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Enhancing Wear Resistance & Fatigue Strength of Mild Steel & Aluminium Alloys Using Detonation Spray Coating

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Abstract: **Materials are precious resources. Different methods are employed to protect the material from degradation. Thermal spraying is one of the most effective methods to protect the material from wear, high temperature corrosion, stresses and erosion, thus increasing the life of material in use. Detonation gun spraying is one of the thermal spraying techniques known for providing hard, wear resistant and dense micro structured coatings. In this paper, to increase the Wear Resistance and the Fatigue Strength of Mild Steel and Aluminium alloys, we are going to use Zirconium and Alumina-Titanium powders for Detonation Spray Coating. They are ceramic materials which can withstand high heat and thermal load. They are easily available ceramics and can be coated by detonation spray coating. The materials chosen for coating are Alloy special Steel EN19 and Al A319. The materials are coated with Zirconium powder and Alumina-Titania by Thermal spray detonation method. After coating, the fatigue strength and wear resistance of the material is tested and compared with the results of the base material. The apparatus for wear testing is Drum type abrasion test. The fatigue test is to be done by high cycle push-pull tensile compression fatigue by Cyclic Deformation and Fatigue Crack Formation. The results are to be evaluated and compared. The percentage increase in wear resistance and fatigue strength is to be calculated.**

***Keywords*:** Detonation Spray Coating, Wear Resistance, Fatigue Strength.

I. INTRODUCTION

Thermal spraying, a group of coating processes in which finely divided metallic or nonmetallic materials are deposited in a molten or semi-molten condition to form a coating. The coating material may be in the form of powder, ceramic-rod, wire, or molten materials. Thermal spray processes are now widely used to spray coatings against, wear and corrosion but also against heat (thermal barrier coating) and for functional purposes. The choice of the deposition process depends strongly on the expected coating properties for the application and coating deposition cost. Coating properties are determined by the coating material, the form in which it is provided, and by the set of parameters used to operate the deposition process. Thermal spray coatings are generally characterized by a lamellar structure and the real contact between the splats and the substrate or the previously deposited layers determine to a large extent the coating properties, such as thermal conductivity, Young’s modulus, etc. The real contact area ranges generally between 20 to 60 % of the coating surface parallel to the substrate. It increases with impact velocities of particles provided that the latter are not either too much superheated or below their melting temperature. That is why roughly the density of coatings increases from flame, wire arc, plasma, HVOF or HVAF and finally D-gun spraying and self-fluxing alloys flame sprayed and then re-fused.

The objective of the work is to analyze the role of detonation gun spray coating to enhance the properties of surface of substrate to counter the problems like wear, erosion, residual stress, fretting fatigue, thermal behavior and corrosion etc.

II. DETONATION SPRAY COATING

D-gun spray process is a thermal spray coating process, which gives an extremely good adhesive strength, low porosity and coating surface with compressive residual stresses. A precisely measured quantity of the combustion mixture consisting of oxygen and acetylene is fed through a tubular barrel closed at one end. In order to prevent the possible back firing a blanket of nitrogen gas is allowed to cover the gas inlets. Simultaneously, a predetermined quantity of the coating powder is fed into the combustion chamber. The gas mixture inside the chamber is ignited by a simple spark plug. The combustion of the gas mixture generates high pressure shock waves (detonation wave), which then propagate through the gas stream. Depending upon the ratio of the combustion gases, the temperature of the hot gas stream can go up to 4000 deg C and the velocity of the shock wave can reach 3500m/sec. The hot gases generated in the detonation chamber travel down the barrel at a high velocity and in the process heat the particles to a plasticizing stage (only skin melting of particle) and also accelerate the particles to a velocity of 1200m/sec. These particles then come out of the barrel and impact the component held by the manipulator to form a coating. The high kinetic energy of the hot powder particles on impact with the substrate result in a buildup of a very dense and strong coating. The coating thickness developed on the work piece per shot depends on the ratio of combustion gases, powder particle size, carrier gas flow rate, frequency and distance between the barrel end and the substrate. Depending on the required coating thickness and the type of coating material the detonation spraying cycle can be repeated at the rate of 1-10 shots per second. The chamber is finally flushed with nitrogen again to remove all the remaining “hot” powder particles from the chamber as these can otherwise detonate the explosive mixture in an irregular fashion and render the whole process uncontrollable. With this, one detonation cycle is completed above procedure is repeated at a particular frequency until the required thickness of coating is deposited.

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III. COATING POWDERS

In principle, any material that does not decompose as it is melted can be used as a thermal spray coating material. Depending on the thermal spray process, the coating material can be in wire or powder form. Choosing a coating material that is suitable for a specific application requires special knowledge about the service environment as well as knowledge about the materials. Apart from the physical characteristics, such as coefficient of expansion, density, heat conductivity and melting point, additional factors, such as particle shape, particle size distribution and manufacturing process of powder material (i.e., agglomerated, sintered, composited) will influence coating performance. In this project, we are using two powders for coating by Detonation Spray Process namely,

A. Zirconium
B. Alumina-Titania

A. ZIRCONIUM

Zirconium is a chemical element with symbol Zr and atomic number 40. The name of zirconium is taken from the name of the mineral zircon, the most important source of zirconium. It is a lustrous, grey-white, strong transition metal that resembles hafnium and, to a lesser extent, titanium. Zirconium is mainly used as a refractory although it is used in small amounts as an alloying agent for its strong resistance to corrosion. The melting point of Zr is 1,855 °C.

B. ALUMINA-TITANIA

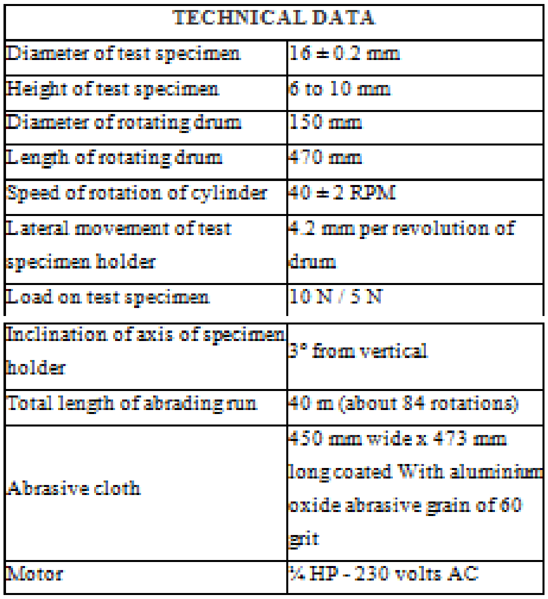
Alumina Titania is a blocky shaped fused Alumina Titania powder having a bluish color. It produces a coating that is dense and hard and it resists wear due to abrasion, fretting, cavitation and particle erosion. It resists corrosion by most acids and caustics. The powder consists of 85% Alumina and 15% Titanium.

WEAR RESISTANCE TEST - ROTARY DRUM ABRASION TESTER

Wear is related to interactions between surfaces and specifically the removal and deformation of material on a surface as a result of mechanical action of the opposite surface. In materials science, wear is erosion or sideways displacement of material from its "derivative" and original position on a solid surface performed by the action of another surface. Wear can also be defined as a process where interaction between two surfaces or bounding faces of solids within the working environment results in dimensional loss of one solid, with or without any actual decoupling and loss of material. Aspects of the working environment which affect wear include loads and features such as unidirectional sliding, reciprocating, rolling, and impact loads, speed, temperature.

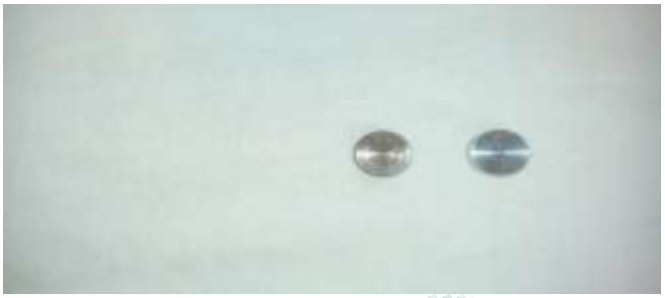
One of the methods for determining the abrasion resistance of materials is by a Rotating Drum Abrasion Tester. In this test the material under test is abraded against an abrading surface mounted over a rotating drum. The abrading surface has a specified abrading power. The test specimen, which is in form of a button, is held against it under a fixed load. The abrading surface is made to rub against the test specimen by rotating the drum at a fixed speed, the test specimen being meanwhile made to move along the axis of the drum. The ratio of the volume loss of a standard material to the volume loss of the material under test, determined under the same conditions and expressed as a percentage, gives the abrasion resistance index of the material under test. The determination of volume loss by this method is suitable for comparative testing and for checking the uniformity of specified products. However, the results of this test give only limited information on the wearing behavior of materials in practice.

The PROLIFIC Rotating Drum Abrasion Tester is designed to determine abrasion resistance index of materials in accordance with the above principle. It consists of test specimen holder with a cylindrical opening adjustable between 15.5 and 16.3 mm to clamp the test specimen, with an arrangement to adjust the length of test specimen protruding out. The holder is mounted on a swivable arm pivoted in a bracket, which is moved laterally by a screw mechanism along the length of a rotating drum on which the abrasive cloth is fixed. The test specimen holder also provides an arrangement to protect the abrasive cloth from damage by preventing the lower edge of the test specimen holder to touch the abrasive cloth. The movement to the screw mechanism and the drum is given by an electric motor coupled to a worm reduction gearbox with V-belt and pulleys to give the specified speed of rotation to the drum and the specified lateral movement to the test specimen holder. The equipment is provided with limit switches, which, in addition to giving over-travel safety to the movement of test specimen holder, also stop the motor automatically after the specified run of the test specimen. The swivable arm and test specimen holder are so disposed that the test specimen is pressed against the drum under the specified load with its Centre axis at an inclination of 3° to the perpendicular in the direction of rotation and placed above the longitudinal axis of drum. The abrasive cloth is firmly fixed to the drum using a suitable peel able adhesive with the ends of the abrasive cloth butt jointed together. Four abrasive cloths in addition to the one fixed on the cylinder are supplied with the equipment as standard accessory.

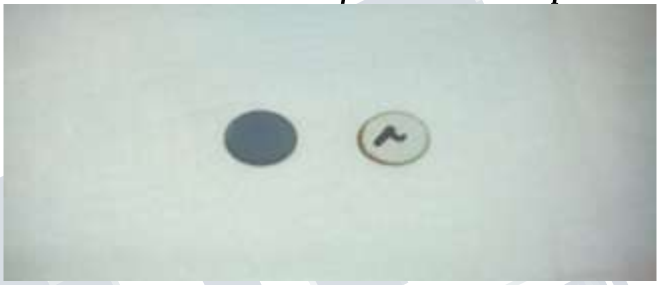


TECHNICAL DATA	
Diameter of test specimen	16 ± 0.2 mm
Height of test specimen	6 to 10 mm
Diameter of rotating drum	150 mm
Length of rotating drum	470 mm
Speed of rotation of cylinder	40 ± 2 RPM
Lateral movement of test specimen holder	4.2 mm per revolution of drum
Load on test specimen	10 N / 5 N
Inclination of axis of specimen holder	3° from vertical
Total length of abrading run	40 m (about 84 rotations)
Abrasive cloth	450 mm wide x 473 mm long coated With aluminium oxide abrasive grain of 60 grit
Motor	¼ HP - 230 volts AC

WEAR TEST SPECIMENS

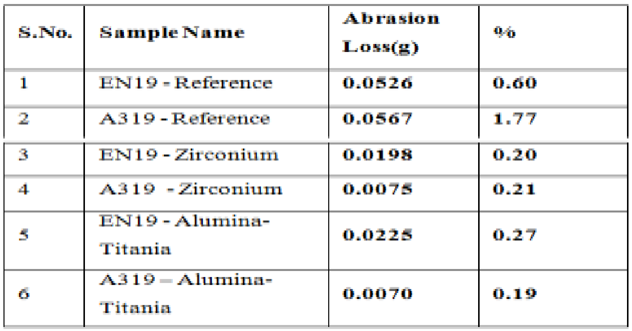


EN19 & A319 Reference Wear test Specimens



EN19 coated with Zirconium & Alumina-Titania

IV. RESULTS OF WEAR TEST



S.No.	Sample Name	Abrasion Loss(g)	%
1	EN19 - Reference	0.0526	0.60
2	A319 - Reference	0.0567	1.77
3	EN19 - Zirconium	0.0198	0.20
4	A319 - Zirconium	0.0075	0.21
5	EN19 - Alumina-Titania	0.0225	0.27
6	A319 – Alumina-Titania	0.0070	0.19

From the above table, the percentage increase in the wear resistance of Zirconium powder coated EN19 material is increased by 66.66%

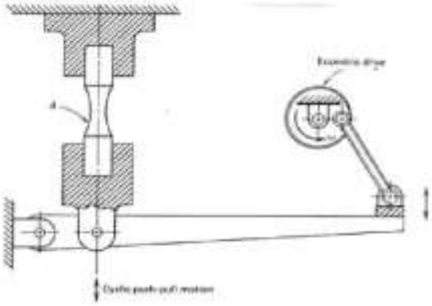
The percentage increase in the wear resistance of Alumina-Titania powder coated EN19 material is increased by 55%

The percentage increase in the wear resistance of Zirconium powder coated Aluminium A319 material is increased by 88.14%

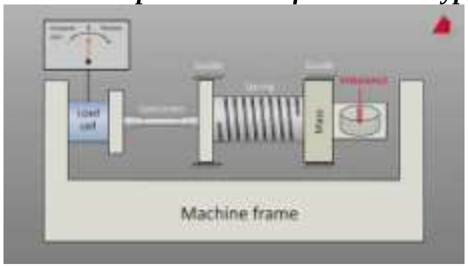
The percentage increase in the wear resistance of Alumina-Titania powder coated Aluminium A319 material is increased by 89.27%

V. FATIGUE TEST – PUSH-PULL TYPE

In materials science, fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values that cause such damage may be much less than the strength of the material typically quoted as the ultimate tensile stress limit, or the yield stress limit. Fatigue occurs when a material is subjected to repeated loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the stress concentrators such as the surface, persistent slip bands (PSBs), and grain interfaces. Eventually a crack will reach a critical size, the crack will propagate suddenly, and the structure will fracture. The shape of the structure will significantly affect the fatigue life; square holes or sharp corners will lead to elevated local stresses where fatigue cracks can initiate. Round holes and smooth transitions or fillets will therefore increase the fatigue strength of the structure.Engineers have used any of three methods to determine the fatigue life of a material: the stress-line method, the strain-line method, and the linear-elastic fracture mechanics method. One method to predict fatigue life of materials is the Uniform Material Law (UML). UML was developed for fatigue life prediction of aluminium alloys by the end of 20th century and extended to high-strength steels, and cast iron.

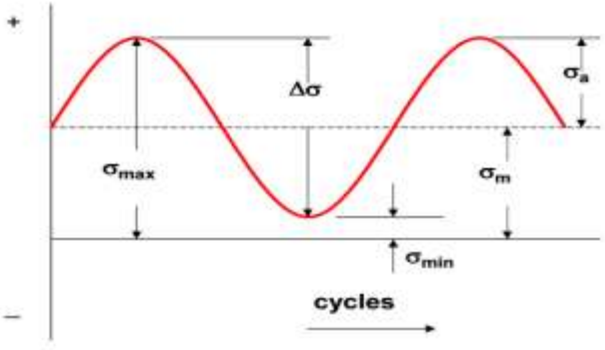


Schematic Representation of Push-Pull Type

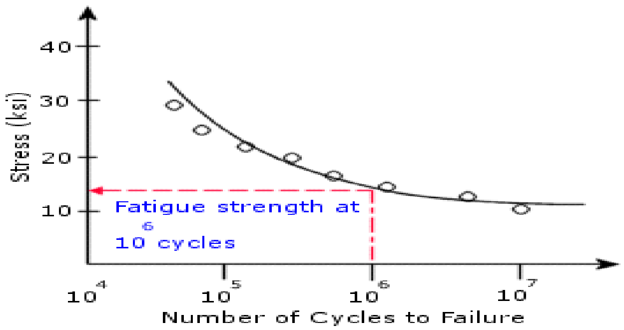


Method: PUSH-PULL TYPE LOAD
Frequency: 0-50 Hz
Type : High cycle Push-Pull tensile compression fatigue by Cyclic Deformation and Fatigue Crack Formation
Stress Range: 0-80% Ultimate Tensile Stress*
(*Specimens Tensile Strength has to be evaluated)
S-N CURVE

In high-cycle fatigue situations, materials performance is commonly characterized by an S-N curve, also known as a Wöhler curve. This is a graph of the magnitude of a cyclic stress (S) against the logarithmic scale of cycles to failure (N).S-N curves are derived from tests on samples of the material to be characterized (often called coupons) where a regular sinusoidal stress is applied by a testing machine which also counts the number of cycles to failure. This process is sometimes known as coupon testing. Each coupon test generates a point on the plot though in some cases there is a run out where the time to failure exceeds that available for the test (see censoring). Analysis of fatigue data requires techniques from statistics, especially survival analysis and linear regression.The progression of the S-N curve can be influenced by many factors such as corrosion, temperature, residual stresses, and the presence of notches. The Goodman-Line is a method to estimate the influence of the mean stress on the fatigue strength.

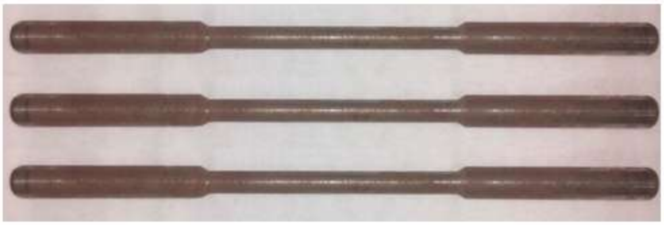


S-N Stress Cycle

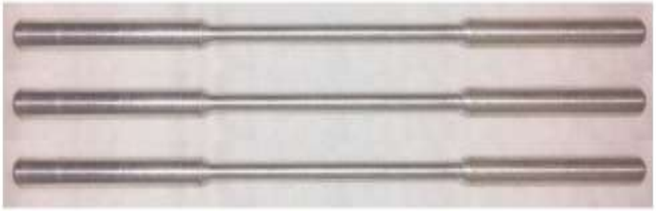


S-N Curve

FATIGUE TEST SPECIMENS



MS EN19 Fatigue Specimens (Reference)



Al A319 Fatigue Specimens (Reference)

Aluminium A319 Fatigue Specimens coated with Zirconium

Aluminium A319 Fatigue Specimens coated with Alumina-Titania

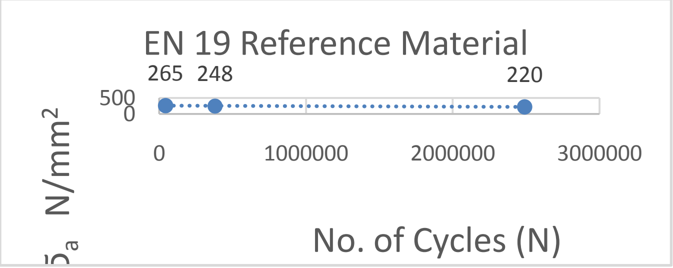
MS EN19 Fatigue Specimens coated with Zirconium

MS EN19 Fatigue Specimens coated with Zirconium

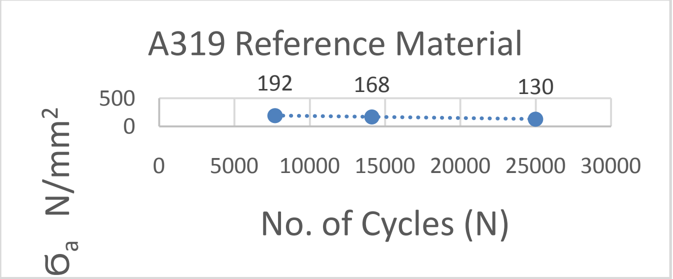
RESULTS OF FATIGUE TEST

Various S-N curves of the Test Specimens:

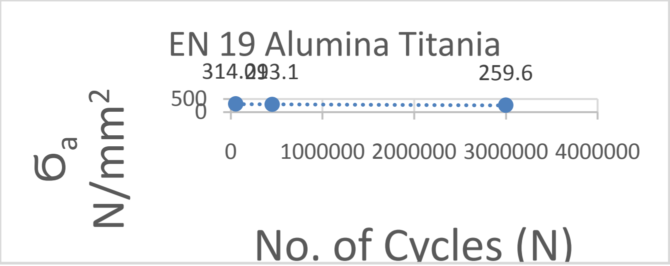
1. EN19 Reference Material
2. A319 Reference Material
3. EN19 Alumina-Titania
4. A319 Zirconium
5. EN19 Alumina-Titania
6. A319 Zirconium



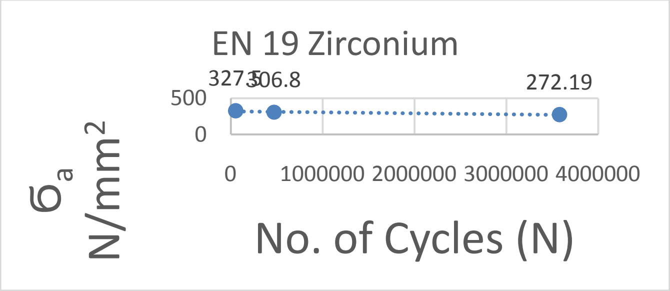
SN Plot EN 19 Reference Material



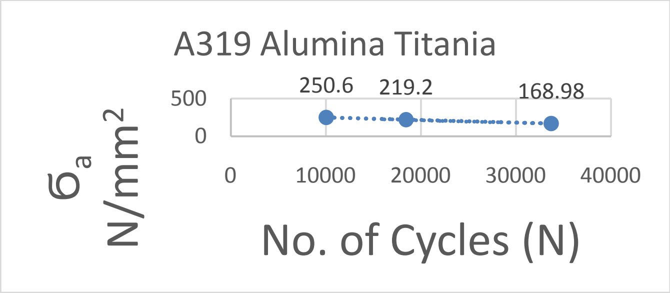
SN Plot for A319 Reference Material



SN Plot for EN 19 Coated with Alumina Titania

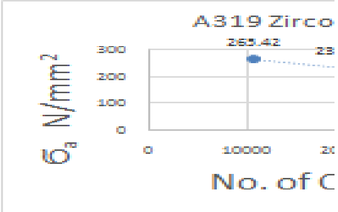


SN Plot for EN19 coated with Zirconium



SN Plot for A319 coated with Alumina Titania

SN Plot for A319 coated with Zirconium

Specimen 	σ_a N/mm^2	No. of Cycles (N)
EN 19 (Reference Material)	220	24,90,015
A 319 (Reference Material)	130	25,098
EN 19 Aluminum Titania	259.6	30,10,009
EN 19 Zirconium	272.19	35,78,636
A 319AluminiumTitania	169.98	33,713
A 319 Zirconium	179.81	35,562

From the above table, the percentage increase in the Fatigue Strength of Zirconium powder coated EN19 material is increased by 23.99%.

The percentage increase in the Fatigue Strength of Alumina-Titania powder coated EN19 material is increased by 17.8%

The percentage increase in the Fatigue Strength of Zirconium powder coated Aluminium A319 material is increased by 38.32%

The percentage increase in the Fatigue Strength of Alumina-Titania powder coated Aluminium A319 material is increased by 30.75%.

VI. CONCLUSION

With Detonation thermal spray, probably more so than any other coating process, there is almost no limitation in the number of options available for substrate and coating material combinations. As a result, detonation spray coatings lend themselves to a broad scope of applications, both for new component manufacture and for repair. The characteristics of the coatings can be varied within a wide range to suit specific application requirements.

Detonation sprayed coatings can play important role in protecting materials and alloys from wear and corrosion phenomena.

Thus, the detonation spray coatings can be used to increase wear resistance and fatigue strength of Steel and Aluminium Alloys.

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