosion rate of Substrate and Coated materials

VI. CONCLUSION

- High velocity oxy-fuel thermal spraying with oxygen and liquid petroleum gas as fuel gases has been used successfully to deposit WC Co-NiCrSi alloy coatings on boiler tube steels. LPG fuel gas is cheap and readily available as compared to other fuels used for HVOF spraying. Under the given spray parameters coating with average thickness 290microns and average porosity of 0.5% has been achieved coating deposited resulted in hardness value of 1223HV.

- WC Co- NiCrAlYSi coatings show retention of higher amount of WC in matrix with a minor amount of W₂C brittle phase.
- The erosion resistance of WC Co- NiCrSi coating maybe attributed to composite ductile and brittle modes of material removal although brittle mode is dominant. The morphology of the eroded surface points out craters.
- Substrate steel exhibit slower steady state volume erosion rate in comparison to HVOF sprayed WC Co- NiCrSi coatings under similar test conditions. The higher hardness ratio between silicon erodent particle and substrate steel might have caused the penetration of silica particles into the surface.
- Erosion rate with respect to angle of impact is maximum at 30degree and minimum at 90degree. Erosion rate with respect to stand of distance is maximum at 100mm and lower for 200mm. This implies that lower the stand of distance greater is the rate of erosion.
- Erosion rate with respect to Pressure increases as the rate of erosion increases.

From the predicted mechanism it is found that the erosion behavior is valid for ductile materials. Hence our observation also follows the same rule.

Having calculated the ideal angle of contact, force of impingement and the distance of fall for a Mild Steel, Aluminum, Stainless Steel, we would now be in a position to predict the condition that should be maintained to minimize wear.

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