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Studies on the behaviour of stellite-6 as plasma sprayed and laser remelted coatings in molten salt environment at 900 °C under cyclic conditions

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Abstract

Stellite-6 (St-6) coating was obtained on boiler tube steels namely ASTM-SA210-Grade A1 (GrA1), 1Cr–0.5Mo steel ASTM-SA213-T-11 (T11) and 2.25Cr–1Mo steel ASTM-SA213-T-22 (T22) through plasma spray process. Ni–Cr–Al–Y was used as a bond coat before applying St-6 coating. Nd:YAG laser has been used for the post-coating treatment. As sprayed and laser remelted steels were subjected to molten salt environment (Na_2SO_4–60%V_2O_5) at 900 °C under cyclic conditions. The samples were visually examined and subjected to weight change measurements at the end of each cycle of study.

Techniques like XRD, SEM/EDAX and EPMA analysis have been used to analyse the oxide scale. The coating was found to be effective in decreasing corrosion rate of the boiler tube steels. Protection is higher when GrA1 steel was the substrate steel and lower for T22 base steel. Due to the formation of vertical cracks, laser remelted coatings have indicated slightly higher corrosion rate in the given molten salt environment.

Keywords: Coatings; Plasma spray; Stellite-6; Laser remelting; Hot corrosion

1. Introduction

Corrosion of metals costs the United States over $300 billion per year (4.2% GNP) according to recent estimates—more than the cost of annual floods and fires. An estimated 40% of total US steel production goes to the replacement of corroded parts and products. Although corrosion problems cannot be completely remedied, it is estimated that corrosion-related costs can be reduced by more than 30% with development and use of better corrosion control technologies [1].

Hot corrosion behaviour of superalloys have been evaluated by Tiwari and Prakash [2,3], and Tiwari [4] in pure Na_2SO_4, Na_2SO_4–15%V_2O_5 and Na_2SO_4–60%V_2O_5 in the temperature range of 700–900 °C. They observed accelerated corrosion rates for Na_2SO_4–60%V_2O_5 composition, i.e. eutectic with melting point of 500 °C.

Protective coatings are being used on structural alloys in energy conversion and utilization systems to protect their surface from oxidation and erosion [5–7]. Thermal sprayed coatings are economical, can be produced by means of relatively simple techniques and offer excellent corrosion and wear protection [8]. It is a versatile technology that has been successful as a reliable cost-effective solution for many industrial problems [9]. It is further reported to be the most flexible thermal spray process with respect to the sprayed materials [10].

Wide use of cermet (WC/Co) thermal spray coatings was reported by Chuanxian et al. [11] and Liao et al. [12] in wear situations because they combine several advantages such as resistance to abrasion, erosion, high temperature and corrosive atmospheres. Numerous works have been carried out for the development of the spraying conditions and the characterization of the specific abrasive and erosive wear resistances of the coatings [12,13].

The residual porosity in plasma spray coatings allows corrosive liquids to penetrate through them, which led to debonding or spallation of the coatings. Accumulation of corrosion products at the coating/substrate interface requires post-deposition treatments to improve these properties [8,14–17].

By laser remelting, essentially the microstructure of a surface layer is modified, although the distribution of elements in the melted zone may also change additionally. This technique

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Table 1
Composition and particle size of the coating powders

Coating powder	Composition (wt.%)	Particle size
Ni–22Cr–10Al–1Y (Praxair NI-343) (sprayed as a bond coat of around 150 μm)	Cr (22), Al (10), Y (1), Ni (balance)	−45 μm + 10 μm
Stellite-6 (Eu Troloy)	Cr (19), C (0.7), Si (2.3), Fe (3), Ni (13.5), B (1.7), W (7.5), Mn (1 maximum), Co (balance)	−180 μm + 53 μm

has also been applied successfully to plasma-sprayed coated surfaces to reduce coating porosity, long-range chemical inhomogeneities and coating/substrate adherence [18]. An inert gas shield, He/Ar, is usually used to prevent oxidation of the materials during the treatment [19].

The present investigation aims to evaluate the cyclic behaviour of stellite-6 plasma sprayed boiler tube steels in molten salt (Na_2SO_4–60%V_2O_5) environment. For some of the selected samples the hot corrosion behaviour has also been evaluated after laser remelting. The surface and cross-sectional corrosion products have been analysed with the help of X-ray diffractometer (XRD), SEM/EDAX and EPMA analysis techniques.

2. Experimental

2.1. Formulation of coatings

The boiler steels namely, low carbon steel ASTM-SA210-Grade A1 (GrA1), 1Cr–0.5Mo steel ASTM-SA213-T-11 (T11) and 2.25Cr–1Mo steel ASTM-SA213-T-22 (T22) were cut to formulate approximately 20 mm × 15 mm × 5 mm size specimens. Stellite-6 (St-6) alloy powder as per the chemical composition given in Table 1 was plasma sprayed on these substrate materials. A 40 kW Miller Thermal Plasma Spray System available with Anod Plasma Spray Ltd., Kanpur (India) has been used to apply the coatings. Ni–22Cr–10Al–1Y powder was sprayed as a bond coat of around 150 μm thickness before applying the final coatings of around 200 μm. Details regarding the various spray parameter and procedure to obtain the coating have been reported elsewhere [20].

2.2. Laser remelting

The laser remelting tracks have been obtained on the plasma sprayed steels for characterization using 300 W, Nd:YAG laser at Atomic Fuel Division (AFD), Bhabha Atomic Research Centre (BARC), Trombay, India. The process parameters are given in Table 2. Argon gas was used as shielding gas during laser remelting. More detailed information regarding characterization can also be found elsewhere [21]. To identify the hot corrosion behaviour of laser remelted coatings complete areas of coated steels were melted by making a series of parallel overlapping tracks for some of the selected samples.

Table 2
Process parameters for laser remelting of the coatings

Type	Pulsed Nd:YAG laser
Power (W)	300
Pulse energy (J)	6
Pulse width (ms)	12
Repetition rate (Hz)	10
Defocus (mm)	5
Traverse speed (mm/s)	2
Shielding gas	Ar
Tracks overlapping (%)	60

2.3. Hot corrosion studies

Cyclic hot corrosion studies up to 50 cycles for as sprayed and laser remelted samples were performed in molten salt (Na_2SO_4–60%V_2O_5) environment. Each cycle consisted of 1 h heating at 900 °C followed by 20 min cooling at room temperature. The coating of uniform thickness with 3–5 mg/cm^2 of Na_2SO_4–60%V_2O_5 was applied with camel hairbrush on the preheated samples (250 °C). The samples were subjected to weight change measurements after visual observation at the end of each cycle with help of Electronic Balance Model CB-120 (Contech, Mumbai, India) with a sensitivity of 1 mg. Spalled scale if any was also included at the time of measurements of the weight change needed to determine total rate of corrosion. The samples after hot corrosion runs were analysed by SEM/EDAX and XRD for surface analysis. Then the samples were cut and mounted to perform SEM/EDAX and EMPA across the cross-section.

3. Physical properties of coatings

The thickness of coatings and depth of laser remelting have been measured with help of SEM, BSEI micrograph after mounting the as coated and laser remelted samples. The thickness of bond coat as well as outer coat had been measured and given in Table 3. The porosity of coatings is also a prime importance in the hot corrosion studies. The dense coatings are supposed to provide very good corrosion resistance as compared to porous coatings. The porosity of as plasma sprayed and laser remelted coatings has been measured with image analyser having software of Dewinter Mateial Plus 1.01 based on ASTM B276. A considerable decrease in porosity had been observed after laser remelting and it was found to be less than 0.5%.

4. Surface morphology

Optical surface micrographs for as coated and laser remelted coating are presented in Fig. 1. As can be seen from the micrograph, Fig. 1(a) the microstructure for as sprayed coating has voids and unmelted particles. After laser remelting the microstructure has been found to be very fine, granular with some directionality.

5. Thermogravimetric data

Weight change (mg/cm^2) data is presented in Fig. 2 as a function of time expressed as number of cycles. GrA1 coated steel seems to be the most beneficial in decreasing the corrosion rate as its weight gain is only around 5% of that for the uncoated steel. The least resistance among the coated steels is provided by T22 type of steel but still its weight gain is only around 14% of that of uncoated T22 steel.

GrA1 and T22 St-6 coated steels exposed to molten salt after laser remelting showed lesser resistance to corroding species.