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Mechanical and microstructural properties of HVOF sprayed WC–Co and Cr_3C_2–NiCr coatings on the boiler tube steels using LPG as the fuel gas

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Abstract

The characteristics and the phase composition of high velocity oxy fuel (HVOF) sprayed WC–Co and Cr_3C_2–NiCr coatings applied onto boiler tube steel substrates using liquid petroleum gas (LPG) as the fuel gas, have been evaluated. The coatings were examined using metallography, SEM/EDAX and XRD techniques. An attempt has been made to describe the transformations that take place during HVOF spraying. The purpose of this study was to compare the microstructure, porosity, surface roughness and microhardness of HVOF sprayed WC–Co, Cr_3C_2–NiCr coatings deposited on boiler steels. The paper will also investigate if there is an application of the deposit in energy generation plants with a view to enhance the life of the component and reduce tube failures in such power plants.

Keywords: Cr_3C_2–NiCr; LPG; Fuel gas

1. Introduction

It is not possible for a single material to have different properties to meet the demand of today's industry. Therefore, a composite system of a base material providing the necessary mechanical strength with a protective surface layer different in structure and/or chemical composition can be an optimum choice in combining material properties [1].

The high velocity oxy fuel (HVOF) process is reported to be versatile technology and has been adopted by many industries due to flexibility, cost effectiveness and the superior quality of coating produced [2]. This spraying process has been designed to retain the characteristics of the coatings. The hypersonic velocity of the flame shortens the time of interaction between the powder and flame, while the low temperature of flame limits the grain growth and decomposition of coating. Due to the high impact velocity of particles the coating shows a high adhesive strength, high cohesive strength of individual splats, high density and low porosity [3–6].

Carbides based coatings are widely used in abrasive, erosive and oxidizing environments. It has been reported that these coatings exhibit high hardness with a high volume fraction of carbide being preserved during the spraying providing different wear behaviors [7]. Nickel–chromium based alloys have been used as coating to prevent oxidation effects in environments raised at high temperature [8]. CrC/NiCr coatings have been claimed to posses' oxidation resistance upto 850 °C [9]. WC–Co coatings are widely used to produce wear protective coating for aeronautical application [10].

2. Experimental procedure

2.1. Substrate materials

Three types of boiler tube steels: low carbon steel ASTM-SA210 grade A1 (GrA1); 1Cr–0.5Mo steel ASTM-SA213-

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Table 1
Chemical composition (wt.%) for various boiler tube steels [11]

Type of steel	ASTM code	C	Mn	Si	S	P	Cr	Mo	Fe
GrA1	SA210-grade A1	0.27	0.93	0.1	0.058	0.048	–	–	Balance
T-11	SA213-T-11	0.15	0.3–0.6	0.5–1	0.03	0.03	1–1.5	0.44–0.65	Balance
T-22	SA213-T22	0.15	0.3–0.6	0.5	0.03	0.03	1.9–2.6	0.87–1.13	Balance

Table 2
Composition and particle size of coating powders

Coating powder	Composition (wt.%)	Particle size (μm)
Cr_3C_2–NiCr (supplied by MEC Jodhpur)	Cr_3C_2 (75), Ni (20), Cr (5)	−45 + 15
WC–Co (supplied by MEC Jodhpur)	WC (88), Co (12)	−45 + 15

T-11 (T11) and 2.25Cr–1Mo steel ASTM-SA213-T-22 (T22) have been used as substrate steels. The low carbon steel (GrA1) has been generally used to construct the water wall. The other two types of steel are employed in conditions influenced by temperature and pressure. The chemical composition of these steels is shown in Table 1. These steel samples were cut to form approximately 3 mm × 15 mm × 15 mm sized specimens. The specimens were polished and grit-blasted with Al_2O_3 (grit 45) before coating.

2.2. *Coating materials*

Two types of coating powder (WC–12% Co and Cr_3C_2–25% NiCr) were deposited by HVOF thermal spraying process. The chemical composition and particle size for these powders are shown in Table 2.

2.3. *HVOF spraying*

Around 350 μm thick coatings were deposited with the collaboration of the Metallizing Equipment Co. Jodhpur (India) on their commercial HVOF (HIPOJET-2100) apparatus operating with oxygen and liquid petroleum gas (LPG) as input gases. The substrate steels were cooled by compressed air jets during and after spraying. The spraying parameters are given in Table 3. Post deposition the specimens were sectioned, mounted and polished for metallurgical examination. SEM, EDAX and XRD techniques were then used to analyse the various parameters of the coatings. The microhardness of the cross-section of the deposits was evaluated using a microhardness tester (HMV-2 series, Mitsubishi). Surface roughness and porosity was also evaluated for all of the coated steels. The porosity measurements for as sprayed HVOF coatings have been made with image analyzer (Soft-Imaging System, Germany) at TIET, Patiala, India. Surface roughness of each coating has been evaluated with Surf corder (SE-2100, Kosaka Lab. Ltd., Japan).

Table 3
Spray parameters as employed during HVOF spraying

Oxygen flow rate (LPM)	250
Fuel (LPG) flow rate (LPM)	70
Air flow rate (L/cm^2)	6200
Spray distance (mm)	200
Powder feed rate (g/min)	30
Particle size (μm)	−45 + 15

LPM: liters per minute.

3. Result and discussion

Cr_3C_2–NiCr and WC–Co coatings have been formulated successfully by HVOF technique on boiler tube steels using LPG as fuel gas. The thicknesses of coating have been measured with a traveling microscope at 100× magnification. The coating thicknesses as reported in Table 4 were close to the desired coating thickness.

The porosity for as sprayed WC–Co and Cr_3C_2–NiCr coatings is in the range of 1.5–2.5% and 2.5–3.5%, respectively, and reported in Table 4. The porosity values of as sprayed WC–Co and Cr_3C_2–NiCr coatings are within the range of porosity values observed for HVOF using propane fuel coating by Wang and Lee [12], Wang and Shui [13], Wang and Lee [14] and Wang [15]. Low value of porosity may be due to the high impact velocity of the coating particles, which cause high density and high cohesive strength of individual splats as suggested by Scrivani et al. [3].

The critical hardness values of the substrate steels were found to be in the range of 200–280 Hv. The microhardness of the Cr_3C_2–NiCr coatings was measured to be around 850 Hv, where as WC–Co coatings have indicated little higher microhardness value in the range of 1000 Hv. The profiles for microhardness through thickness are presented in Figs. 1 and 2. The microhardness of as sprayed WC–Co coating is almost identical to the findings of Scrivani et al. [3], Mann and Arya [16], Lima et al. [17], Stewart et al. [4], Sudaprasert et al. [18], Karimi et al. [19] and Hawthorne et al. [20]. Hardness of Cr_3C_2–NiCr coating is consistent with

Table 4
Thickness, roughness and porosity of coatings

Type of coating	Coating thickness (μm)	Roughness (μm)	Porosity (%)
Cr_3C_2–NiCr	355	3.618 ± 0.36	2.5–3.5
WC–Co	380	3.385 ± 0.82	1.5–2.5