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Laser treatment of dual matrix structured cast iron surface: Corrosion resistance of surface

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ABSTRACT

Laser gas assisted treatment of dual matrix structured cast iron surface is carried out and the corrosion response of the surface is examined. A carbon film containing 15% SiC particles and remaining 85% carbon are formed at the workpiece surface prior to the laser treatment process. The formation of carbon film enhances the absorption of the incident laser beam and accommodates uniformly the SiC particles at the workpiece surface. Nitrogen at high pressure is used as an assisting gas during the laser treatment process. Metallurgical and morphological changes in the laser treated layer are examined using a scanning electron microscope, energy dispersive spectroscopy, and X-ray diffraction. Electrochemical tests are carried out to measure the corrosion response of the laser treated and untreated workpiece surfaces. It is found that laser treatment results in a dense layer consisting of fine grains, partially dissolved SiC, and nitrogen compounds in the treated region, which improves corrosion resistance of the laser treated workpiece surface.

1. Introduction

Iron base composites are one of the important candidates for low cost composites with high wear and corrosion resistance [1]. The composite material with iron matrix and hard particle reinforcement has superior properties such as hardness, fracture toughness, and wear resistance. Depending on hard particle size, shape, and concentration, surface properties of the iron matrix composite changes [2] while limiting its practical applications. Iron based composites are generally formed from the mixture of iron powders and hard particles [3]. Although mechanical mixing provides uniform distribution of hard particles in the composites, pores are formed around the hard particles during the solidification cycle because of the large differences in thermal expansion coefficients and melting temperatures of the metal base and the hard particles. This, in turn, causes surface asperities and defect sites in the composite structure. In order to form the uniform structures and to minimize the defect sites, control melting at the surface becomes essential. A high power laser processing can be considered as one of the alternative controlled melting methods for hard particles reinforced composites. Laser processing of the substrate surface has several advantages over the other melting methods such as plasma arc, plasma torch, etc. This is because of the fact that laser controlled melting provides short processing time, precision of operation, and local treatment. On the other hand, laser control melting results in high temperature gradients and thermally induced stresses in the irradiated region despite its several advantages [4]. In addition, grain refinement, volume shrinkage, and thermal mismatch between the base matrix and the hard particles can further contribute to the stress levels in the laser treated layer. The surface asperities and high stress levels can modify the wear characteristics and corrosion resistance of laser treated composite. Consequently, investigation into laser controlled melting of SiC reinforced dual phase structured iron base substrate surface becomes essential.

Considerable research studies were carried out to examine laser treatment of iron based composites. The compositionally graded silicon carbide dispersed composite surface on mild steel developed by laser surface cladding was studied by Dutta et al. [5]. They showed that in the laser treated layer, SiC particles were partially dissociated and the degree of dissociation was higher at the bottom layer as compared to the top layer of the workpiece. A comparative study of corrosion behavior of Al/SiCp composite with cast iron was carried out by Saraswathi et al. [6]. They indicated that in NaOH solution, cast iron exhibited insignificant corrosion rates; however, the composite exhibited minimum corrosion rates in NaCl media and maximum rates in NaOH solution. Effects of silicon content on the microstructure and corrosion behavior of iron based hardfacing alloys were investigated by Azimi and Shamanian [7]. The potentiodynamic polarization studies in the 3.5 wt% NaCl solution showed that high corrosion resistance of the

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tungsten-inert gas coated substrate occurred. Microstructure of SiC particles reinforced iron-based alloy composite coating was examined by Song et al. [8]. They showed that the pre-coated SiC particles were not dissolved significantly and they retained original shape in martensitic matrix. The iron-based composite plating and surface characteristics were investigated by Fu et al. [9]. Their findings revealed that the microcracks in composite coatings were reduced and the hardness, wear resistance and corrosion resistance increased by adding SiC particles under the optimum processing condition. Microstructure of chromium cast irons and their resistances to wear and corrosion were studied by Tang et al. [10]. They indicated that the wear resistance of the substrate surface was affected by the volume fraction, types and size of carbides, while their corrosion resistance was dominated by the free chromium content in the matrix and the ratio of volume fraction of carbides to ferrous matrix as well. Corrosion resistance of metal matrix nanocomposites was investigated by He et al. [11]. They demonstrated that the corrosion resistance for the nanocomposite slightly decreased when the volume fraction increased due to both SiC nanoparticle agglomeration and promoting galvanic corrosion between SiC and Al. The wear behavior of white cast irons with different compositions was studied by Cetinkaya [12]. He indicated that the specimen containing 3.3% C, 15.1% Cr and 2.5% Mo exhibited the least wear, while the specimen containing 2.94% C, 16.7% Cr and 1.2% Mo exhibited the most wear for both types of abrasives used. Preparation and characterization of Fe/SiC ceramic–metal composite were studied by Liu et al. [13]. They showed that SiC and Cu were homogeneously mixed in the composite powders obtained by the heterogeneous deposition method, and that the composites with 5 wt% of SiC (Cu) obtained at 950 °C have high relative density, improved hardness and a high bending strength.

Although thermal stability of steel surfaces has been presented earlier [14–16] and the corrosion resistance of the cast iron surface has been investigated previously [17–19], electrochemical response of the dual phase structured cast iron with the presence of SiC particles at the surface was left for the future study. In the present study, morphological, metallurgical, and corrosion resistance of laser treated dual matrix structured cast iron with the presence of 15% SiC at the surface was investigated. Microstructural and morphological changes in the laser treated layer are examined incorporating the scanning electron microscope, energy dispersive spectroscopy, and X-ray diffraction. The potentiodynamic polarization experiments are performed to assess the corrosion response of the laser treated and untreated surfaces.

2. Experimental

The material used in the present study was dual matrix structured cast iron. The chemical composition of the material is shown in Table 1. To produce dual matrix structures (DMS) with different ausferrite volume fractions (AFVF), as cast specimens were intercritically austenitized at the dual phase region of 810 °C for 90 min and then rapidly transformed to a salt bath containing 50% KNO_3 + 50% $NaNO_3$ held at 315 °C and 375 °C for austempering for 120 min. The details of the heat treatment process are given in the previous study [20]. The circular workpieces with 25 mm × 3 mm (diameter × thickness) were prepared. The water soluble phenolic resin was mixed with 15% (wt) of SiC powders of about 250 nm particle size and homogeneous mixing was ensured prior to applying at the workpiece surface. A direct spraying technique was used to form a thin layer of coating from the mixture onto the workpiece surface. The coated workpieces were placed in a furnace with a controlled chamber at 8 bar pressure and 175 °C for two hours to form a 50 μm thick film at the surface. The workpieces were then heated to 370 °C in an argon environment for six hours to ensure the conversion of the phenolic resin into carbon. The pre-prepared sample surfaces were scanned by a laser beam according to the parameters shown in Table 2.

The CO_2 laser (LC-ALPHAIII) delivering a nominal output power of 2 kW was used to irradiate the workpiece surface. The nominal focal length of the focusing lens was 127 mm and the diameter of the laser beam focused at the workpiece surface was ~0.3 mm. Nitrogen gas was used as the assisting gas, which was applied co-axially with the laser beam using a conical nozzle. The laser treatment was repeated several times using different laser parameters and laser parameters resulting in controlled melting of the surface with a minimum of surface defects, such as very small cavities without cracks/crack networks, were selected. The laser treatment conditions are shown in Table 2.

Material characterization of the laser treated surfaces was conducted using an optical microscope, SEM, EDS, and XRD. A Jeol 6460 Scanning Electron Microscope was used for SEM examinations and a Bruker D8 Advanced X-ray Diffractometer using CuKα radiation was used for XRD analysis. Typical settings of the XRD were 40 kV and 30 mA with the scanning angle (2θ) ranging from 20° to 90°. Surface roughness measurement of the laser-melted surfaces was performed using an Agilent 5100 AFM in the contact mode. The tip was made of silicon nitride probes (r=20–60 nm) with a manufacturer specified force constant, k, of 0.12 N/m.

Corrosion tests were carried out in a three electrode cell, which composed of a specimen as a working electrode, a Pt wire as a counter electrode, and a saturated calomel reference electrode (SCE). The specimens were degreased in benzene, cleaned ultrasonically, and subsequently washed with distilled water prior to electrochemical tests. The investigations were carried out with an exposed working electrode area of 0.05 cm^2 in 0.5 M NaCl solution at room temperature in PCI4/750 Gamry potentiostat and repeated several times to ensure the reproducibility of the data. DC105 corrosion software was used to analyze the Tafel region, while Potentiodynamic polarization experiments were performed at a scan rate of 0.5 mV/s. Electrochemical impedance spectroscopy (EIS) measurements were carried out at open circuit potential (OCP), by applying a sinusoidal potential perturbation of 10 mV with frequency sweep from 100 kHz to 0.01 Hz. The impedance data were analyzed and fitted to appropriate equivalent electrical circuit using the GAMRY framework software.

3. Results and discussion

Laser controlled melting of dual matrix structured iron based alloy with the presence of 15% SiC particles at the surface was carried out. Morphological and metallurgical changes in the laser treated layer were examined using the analytical tools. The

Table 1
Elemental composition of as received and after the laser treatment of workpiece surface (wt%).

	Si	N	Fe
As received	2.7	0.0	Balance
Laser treated	16.4	6.2	Balance

Table 2
Laser processing parameters.

Scanning speed (m/s)	Laser power (W)	Frequency (Hz)	Nozzle gap (mm)	Nozzle diameter (mm)	N_2 pressure (kPa)
0.1	95	1500	1.5	1.5	600