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# Effect of $La_2O_3$ addition on the microstructure, hardness and abrasive wear behavior of flame sprayed Ni based coatings

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ABSTRACT

This paper describes the effect of rare earth elements ($La_2O_3$) on the microstructure; hardness and abrasive wear behavior of Ni based flame sprayed coatings. The mechanical and tribological properties of the coatings can be significantly improved by refinement of grain structure of the coatings. A commercially available Ni based powder was modified with the addition of $La_2O_3$ (0.4–2 wt.%) to refine the grain structure of coatings. Unmodified and La-modified coatings were investigated in respect of microstructure, hardness and abrasive wear behavior. It has been observed that an optimal addition of $La_2O_3$ (1.2 wt.%) refines the grain size, improves hardness and abrasive wear resistance of the coatings. The XRD of the unmodified and La-modified coating with optimum addition of $La_2O_3$ (1.2 wt.%) was also carried out to identify the various phases present in the coating.



## 1. Introduction

The hard facing alloys are usually iron, nickel and cobalt based alloys. Nickel based alloy (NiCrBSi) coatings are used in applications (mill rolls, pumps, piston extruders and glass mould industry) where wear resistance combined with oxidation or hot corrosion resistance is required. Nickel being the major element provides ductility and enhances the corrosion resistance. Chromium provides high resistance to wear and corrosion. Boron enhances wear resistance and along with silicon reduces the melting point of the alloy and acts as a flux.

Abrasive wear behavior of a coating is determined by a number of factors describing the wear test parameters (load, abrasive size and environment) and the material parameters such as: (i) the size, shape and distribution of hard phase precipitates; (ii) the volume content of the hard phase; (iii) its properties and texture and (iv) hardness of the matrix and the hard phase [1]. Various researchers reported the increase in hardness of Fe and Ni based alloys by adding hard carbides such as WC, TiC and rare earth oxides such as cerium oxide ($CeO_2$) and lanthanum oxide ($La_2O_3$). The hard carbides such as WC and TiC increase the hardness only. The increase in hardness is achieved at the cost of toughness of the coatings. The rare earth elements make a compromise between hardness and toughness besides improving the corrosion and oxidation resistance of the coatings. Refinement in microstructure, increase in micro-hardness and decrease in friction coefficient and increase in wear and corrosion resistance by the addition of $CeO_2$ and $La_2O_3$ in Ni based laser clad coatings has been reported [2–12]. An optimum addition of $La_2O_3$ in the TiC/Ni composite laser clad coatings refines the microstructure and increase in micro-hardness and wear resistance [13]. Flame sprayed Fe–Ni coatings with rare earth elements have also been reported to increase micro-hardness and wear resistance [14]. In earlier work, refinement in microstructure, increase in micro-hardness and abrasive wear resistance of NiCrBSi flame sprayed coatings with the optimum addition of $CeO_2$ (0.8 wt.%) has been reported by the author [15]. Literature did not reveal any systematic study of $La_2O_3$ addition and the effect of $La_2O_3$ addition on the NiCrBSi flame sprayed coating on microstructure, hardness and abrasive wear resistance. In view of the above an attempt has been made in this investigation to study the effect of addition of $La_2O_3$ in the NiCrBSi flame sprayed coatings on microstructure, hardness and abrasive wear resistance.

## 2. Experimental procedure

### 2.1. Materials and methods

Carbon steel was used as a substrate. The substrate was degreased and ground to average surface roughness Ra 3.15 μm (Rmax 18.2 μm). Surface roughness was measured by Mahr–Perthometer ($M_2$ 409). The flame spraying was performed using neutral flame of oxy-acetylene gas using oxygen and acetylene pressures 0.3 MPa and 0.12 MPa, respectively. The substrate was preheated to $150 \pm 20\,^{\circ}C$.

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**Table 1**
Chemical composition (wt. %) of substrate and surfacing powder.

| | Fe | Ni | Cr | B | Si | Mn | C |
|---|---|---|---|---|---|---|---|
| Substrate | Bal. | – | – | 0.2–0.22 | 0.4–0.6 | 0.4–0.8 | 0.6–0.9 |
| Coating powder | – | Bal. | 1.2–1.6 | 0.4–0.8 | 3–3.5 | 0.3–0.5 | 0.4–0.8 |

**Table 2**
Chemical composition (wt. %) of various coatings developed.

| Composition | Coating designation |
|---|---|
| 1004EN + 0 wt.% $La_2O_3$ | 0% Unmodified |
| 1004EN + 0.4 wt.% $La_2O_3$ | 0.4% $La_2O_3$ |
| 1004EN + 0.8 wt.% $La_2O_3$ | 0.8% $La_2O_3$ |
| 1004EN + 1.2 wt.% $La_2O_3$ | 1.2% $La_2O_3$ |
| 1004EN + 1.6 wt.% $La_2O_3$ | 1.6% $La_2O_3$ |
| 1004EN + 2 wt.% $La_2O_3$ | 2% $La_2O_3$ |

Commercially available NiCrBSi (EWAC 1004EN) powder was used for development of coating by Super Jet spray torch (L & T, India). The nominal compositions of substrate and coating powder are shown in Table 1. The commercially available EWAC 1004EN (NiCrBSi) powder was modified with 0.4–2 wt.% of lanthanum oxide ($La_2O_3$). $La_2O_3$ was added in steps of 0.4 wt.% from 0 wt.% to 2 wt.%. In this way a total of 6 coatings were developed. The compositions and coating designation are shown in Table 2. The lanthanum oxide ($La_2O_3$) with 99.9% purity and an average particle size of 32 nm was used in the study (Loba Chemie Pvt. Ltd., Mumbai (India)).

### 2.2. Characterization of coating

Coated samples were cut transversely for microstructural characterization (SEM, SEM- LEO–435-VP, England), X-ray diffraction, porosity and hardness. The samples were polished using standard metallographic procedure and etched with a chemical mixture of 30 ml acetic acid +30 ml $HNO_3$ +10 ml glycerin. SEM micrographs are used to study microstructure and worn surfaces. The X-ray diffraction of the unmodified and La-modified coating with optimum addition of $La_2O_3$ was carried out using Cu Kα radiations. The XRD was carried out from 30° to 100° at a speed of 1.5° per minute The various phases were identified using the JCPDF software. The porosity was measured by the point counting method. In this method a grid (having grid points $N_G$) is used to find the fraction of specific micro-constituent (porosity). The number of porous points that lie on the grid point is taken as one ($N_1$) whereas the porous points lying on the grid boundary is taken as half ($N_2$). The ratio of total number of porous points ($N_P = N_1 + N_2$) and number of grid points ($N_G$) is the porosity percentage ($N_P \times 100/N_G$) [16–18]. The average of 25 readings of each coating has been used for this study. Vickers hardness of the coating was measured using a load of 49 N and average of six readings of the coating has been taken in this study. Vickers hardness number (VHN) was calculated using the following equation

$$\mathrm{VHN} = 189 \times 10^3 \times \left(\frac{F}{d2}\right)$$

where $F$ is the load applied in $N$ and $d$ is the average of two diagonal lengths of indentation in microns. Scanning electron microscopy of the worn surfaces of coatings was also carried out to study the abrasive wear mechanism.

### 2.3. Wear test

Abrasive wear behavior of unmodified and La-modified flame sprayed coatings was studied using pin on disc type abrasive wear tester. For abrasive wear tests coated wear pins (5 mm × 5 mm × 25 mm) were held against abrasive medium. Water proof SiC abrasive paper of 120 grit size (110 μm) was used as an

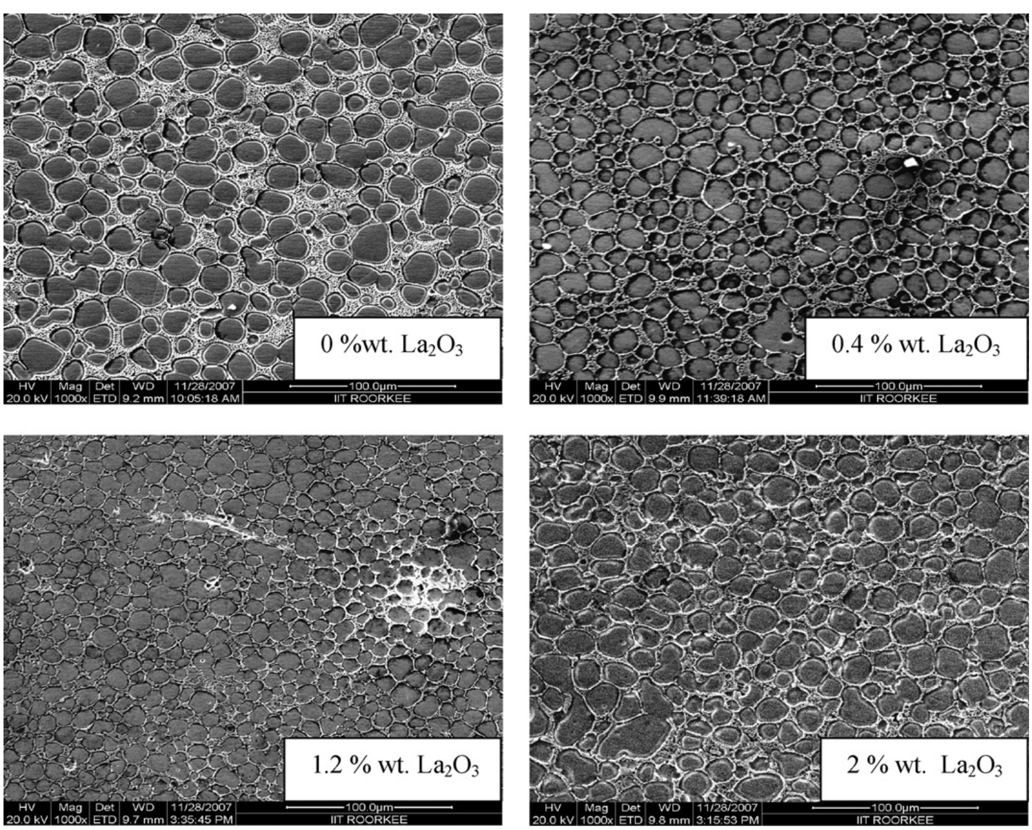


**Fig. 1.** Microstructure of unmodified and La-modified coatings.