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Wear protection on metals through HVOF spray coating Techniques

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***Abstract-* In current technological trends related to material selection for ay manufacturing process is highly competitive in nature. The industries are always trying to find new materials and its alloys for better physical and mechanical properties, and they are supportive for machining operations which results in super finishing of parts created by machine tools. In this regard all the research works are leaning towards the alloys and its additives which are useful for the manufacturing process. In present scenario high velocity oxygen fuel (HVOF). A new method of spraying coatings, called high velocity oxygen-fuel (HVOF), has been developed. It is in developmental use for high temperature coatings. The HVOF coating also has much less oxidation of the particles than air plasma spray. Here oxygen and corrosion resistant coatings are very much essential to give good properties of metals in most of the manufacturing applications.**

I. INTRODUCTION

High temperature gas turbine coatings have developed from simple aluminised coatings designed to provide enhanced oxidation protection for jet engine turbine blades in the 1960s, to complex, multilayer coatings that reduce the temperature of the turbine blades. High temperature coatings continue to advance as we learn more about them, and as we develop new coatings and new methods of applying them. The two principal types of high temperature coatings are oxidation and corrosion resistant coatings, and thermal barrier coatings. Oxidation and corrosion resistant coatings are used to provide protection from environmental attack due to high temperature oxidation and hot corrosion. They consist primarily of aluminide and overlay coatings. Thermal barrier coatings (TBCs) are used to reduce the temperature of the component, as well as to provide some resistance to oxidation and corrosion. Thermally sprayed hard metal coatings are used in many industrial applications for wear protection under very different service conditions, including high temperatures and aggressive media. Corrosion protective coatings have been demonstrated to extend the service life of gas turbine blades operating at elevated temperatures and in corrosive environments. Despite the great variety of coating types and their utilization, the basic requirements for surface protection are generally valid for all systems: good environmental resistance; long term stability of protective layer and strong adhesion to the substrate. These composite coatings consist of hard phase particles (typically carbides) dispersed in a metal matrix. The objective of this tutorial is to provide an overview of high temperature coatings technology for the gas turbine user. Included in this overview are the different types of coatings, what makes them work, how they are made, how they degrade, recoating, and environmental attack. Also presented is a brief look at future development trends in coating technology and its practical applications.

A. How coatings work

Oxidation and Corrosion Resistant Coatings works by forming a thin oxide barrier on the surface, as shown in Figure 1.2. This barrier separates the base metal and coating from the reactive gases. This barrier is extremely thin, on the order of 0.0001 inch (100 micro inches, or 2 microns). Without this barrier, the reactive gases would oxidize and corrode both the base metal, as well as the coating itself. This oxide barrier is typically alumina, Al203, although chromia, Cr203, will also provide protection at lower temperatures in effective manner. And also the coating on surface is given in below figure.1

Figure-1.1: coating substrate

B. Purpose of coating

In many cases most surface coatings are to some extent protecting the substrate like chemical resistant coatings, wear resistance and barrier coatings on metals and alloys subjected to erosion or abrasive attack on surfaces where the coatings are required in high density. and in some cases required for the fallowing cases of anticorrosion

- Under body sequence for cars
- Wear resistance
- Many plating products
- Preserving equipment and structural steel from degradation
- Under thermal insulation and under protective fire proofing from structural steels

II. LITERATURE SURVEY

During the survey made on real applications of spray coatings of different substrate the fallowing outcomes by the previous author's work is the basis for our testing results. In Nickel Based Super alloys for Advanced Turbine Engines tells that NIMONIC 80A alloy is wrought, hard enable nickel-chromium alloy, strengthened by additions of titanium, aluminium and carbon, developed for service at temperature up to 8150C (1500F). It is produced by high-frequency melting and casting in air for forms to be extruded. Elecro-slag refined material is used for forms to be forged. Vacuum refined versions are also available. NIMONIC 80A alloy is currently used for gas turbine components (blades, rings and discs), bolts, nuclear boiler tube supports, die casting inserts, cores and for automobile exhaust valves. [1] .Advisory Committee on Exiting Chemicals of the Association of Germany Chemists, in his UNEP publication tells about the selection of coating powders. Wear Resistant Thermal Spray Coatings of tungsten carbide are used for their hardness and wear resistance. When choosing a tungsten carbide powder, the particle size and type of carbide selected are important in determining the correct material to combat various forms of erosion, abrasion and wear, whereas the amount of metal matrix in the coating (nickel, cobalt or alloy) will depend on the toughness and abrasion resistance required. Chromic forming elements used in Ni and Co base coatings against hot corrosion and oxidation up to 9000C. Ni base substrates to minimize the inter diffusion depresses chemical activity of Al. Co improves the adherence of chromium scales on Ni base alloys [2]. HVOF process-its characteristics, advantages and uses tells that - A new method of spraying coatings, called high velocity oxygen fuel (HVOF), has been developed. In this method, the powder is both heated and propelled by a high velocity flame onto the substrate. The high velocity allows denser coatings. The higher particle velocity of HVOF produces a denser coating, which improves the properties of the coating. The HVOF coating also has much less oxidation. [3]. High temperature corrosion by molten salts, also known as hot corrosion, is a phenomenon observed in power plants using residual fuel oils, in which the metallic surfaces are covered by a thin molten salt layer exposed to a gaseous environment [4] Nickel base super alloys are normally used in gas turbines, nuclear power plant reactors, steam turbines, etc. [5] Nickel base super alloys are very common commercial materials, fabricated for being used in high temperature atmospheres [6] The consequence of this corrosion attack can be a severe loss of metal from the process units, leading to high-cost maintenance and serious safety issues. Various industrial failures due to metal dusting have been reported, including among others the Moss gas plant converting natural gas to synthetic transportation fuels [7] Just below the metal-scale interface, whereas exposed to the high vanadium molten salt, Inconel-600 corroded by means of a generalized corrosion process, which was due to the diffusion of sulphur to the surface and inside the alloy. [8] The copper deterioration causes and its risks were identified and applied on different layers in additive coating method in his work. [9] The diffusion of sulphur inside the alloy is a typical phenomenon of continuous dissolution of the protective oxides [10] In this way the authors' were thought in their own views with different conditions on their experimental analysis.

III. COATING TYPES AND ITS SELECTIONS

A coating is a covering that is applied to the surface of an object, usually referred to as the substrate. The purpose of applying the coating may be decorative, functional, or both. The coating itself may be an all-over coating, completely covering the substrate, or it may only cover parts of the substrate.To protect the underlying metallic substrate against a corrosive environment a coating that forms a thermally grown oxide should be applied. If the requirement is to protect against a high temperature, a coating type that acts as a thermal barrier can be applied. Coating used in gas turbines can be divided into three major types: diffusion coatings, Overlay coatings and thermal barrier coatings. They are briefly described below.

A. Diffusion Coatings:

Produce a corrosion/oxidation resistant thermally grown Oxide by enriching the surface with Al, Cr or Si through diffusion. Diffusion Coatings are the most widely used types in gas turbine engines. For example we say, on rotating parts like turbine blades. They have a homogeneous microstructure with good thermos-mechanical fatigue properties. A critical limitation is the high ductile-to-brittle transition temperature and the very brittle nature below the Transition temperature.

B. Overlay Coatings:

Produce a corrosion/oxidation resistant thermally grown oxide by depositing a pre-alloyed material with desired composition on the surface. Typical compositions are based on the MCrAlX alloy system, where M is Ni, Co, Fe or a combination of these and X is Y, Si, Ta, Hf, etc. The main advantage in Comparison to diffusion coatings, which have properties that strongly depend on the Substrate composition, is that their properties can be better controlled and balanced for a specific application. In general, overlay coatings have better oxidation and corrosion Resistance than diffusion coatings and can be used at higher temperatures. They can also be deposited in thicker layers. The limitations of overlay coatings are the relatively poor reproducibility of the properties as they are highly dependent on the process.

C. Thermal Barrier Coatings:

Thermal barrier coatings (TBCs) are applied in order to reduce the heat flux between the surface and the substrate component. Depending on heat flow conditions and the thickness of the coating, the temperature difference across the thermal barrier coating can reach 1750C. Thermal barrier coatings are built up by an outer Ceramic topcoat with low thermal conductivity and an intermediate oxidation and Corrosion resistant bond coat. At high temperature exposure, oxygen easily penetrates the low-density topcoat and reacts with the bond coat, which oxidises and produces a protective thermally grown oxide (TGO) at the interface between the topcoat and the bond coat. Thermal barrier coatings are mainly produced by the following methods

- Air plasma spray (APS)
- Low pressure plasma spray (LPPS)
- Vacuum plasma spray (VPS)
- Shrouded plasma spray (SPS)
- High velocity oxygen fuel (HVOF)
- Electron beam physical vapour deposition (EB-PVD)

The main application of TBC is to Increase the hot gas temperature without increasing the substrate temperature (increased efficiency). Reduce the cooling air flow while keeping the hot gas temperature unchanged (increased efficiency Reduce the substrate temperature while keeping the cooling airflow unchanged (increased lifetime of component). Reduce the transient stresses (increased lifetime of component).

D. Effect of Alloying Elements:

The selection of the appropriate coating composition depends on the environment of the coatings and the substrate they are applied on. The complexity of interactions between environment, coating and substrate makes the design and selection of coatings very difficult, and in general, compromises must be done between the requirements of mechanical strength, corrosion/oxidation resistance and adhesion. Over the years, experience and modelling of the behaviour of coating systems along with improved deposition techniques, has led to multi-component coatings of advanced chemistry. The main alloying elements in metallic coatings are briefly described below

- Nickel: Base element for overlay coatings on Ni base substrates to minimise the inter diffusion depresses chemical activity of Al.
- Cobalt: Base element for overlay coatings on Co base substrates to minimise the inter diffusion raise chemical activity of Al.
- Aluminium: Alumina forming element in coatings and Ni and Co base alloys protects against oxidation up to 1200oC

- Chromium: Chromia forming element; used in Ni and Co base coatings against hot corrosion and Oxidation up to 900oC; reduces the critical level of Al neede to form protective Al2O3.
- Silicon: Silica forming element; effective against low temperature hot

In another case the Properties Of NIMONIC 80A places good results It is a wrought, age-hard enable nickel chromium alloy. Alloy has a good corrosion and oxidation resistance. High tensile and creep rapture properties at temperature of 815°C.It is used in higher temperature applications around 7500C. It is easily available. And some manufacturing cpst reduces and. It can withstand corrosion & erosion in high temperature applications.

E. Physical Properties Of NIMONIC 80A:

Some physical properties for super alloy are given in Table 3.2. The density was determined on extruded bar, subsequently forged, and extruded section, subsequently cold rolled, given a heat treatment of 8 hours/1080°C (1976°F)/air cool + 16 hours/700°C(1292°F)/air cool.

Table 3.1: Properties of NIMONIC 80A

Density	8.19 g/cm^3
Melting range	1320-1365 °C
Mass Susceptibility (magnetic property)	5.85 x 10-6 at 1000 gauss
Volume Susceptibility (magnetic property)	4.78 x 10-5 at 1000 gauss

F. Selection of coating powder

Tungsten Carbide, Nickel, Chromium and Cobalt Powders , Wear Resistant Thermal Spray Coatings of tungsten carbide are used for their hardness and wear resistance. When choosing a Tungsten Carbide Powder, t particle size and type of carbide selected are important in determining the correct material to combat various forms of erosion, abrasion and wear. Whereas the amount of metal matrix in the coating (nickel, cobalt, or alloy) will depend on the toughness and abrasion resistance required. Chromia forming element; used in Ni and Cr base coatings against hot corrosion and Oxidation up to 900^{o}C. Ni base substrates to minimise the inter diffusion depresses chemical activity of Al. Co improves adherence of alumina and chromia scales on Ni and Cr base alloys definitely.

G. High Velocity Oxy-fuel (HVOF) spray coating ad it's processing

A new method of spraying coatings, called high velocity oxygen-fuel (HVOF), has been developed. It is in developmental use for high temperature coatings. The HVOF coating also has much less oxidation of the particles than air plasma spray. Thus, HVOF coatings can be produced that are far superior to air plasma sprayed coatings, despite the HVOF process being done in an air environment. HVOF is being considered as an alternative to LPPS because of its lower cost. While LPPS coatings are still of higher quality than HVOF coatings, the quality of HVOF coatings may be sufficient for many applications

I. Process of HVOF Spray Coating:

In this process, the powder is both heated and propelled by a high velocity flame onto the substrate. The high velocity allows denser coatings to be made than can be achieved by conventional plasma spray processes. Plasma spray produces a hotter flame than HVOF, but has a lower particle velocity. The higher particle velocity of HVOF produces a denser coating. And the advantages of HVOF, which reduces oxide content, compressive stress, smooth spray and smooth coating uniformity.

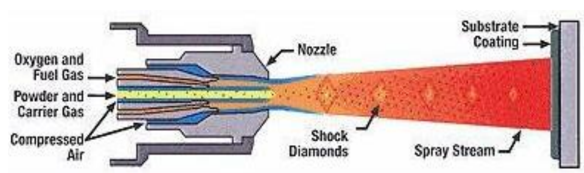

Figure-3.1: HVOF spray coating process

J. Base metal-NIMONIC 80a

NIMONIC alloy 80A is a wrought, age-hard enable nickel-chromium alloy, strengthened by additions of titanium, aluminium and carbon, developed for service at temperatures up to 815°C (1500°F). It is produced by high-frequency melting and casting in air for forms to be extruded. Electro slag refined material is used for forms to be forged. Vacuum refined versions are also available. NIMONIC alloy 80A is currently used for gas turbine components (blades, rings and discs), bolts, nuclear boiler tube supports, die casting inserts and cores, and for automobile exhaust valves. The chemical compositions are given in Table.3.2

Table 3.2: Chemical composition of NIMONIC 80A

Alloy	Ni	Cr	Ti	Al	C	Si	Cu	Fe	Mn	Co	B	Zr	S
Wt.%	54	21	2.7	1.8	0.1	1	0.2	3	1	2	0.008	0.15	0.015

Figure-3.2: Nimonic 80 A

IV. OBJECTIVES AND METHODOLOGY

The aim of this work has been to use test methods to determine the high temperature mechanical behaviour of some gas turbine coatings. The specific Objectives are set

- To study corrosion test on NIMONIC 80A alloy.
- To study microstructure test on NIMONIC 80A alloy.

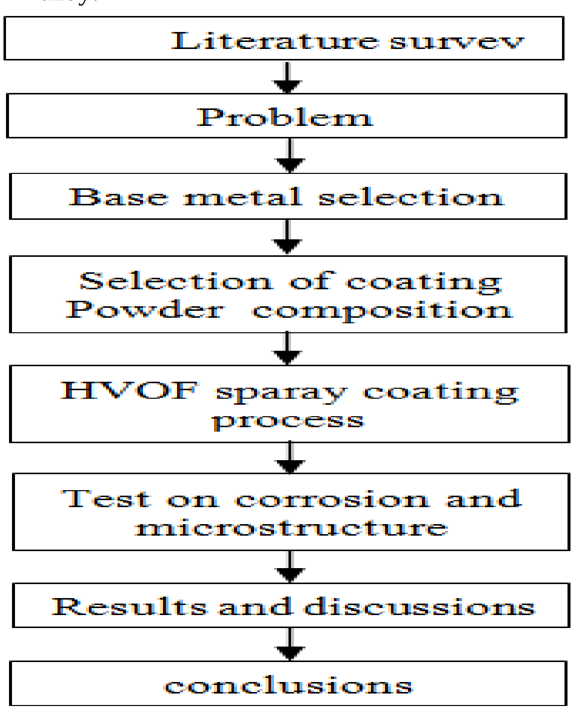

Fig.4.1: Methodology

Test specimen	Lenth(mm)	Breadth (mm)	Thickness (mm)
Corrosion	25	25	04
OEM	10	10	04

Fig.4.1: Methodology

A. *Sample preparation :*

A number of samples will be prepared from NIMONIC 80A alloy & it is coated by HVOF spray process by taking the mixture of powders that is tungsten carbide 70%, nickel 18%, chromium 10% & Cobalt 2%. The samples prepared for corrosion (hot corrosion)test, SEM analysis and XRD.

B. Surface Preparation:

Surface preparation is the essential first stage treatment of a substrate before the application of any coating. The performance of a coating is significantly influenced by its ability to adhere properly to the substrate material. It is generally well established that correct surface preparation is the most important factor affecting the total success of surface treatment. The presence of even small amounts of surface contaminants, oil, grease, oxides etc. can physically impair and reduce coating adhesion to the substrate. Chemical contaminants that are not readily visible, such as chlorides and sulphates, attract moisture through coating systems resulting in premature failure. The adhesion of coating materials such as zinc by hot dip galvanizing is particularly good due to the metallurgical alloying with the NIMONIC surface. In this process, the molten zinc reacts with the NIMONIC to form a series of nimonic/zinc alloy layers of varying composition to form an intimate bond with the substrate Residues of oil, grease, marking inks, cutting oils etc. after fabrication operations will seriously affect the adhesion of applied coatings and must be removed. It is erroneous to think that subsequent cleaning operations will remove such contaminants and it is bad practice to permit them to remain on the surface. Failure to remove these contaminants before blast cleaning results in them being distributed over the steel surface and contaminating the abrasive. Suitable organic solvents, emulsion degreasing agents or equivalents should be applied to remove contaminants in preparation for subsequent decaling treatments. And specimen dimensions are selected as fallows Table.5

V. EXPERIMENTAL TESTS

A. Corrosion Test:

In this process first the material is salt coated & heated in a oven around 2000 C for about one hour & the material is placed in a tube furnace around 7500 C for 3 hours, weight loss in the material is noted by allowing it to cool at room temperature around 1 hour and the process is continued up to 3 cycles.

Figure 5.1: Corrosion equipment

B. Optical Electro-Microscopy (OEM) Test:

The optical microscope, often referred to as light microscope, is a type of microscope which uses visible light and a system of lenses to magnify images of small samples. Basic optical microscopes can be very simple, although there are many complex designs which aim to improve resolution and sample contrast. In addition, the interaction of the electron beam with the specimen causes the sample to emit highly localized signals, such as x-ray photons, which can be monitored with specialized detectors. The energy or wavelengths of these x-rays indicate the elemental composition at the focal point of the beam.

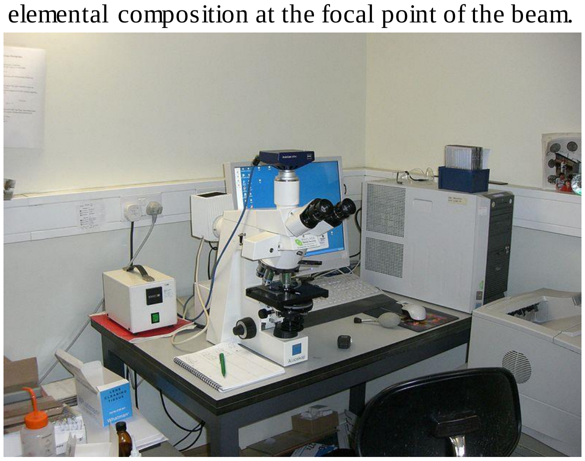

Figure- 5.2: OEM equipment

The OEM can be especially useful for wear particle studies due to its specificity – that is, its ability to characterize a particle population while retaining the distinct characteristics of each particle analyzed. In this way, the size, shape, morphology, and elemental constituents of each particle can be reviewed and can be used for making decisions based on the data generated. When evaluating the trade-offs of using OEM versus conventional wear particle analysis, this specificity must be weighed against the speed and cost of the latter techniques.

C. Corrosion Test of Specimen:

Corrosion test specimens are prepared according to ASTM G111-97 standards having length 60mm, width 30mm & thickness is about 5mm. Corrosion test specimen and its geometry is as shown in figure below

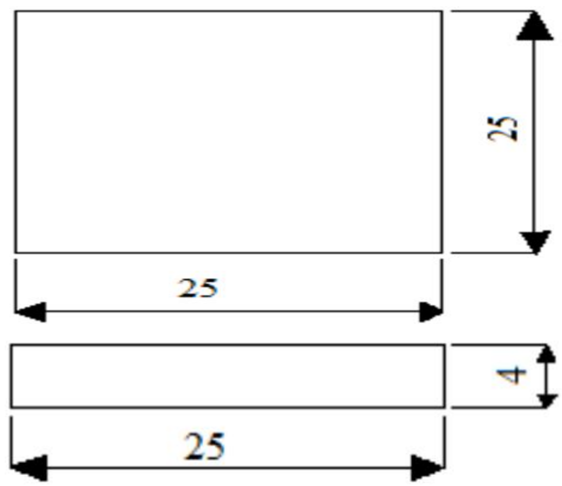

Figure 5.3: corrosion speciman Detail drawing

Figure 5.4: corrosion speciman

D. Microstructure (Test OEM Test Specimen)

Wear test specimens are prepared according to ASTM E883-11standards having length 5mm, width

5mm & thickness 5mm. Wear test specimen and its geometry is as shown in the figure

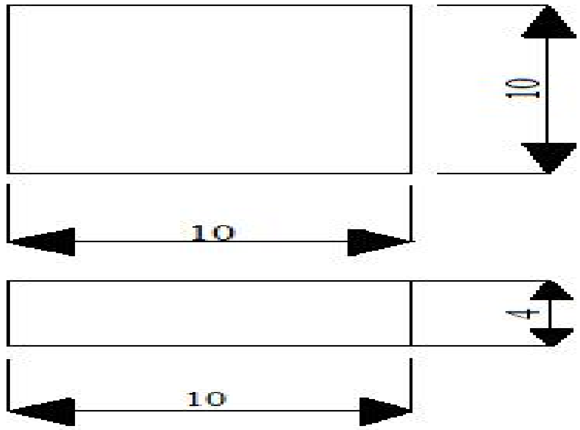

Figure-5.5: Detail drawing of OEM Specimen

Figure-5.6: Without coated specimen before test

\Figure- 5.7: with coated specimen after 120hrs

E. OEM test:

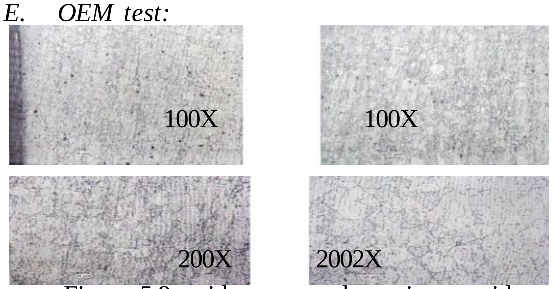

Figure-5.8: without coated specimans with magnifications

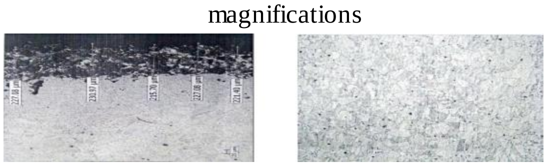

Figure-5.9: coated specimans with magnifications

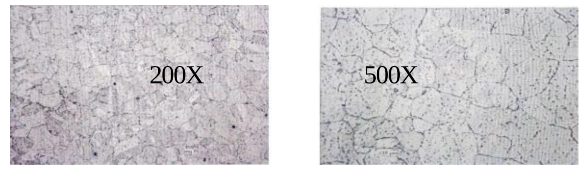

Figure-5.10 surface of the specimen 224μm

VI. CONCLUSION

- The conclusions drawn from present investigation as follows;
- Nickel based metal alloy (NIMONIC 80A) have been successfully coated by HVOF spray coating process to an average thickness of 224μm.
- It is found that no red rust have been observed under corrosion test conducted for 120 hours.
- Under OEM test, microstructure consists of fine precipitates of carbides particles dispersed in the matrix of Nickel rich solid solution.

VII. SCOPE FOR FUTURE WORK

- Similar metal alloy can be coated using other coating techniques like plasma spray coating etc. and results can be compared with HVOF spray coating.
- Properties of the metal alloy can be improved by altering the chemical composition of coating powders.
- For better corrosion resistance the thickness of the coat can be increased.

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