

# Erosion Wear Study on HVOF Sprayed NiCrSiB/CeO<sub>2</sub> Composite Coating

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**ABSTRACT:** High Velocity Oxy-Fuel (HVOF) thermal spraying technique is widely used in many industries to protect the components against erosion, corrosion and wear. It produces coatings with low porosity, low oxide content, better density, better coating cohesive strength and bond strength than many thermal spray processes. Ni based alloy coating is widely used for enhancing the wear and corrosion resistance at higher temperatures. Even though NiCrSiB having excellent wear and corrosion resistant properties, it is not used as the primary material in the industry because of lower hardness in comparison to other materials (carbides and ceramics). But it was incessantly proved that Ni based alloy coating reinforced with additives giving good results in the field of erosion-corrosion resistance. Various hard phases used as reinforcing additives along with NiCrSiB are WC, Al<sub>2</sub>O<sub>3</sub>, Cr<sub>3</sub>C<sub>2</sub>, Cr<sub>2</sub>O<sub>3</sub>, TiC, TiO<sub>2</sub>, SiC, TiN etc. In that respect, the addition of Al<sub>2</sub>O<sub>3</sub> has gained attention due to its higher hardness, wear and oxidation resistance and low cost.

In this work, the effect of addition of CeO<sub>2</sub> particle on the microstructure, micro hardness, fracture toughness and density of NiCrSiB coating on AISI 304 substrate. The CeO<sub>2</sub> added feed stock powder was prepared by mechanical alloying and the coating was developed using HVOF technique. The microstructure of the coating was characterized with the help of Scanning Electron Microscope (SEM) equipped with Energy Dispersive Spectroscopy (EDS), Optical Microscope (OM) and X-ray Diffraction (XRD). The microhardness and toughness of the coatings were measured using Vickers's microhardness tester. The density of the coatings was determined using Archimedes's principle.

**KEYWORDS:** High Velocity Oxy-Fuel (HVOF) thermal spraying, Optical Microscope (OM) and X-ray Diffraction (XRD), Optical Microscope (OM), Scanning Electron Microscope (SEM).

## I. INTRODUCTION

In order to be competitive in the market, it is important to be able to produce surfaces that wear only a little, are more resistant to tarnishing and corrosion, and retain their electrical, optical, or thermal properties over a long period. It is also interesting to have technologies to simplify product ranges or maintenance requirements. Surface treatments and coatings have a prominent role to play in this respect.

Currently emerging technologies contains some of the most prominent ongoing developments, advances and innovations in various engineering field to improve surface property by using different type of modern technology. Critical industrial components are subjected to increasingly harsh environments during routine operation and are therefore, prone to more rapid degradation as the parts fail to withstand the rigors of aggressive operating conditions and taking a heavy toll of industry's economy.

In large number of cases i.e., by hostile environments and also by high relative motion between mating surfaces, corrosive media, extreme temperature and cyclic stresses, the accelerated deterioration of parts and their eventual failure has been traced to material damage. So it became necessary to develop research on new techniques and new materials for fabrication. Surface engineering is a multi-disciplinary activity intended to tailor the properties of the surfaces of the engineering components to improve their function and serviceability. It is a treatment of the surface and near surface regions to provide enhanced performance such as wear resistance, corrosion resistance, fatigue resistance and bio compatibility.

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Serviceable engineering components not only rely on their bulk material properties but also on the design and characteristics of their surface. This is especially true in wear, corrosion and fouling resistant components, as their surface must perform many engineering functions in a variety of complex environments. The behavior of a material is therefore greatly dependent on the surface of a material, surface contact area and the environment under which the material must operate. The surface of a metallic material is made up of a matrix of individual grains, which vary in size and bond strength depending on the means by which the material was manufactured and on the elements used to form those grains. Surface engineering means modification of near-surface structure, chemistry or property of a substrate in order to achieve superior performance and/or durability. It is an enabling technology and can impact a wide range of industrial sectors.

Combining chemistry, physics, and mechanical engineering with metallurgy and materials science, it contributes to virtually all engineering disciplines. It can be done on a given surface by metallurgical, mechanical, physical, and chemical means, or by producing a thick layer or a thin coating. Both metallic and non-metallic surfaces can be engineered to provide improved property or performance. Wear, friction, corrosion, fatigue, reflectivity, emissivity, color, thermal/electrical conductivity, bio-compatibility, etc. are the properties which rely on the surfaces. Extend product life (durability), Improve resistance to wear oxidation and corrosion (performance), Satisfy the consumer's need for better and lower cost components, Reduce maintenance (reliability and cost), Reduce emissions and environmental waste, Improve the appearance; visually attractively Improve electrical conductivity Improve solder ability Metalize plastic component surfaces are the benefits of surface engineering or coating.

Treatment of surface is an established provider of advanced materials processing and coating technologies for a wide range of application in the automotive, aerospace, oil & gas, semiconductor, missile, power, textile, petroleum, petrochemical, chemical, steel electronic, biomedical, cement, machine tools, and construction industries. The development of a suitable high performance coating on a components fabricated using an appropriate higher mechanical strength metal/alloy, offers a promising method of meeting both the bulk and surface property requirements of virtually all imagined application.

Generally speaking, coatings can be regarded as materials with greater resistance to the significant surface degradation process. 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. An advantage of coatings is that they are relatively cheap and they can be applied in situ. There are many coating deposition techniques available, and choosing the best process depends on the functional requirements, adaptability of the coating material to the technique 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 are weld overlay, diffusion coatings, thermal spraying and laser cladding. The most important drawbacks of diffusion coatings are that they are thin and cannot be produced on-site or repaired. In comparison with diffusion coatings, thermal sprayed coatings do not require such a high temperature of the base metal that would impair the mechanical or microstructural properties. In the case of weld overlay, there is increasing concern that repeated weld overlay application to the same tube area may result in embrittlement of the old overlay and lead to cracks that could propagate into the overlaid tube. Because of aforementioned shortcomings in diffusion and weld overlay coatings, attention is increasingly being focused on thermal sprayed coatings.

## II. OBJECTIVE OF THESIS

- Carry out HVOF thermal spray coating using NiCrSiB/CeO<sub>2</sub> composite powder
- Characterization of the coating to assess the quality of the same
- Optimization of process variables
- To assess the capabilities of coating in combating erosion wear.

## III. SCOPE OF THESIS

Scope of this work relies completely on high temperature applications in power plants. Boiler tubes and heat exchangers are the major victims of erosion problem resulting in material degradation. One quarter of all the boiler tube failures are caused by fly ash erosion. Till now WC fills the gap of powder material for spraying due to its excellent

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quality in high temperature tribological application. Same time material cost of WC is large and coating becomes expensive. This work tries to explore the use of alumina strengthened NiCrSiB because of its higher hardness at low cost.

## IV. HIGH VELOCITY OXYGEN FUEL SPRAYING (HVOF)

During the 1980s, a class of thermal spray processes called high velocity oxy-fuel spraying was developed. A mixture of gaseous or liquid fuel and oxygen is fed into a combustion chamber, where they are ignited and combusted continuously. The resultant hot gas at a pressure close to 1 MPa emanates through a converging diverging nozzle and travels through a straight section. The fuels can be gases (hydrogen, methane, propane, propylene, acetylene, natural gas, etc.) or liquids (kerosene, etc.). The jet velocity at the exit of the barrel (>1000 m/s)

Type	Temperature C	Velocity m/s	Features
Combustion	3000	40 - 100	Porosity and oxidation
High Velocity Oxy-Fuel	3000	400 - 800	Dense, good adhesion, compressive stress
Two wire arc	3000 – 6000	50 - 150	Dense, thick
Plasma	5000 - 25,000	80 - 300	Ceramics porous
Cold spray	Ambient	400 - 800	Dense, compressive stresses

**Table 1: Characteristics of some thermal spray processes.**

exceeds the speed of sound. A powder feed stock is injected into the gas stream, which accelerates the powder up to 800 m/s. The stream of hot gas and powder is directed towards the surface to be coated. The powder partially melts in the stream, and deposits upon the substrate. The resulting coating has low porosity and high bond strength.



**FIG 1: SCANNING ELECTRON**

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### MICROSCOPE

HVOF coatings may be as thick as 12 mm (1/2"). It is typically used to deposit wear and corrosion resistant coatings on materials, such as ceramic and metallic layers. Common powders include WC-Co, chromium carbide, MCrAlY, and alumina. The process has been most successful for depositing cermet materials (WC-Co, etc.) and other corrosion-resistant alloys (stainless steels, nickel-based alloys, aluminium, hydroxyapatite for medical implants, etc.

### V. SCANNING ELECTRON MICROSCOPE

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. The electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image. SEM can achieve resolution better than 1 nanometer. Specimens can be observed in high vacuum, in low vacuum, in wet conditions (in environmental SEM), and at a wide range of cryogenic or elevated temperatures.

The most common SEM mode is detection of secondary electrons emitted by atoms excited by the electron beam. The number of secondary electrons depends on the angle at which beam meets surface of specimen. i.e. on specimen topography. By scanning the sample and collecting the secondary electrons with a special detector, an image displaying the topography of the surface is created

### VI. OPTICAL MICROSCOPE

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. The image from an optical microscope can be captured by normal light-sensitive cameras to generate a micrograph. Originally images were captured by photographic film but modern developments in CMOS and charge-coupled device (CCD) cameras allow the capture of digital images. Purely digital microscopes are now available which use a CCD camera to examine a sample, showing the resulting image directly on a computer screen without the need for eyepieces.

### VII. ENERGY DISPERSIVE SPECTROSCOPY

**Energy Dispersive X-Ray Microanalysis (EDXMA)**, Is An Analytical Technique Used for the elemental Analysis Or Chemical Characterization Of A Sample. It Relies On An Interaction Of Some Source Of X-Ray Excitation And A Sample. Its Characterization Capabilities Are Due In Large Part To The Fundamental Principle That Each Element Has A Unique Atomic Structure Allowing Unique Set Of Peaks On Its X-Ray Emission Spectrum. to Stimulate The Emission Of Characteristic X-Rays From A Specimen, A High-Energy Beam Of Charged Particles Such As Electrons Or Protons (See PIXE), Or A Beam Of X-Rays, Is Focused Into The Sample Being Studied. At Rest, An Atom Within The Sample Contains Ground State (Or Unexcited) Electrons In Discrete Energy Levels Or electron Shells Bound To The Nucleus.

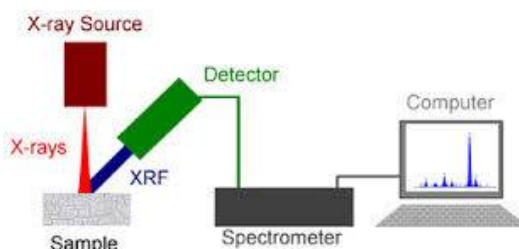


Fig 2: Energy Dispersive Spectroscopy

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## 8. METHODOLOGY AND EXPERIMENTAL PROCEDURE

### Methodology

Before preparation of coating, some basic process required for substrate material. i.e. size measurement of coating powder, grit blasting and cleaning substrate. After HVOF spraying, the coated materials have been subjected to series of characterization test i.e. micro-structural characterization of the surfaces, X-ray diffraction studies, surface roughness test, porosity measurement, micro-hardness measurement and erosion wear test. Each process is briefly described here.

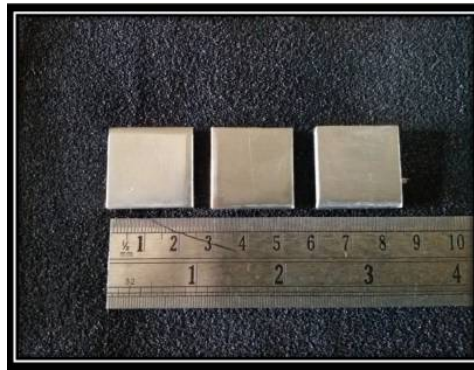


Fig 3: AISI 304 Stainless steel substrate material

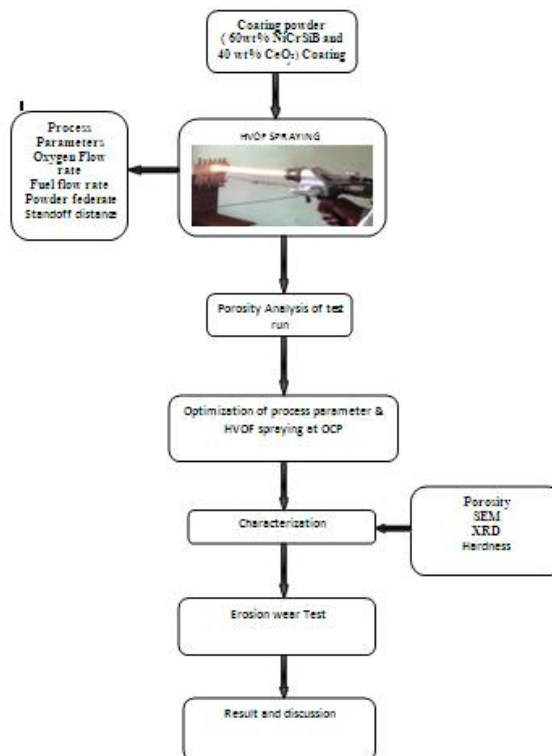


Fig 4: Methodology of thesis

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## IX. RESULTS AND DISCUSSION

The HVOF thermal spray technique was used to develop 60%Ni-Cr/ 40% CeO<sub>2</sub> coating on SS 304 substrate. Characterizations of the coating were done and erosion wear test performance of the coating was investigated. The result of various tests are presented and discussed in this chapter.

### Particle size analysis

The particle size distribution of Ni-Cr/CeO<sub>2</sub> powder just before spraying was characterized by using Laser particle size analyzer of make Malvern Instruments. The particle size distribution of the powder is shown in fig. 4.1. The particles are found to be in the range of 10 to 100 μm. Mean volume fractions of the particle are in the range of 53.659 μm.

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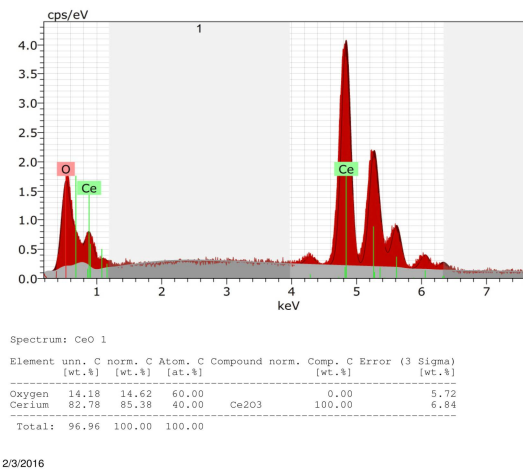


Fig 5: Particle size analysis of Ni-Cr/ CeO<sub>2</sub> coating powder

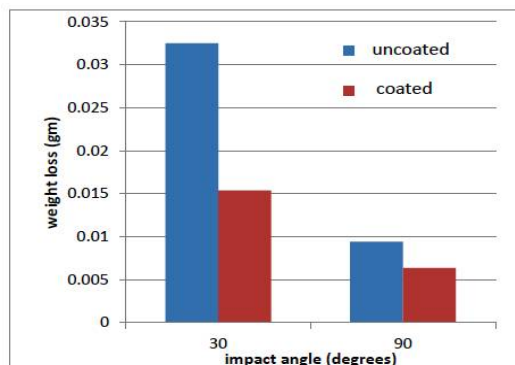


Fig 6: Erosion rate of coated and uncoated substrate at different impact angle

## X. CONCLUSION

The effect of HVOF spray parameter (oxygen flow rate, Fuel flow rate, powder feed rate and the standoff distance) on the porosity was investigated for 60 wt% NiCrSiB-40 wt% CeO<sub>2</sub> coating on AISI 304 material using L9 Taguchi experimental procedure. It was found that the HVOF spray parameters such as oxygen flow rate of 250lpm,



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fuel flow rate of 551pm, spray distance of 250mm and powder feed rate of 32gm/min, yielded minimum porosity in the coating. The important sequence of HVOF spray parameter on the porosity of the coating is standoff distance>oxygen flow rate>powder feed rate>fuel flow rate. The HVOF sprayed NiCrSiB/CeO<sub>2</sub> coating deposited under the optimized The morphology of the eroded surface points out craters and groove formation. The coated substrate exhibit lower erosion rate in comparison with uncoated substrate under similar testing conditions. Orthogonal array we are opted for this work was L<sub>9</sub>.

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