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Full Length Article

Surface properties tuning of welding electrode-deposited hardfacings by laser heat treatment

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ABSTRACT

In this paper, several Cr-Mn-rich hardfacings have been open-arc deposited on S275JR carbon quality structural steel and further submitted to laser treatment at different powers. An overall increase with 34–98% in the average microhardness and wear resistance of the coatings has been obtained, due to the formation of martensite, silicides, as well as simple and complex carbides on the surface of the hardfacings, in comparison with the reference, not submitted to laser thermal treatment. Surface laser treatment of electrode-deposited hardfacings improves their chemical resistance under corrosive saline environments, as determined by the 43% lower amount of leached iron and respectively, 28% lower amount of manganese ions leached in a 10% wt. NaCl aqueous solution, comparing with the reference hardfacings. Laser heat treatment also promotes better compatibility of the hardfacings with water-based paints and oil-based paints and primers, through the relative increasing in the polar component of the surface energy (with up to 65%) which aids both water and filler spreading on the metallic surface.

1. Introduction

Hardfacing is a commonly used process, designed to increase the wear resistance of the metallic base material or to recondition worn-down surfaces of components [1–3]. Among the usual processes, hardfacing by open arc welding is the simplest method employed to restore a component's surface properties (hardness, wear resistance) or dimensions, in various applications such as mining, petrochemical or food industry [4–6]. Other processes, such as thermal spraying (especially high velocity oxygen fuel coating) [7,8] or laser cladding [9] are more energy demanding, consume a higher amount of raw hardfacing powder material and usually generate coatings with an increased number of defects (cracks, pores, foreign inclusions) [10]. Alloys from the Stellite (Co-Cr) [11], Colmonoy (Ni-Cr-W-B) [12] families or Cr-Mn, Cr-Mo-Mn, Co-Cr-W-Ni [13] are commonly used as hardfacing electrodes, either by shielded or open arc welding alone, or combined with further thermochemical processes, such as nitriding or nitrocarburation [14]. Subsequent electrode melting followed by rapid solidification can generate a dendritically-shaped grain morphology. At compositional level, a majoritarian solid solution matrix, reinforced with carbides and/or borides could occur [15].

Usually, the hardfacing microstructure is refined through an additional heat treatment for stress-relieving or subsequent hard-phases formation (carbides, borides) purposes. Laser surface heat treatment has been frequently employed for carbon steel and alloyed steel components treatment, owing to its better directionality and time efficiency regarding reaching and maintaining of the desired temperature [16,17]. Tuning the hardness and wear resistance of the surface an improvement in fatigue strength and corrosion resistance of the hardfacings could be achieved [18–20]. Hardness improving due to laser heat treatment could be due to microstructural development of austenite in Fe-C-containing systems, which is in-situ quenched to martensite due to the high occurring temperature gradients [21], avoiding the use of any liquid or gaseous quench media. Subsequently, laser heat treatment can enhance the formation of carbides or borides in the microstructure of the materials, which positively contribute to the hardness and wear resistance increase.

This paper studies the influence of continuous wave Nd:YAG laser surface heat treatment parameters on the surface properties of two types of hardfacings of the Cr-Mn-Si and Cr-Mo-W-V-Si type, deposited on S275JR carbon quality structural steel by means of open arc-welding.

The novelty of this study consists in both applying a post-welding laser thermal treatment on the deposited metal to enhance its mechanical performance (wear resistance, hardness, corrosion resistance) as well as in using carbon steel as substrate, as, to the

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best of our knowledge, the majority of laser heat treatments are performed on stainless steels. Through this subsequent laser heat treatment, the hardness and corrosion resistance could be in-situ modified without modification in dimensions as for traditional processes. The advantage of our post-hardfacing laser heat treatment resides in its economic efficiency (low treatment duration, high Nd:YAG laser beam absorptance of S275JR [22]) coupled with its versatility in allowing a more precise heat control, generating a lower residual stress than using the traditional post-welding oven heat treatment processes. Supplementary, the possibility of tuning the surface properties and the stability of the hardfacing through laser heat treatment could constitute a viable alternative to the more expensive laser powder deposition techniques.

The paper aims to extend our previous studies regarding the laser treatment of several metallic materials [17], providing further insight on the influence of laser power on the surface properties of open-arc deposited hardfacings. In this regard, the compatibility of the coating with several paints and primers, the saline environment corrosion resistance as well as environmental issues (monitoring the leaching of metal ions from the cladding) are discussed, aspects that have not being extensively studied up to date in relation to arc-deposited hardfacings.

2. Materials and methods

2.1. Materials

Rectangular samples of S275JR carbon quality structural steel (Table 1) with the dimensions of 60 mm × 200 mm × 20 mm (length × width × thickness) have been used as substrate for hardfacing.

Two welding electrodes, namely ElCrMn2 and E 48T purchased from Ductil Buzau, Romania have been used for the hardfacings obtaining. The mean chemical composition of the electrodes, according to the manufacturer's specifications are depicted in Table 1.

2.2. Methods

2.2.1. Hardfacings obtaining

The hardfacing of S275JR carbon quality structural steel has been performed with an Luftarc 150 arc welding equipment at a voltage of 40 V and current intensity of 700 A. The welding speed has been set at 500 mm/min. The average thickness of all the obtained hardfacings was 3 mm (relative standard deviation of 1.2%). After the hardfacing deposition, the samples have been annealed at 600 °C for 1 h to eliminate potential residual stresses.

2.2.2. Supplementary laser heat treatment

Surface heat treatment was applied on the hardfacings, at different laser power outputs presented in Table 2 by means of an Nd:YAG Rofin DY 570 laser source (emission wavelength of 1064 nm), top-hat energy distribution shape, coupled with an ABB industrial robot. Laser power densities of 304 W/mm^2 for L-6 and N-6 hardfacings, respectively 343 W/mm^2 for L-7 and N-7 have been used. A 35% overlapping of laser tracks has been employed to uniformly treat the entire hardfacing coating surface. This percent has been chosen taking into consideration the minimization in surface roughness of the hardfacings (below Ra values of 2 μm, above which the errors in surface energy determination are significant), as determined from several prior experimental optimization trials.

Several hardfacings were not submitted to laser treatment and have been kept as reference materials (L-0 and N-0).

After the laser treatment of the coatings, the samples have been cross-sectioned and polished on different abrasive pads, up to P2500 microgrit.

2.2.3. Scanning electron microscopy (SEM), energy dispersive X-ray analysis (EDX) and optical microscopy

The cross-section of the laser treated samples and reference has been analyzed with the help of a Nova NanoSEM 650 scanning electron microscope coupled with an Orbis Micro EDX module to determine the morphological appearance and the distribution of the chemical elements of interest. The SEM micrographs were taken at 30 kV with the magnification specified on each micrograph, in secondary electron imaging mode. For the SEM analysis, the samples have been etched by immersion into 20 mL of 5% wt. HNO_3 solution in 96% wt. ethanol (nital reagent) for 5 s.

For the optical microscopy analysis (Omnimet-Buehler structural analysis system, with Nikon Eclipse MA 100 optical microscope), after nital etching of the sample, Beraha's PbS reagent (24 g $Na_2S_2O_3 \cdot 5H_2O$, 3 g citric acid, 2.4 g lead acetate per 100 mL of distilled water) has been used to etch the samples cross-section. This reagent colors carbides in black, solid solutions and martensite in yellow/brown, while intermetallic compounds are not attacked (they appear white) [24].

2.2.4. Atomic force microscopy (AFM)

The AFM measurements on the reference hardfacings (L-0, N-0) not submitted to laser surface treatment as well as on the laser-treated hardfacings (L-6, L-7; N-6, N-7) have been performed with an NTEGRA Spectra II (NT-MDT Instruments) atomic force microscope working in semi-contact mode. This measurement has been performed to determine the roughness profile of the hardfacings.

2.2.5. Microhardness and wear tests

Micro-Vickers hardness measurements were performed with a PMT-3 micro-hardness tester on the cross-section of the hardfacings and base material, at determined distances, measured from the top of the hardfacing, with a load of 0.1 Kgf holding for 15 s.

For convenience, the average value of the micro-Vickers hardness of the hardfacings has been depicted on their SEM micrographs (Fig. 1)

Wear tests have been performed on the surface of the hardfacings using a custom instrument [23], which has the advantage of adaptation to any drilling machine, thus eliminating the use of expensive wear test equipment.

The principle of the wear tests involves placing the sample on the instrument's stage, in contact with a revolving silicon carbide disk, at a constant and controllable loading. The sample has been weighed initially (m_0), and at determined time intervals of wear (15, 30, 60, 120 min) (m_t).

$$\Delta m = \frac{(m_0 - m_t) \cdot 100}{m_0} \quad (1)$$

The material loss by wearing has been correlated with the relative mass difference (Δm) kinetic.

2.2.6. X-ray diffraction spectroscopy measurements

The crystalline structure of the hardfacings has been determined with a Bruker Advanced D8 Discover diffractometer (2θ range from 20 to 80°, Cu-$K_{\alpha 1}$ = 1.5406 Å, 40 kW, 20 mA, scan speed 5°/min).

2.2.7. Surface energy determinations

Contact angle measurements have been obtained at 25 °C using distilled water and glycerol as reference liquids, with an OCA System 20 goniometer (Data Physics Co., Ltd.). Three drops of test liquid with 5 μL volume were placed in different regions of the unrectified surface of each hardfacing, and the average contact angle (θ^{meas})

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