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Laser gas assisted treatment of steel 309: Corrosion and scratch resistance of treated surface

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ABSTRACT

Laser gas assisted surface treatment of steel 309 is carried out and the characteristics of the resulting surface are analyzed using the analytical tools. Scanning electron and 3-D optical microscopes are used to assess the morphological and metallurgical changes in the laser treated layer. Energy spectroscopy and X-ray diffraction are carried out to determine the elemental composition and compounds formed on the laser treated surface. The friction coefficient of the laser treated surface is measured using the micro-tribometer and compared to that of the as received surface. The corrosion resistance of the laser treated and as received surfaces is measured incorporating the electrochemical tests. It is found that laser treatment results in a dense layer and formation of nitride compounds at the surface. This enhances the microhardness at the laser treated surface. The friction coefficient attains lower values at the laser treated surface than that corresponding to the as received surface. The corrosion rate of the surface reduces significantly after the laser treatment process, which can be attributed to the passive layer at the surface via formation of a dense layer and nitride compounds in the surface vicinity. In addition, the number of pit sites decreased for the laser treated surface than that of as received surface.

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1. Introduction

In a controlled gas ambient, combination of laser melting and ablation at the surface can results in surface texture consisting of micro/nano scale pores and dimples. The type of assisting gas used during laser texturing process gives rise to the formation of compounds, such as aluminum nitride [1] or titanium oxide [2] phases. These phases modify surface chemistry; in which, free energy of the laser textured surface can be reduced [3] while improving the hydrophobic characteristics of the resulting surface. Laser gas assisted texturing has two fold effects including increasing the total area of the free surface, because of the increased roughness of the surface, and modifying chemistry of the textured surface towards reducing the surface free energy. The combination of surface texture and modified surface chemistry results in superior characteristics of the surface in terms of the wetting state. On the other hand, to achieve such surface texture via laser processing, the combination of surface melting and ablation becomes necessary [4]. In this case, laser beam intensity distribution at the surface, which is in general Gaussian, plays an important role. Surface ablation at the irradiated spot center, due to high intensity beam, and melting towards the irradiated spot edge, because of low beam intensity, result in the combination of melting and evaporation across the irradiated spot. The melt flow from irradiated spot edge towards the cavity, which is formed at the irradiated pot center during the ablation, modifies the cavity depth and its profile while giving the birth of micro/nano scale poles and pillars at the surface [5]. In addition, high temperature assisting gas reactions with the molten metal at the irradiated spot causes the modification of the surface chemistry. However, laser processing involves with high temperature heating at the surface, which in turn results in high temperature gradients and thermal strain in the close region of the irradiated spot. In some situations, this causes high stress levels and thermally induced crack formations at the textured surface. Once the asperities such as cracks and crack networks are formed at the textured surface, the quality of the textured surface degrades and its practical applications become in question. Moreover, the change of the chemistry and increased total area of the textured surface influence the electrochemical resistance of the surface. Consequently, investigation of the laser surface texturing of stainless steel and surface characteristics towards improvement of surface corrosion and erosion resistance becomes essential.

Considerable research studies were carried out to examine laser heating of steel surfaces towards improvement of corrosion

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resistance. Laser assisted coating of 304 stainless steel surface towards enhancing corrosion and cavitation erosion resistance was studied by Zhang et al. [6]. They showed that with the use of appropriate laser processing parameters, FeCoCrAlNi coating with good metallurgical bonding to the substrate was achieved and the coating improved the corrosion and erosion resistance of the surface. Electrochemical and pitting corrosion resistance of AISI 4145 steel subjected to a laser shock peening was examined by Lu et al. [7]. They indicated that laser shock peening resulted in improvement of pitting corrosion resistance of AISI 4145 steel. The increased coverage layer also contributed to the improvement of the corrosion resistance of the surface. In addition, the laser shot peeing treatment with multiple layers influenced the pitting corrosion behavior in a standard corrosive solution. Investigation of coating deposition on austenitic steel was carried out by Gorunov and Gilmutdinov [8]. They demonstrated that insufficient laser power led to disruption of the deposition process stability and caused coating cracking. Laser assisted etching of austenitic stainless steel surface towards micro-structural evaluation was investigated by Baghra et al. [9]. They indicated that pulsed Nd-YAG laser etching was the fast and effortless technique which could be effectively employed for non-contact remote etching of austenitic stainless steels for micro-structural evaluation. Laser surface texturing of 316L stainless steel towards increasing hydrophobicity was examined by Razi et al. [10]. They demonstrated that remarkable differences took place in the surface oxygen content when laser texturing parameters were changed. The wettability of the textured surfaces depended on the laser processing parameters and properties of the texturing environments such as air or water. The microstructure, mechanical properties and corrosion resistance of 316 L stainless steel fabricated using laser engineered net shaping technique were studied by Ziętala et al. [11].The findings revealed that the microstructure of the SS316L fabricated via using the net shaping technique was heterogeneous and its impact on the mechanical properties was visible. However, the corrosion potential of laser treated surface and classically manufactured steel was found to be similar. Investigation of aging time due to intergranular and pitting corrosion behavior of Cu-bearing 304L stainless steel in comparison with 304L stainless steel was carried out by Jiang et al. [12]. They showed that the Cu-bearing 304L stainless steel possessed a higher intergranular corrosion tendency and a higher pitting corrosion rate for extended aging time. This behavior was associated with the precipitation of the Cu-rich phase in the Cu-bearing 304L stainless steel. A study on the impact of the nano-structuration on the corrosion resistance and hardness of laser irradiated 316 austenitic stainless steel was conducted by Hug et al. [13]. They indicated that potentiodynamic polarization tests highlighted a definitive deterioration of the corrosion resistance of coarse grain steel with laser irradiation; however, downsizing the grain to a few hundred of nanometers enhances the corrosion resistance of irradiated samples, despite the fact that the hardness of nanocrystalline austenitic steel was only weakly affected by irradiation. Effects of surface treatments on the corrosion and erosion-corrosion of 304 stainless steel in 3.5% NaCl solution was investigated by Zheng and Zheng [14]. They demonstrated that only citric acid treatment increased the critical flow velocity and erosion-corrosion resistance of 304 stainless steel surface under impingement. In addition, the passive film formed on the nitric acid treated stainless steel was easily destroyed by the sand particles. Erosion–corrosion resistance of various stainless steel grades in high-temperature sulfuric acid solution was examined by Lindgren et al. [15]. The findings revealed that the erosion–corrosion mass loss under higher erosion intensity was larger due to the selective dissolution of the austenite phase of all the tested duplex grades. The galvanic coupling between the phases was responsible for the selective dissolution. The influence of nitride compounds on microstructure and corrosion resistance of laser welded 2205 duplex stainless steel joint was investigated by Lai et al. [16]. They indicated that the microstructure of weld cross-section tended to be homogeneous and the corresponding austenite content was over 40% of the cross-section. The shielding gas of nitrogen contributed to the corrosion resistance enhancement of the weld section. Localized corrosion of laser treated martensitic stainless steel for biomedical applications was studied by Manhabosco et al. [17]. They showed that laser treatment greatly increased the active dissolution of the affected region and decreased the pitting potential due to chromium loss by volatilization and oxidation on the laser-melted zone. In addition, laser treatment increased the cathodic currents and the oxide layer formed resulted in a high susceptibility to active dissolution and pitting corrosion. Laser short-pulse modification of AISI 304L stainless steel surface and the influence the beam overlapping on the pitting corrosion resistance was examined by Pacquentin et al. [18]. The findings revealed that that the crystallographic structure, the chemical composition, the properties of the induced oxide layer, and consequently the pitting corrosion resistance were strongly depended on the overlapping rate. In addition the improvement of the corrosion resistance was correlated to chromium enrichment at the surface of the stainless steel and the induced absence of martensite and ferrite phases.

Although laser controlled melting and evaporation of the metallic substrates was studied earlier [3–5], the main focus was to examine the texture profile in relation to the surface hydrophobicity. The corrosion and erosion resistance of the surface was left for the future study. In the present study, laser gas assisted texturing of St 309 steel surface is carried out and the resulting surface characteristics including microhardness, friction coefficient, and corrosion and erosion resistance are examined using the analytical tools. It should be noted that St 309 widely used in industry and some the applications include oven linings, boiler baffles, fire box sheets, furnace components and other high temperature containers. The metallurgical and morphological changes in the laser treated layer are investigated. The friction coefficient of the laser treated and untreated surfaces were measured using micro-tribometer. The corrosion resistance was evaluated by potentiodynamic tests using Gamry potentiostat while erosion tests were conducted in a solid particle erosion tester.

2. Experimental

A CO_2 laser (LC-ALPHA III) delivering a nominal output power of 2 kW in pulse mode with different frequencies was used to irradiate the workpiece surface. The nominal focal length of the focusing lens was 127 mm. The laser beam diameter focused at the workpiece surface was 0.3 mm. Nitrogen assisting gas was fed through a conical nozzle co-axial with the laser beam. Several tests were carried out to identify the laser parameters, which resulted asperity free treated layer. Consequently, laser processing parameters resulting in crack free homogeneous treated layer were selected. The laser treatment parameters are given in Table 1.

Steel 309 samples of 15 mm × 10 mm × 3 mm (length × width × thickness) were used in the experiments. A JEOL JDX-3530 scanning electron microscope (SEM) was used to obtain micrographs of the cross-section of the workpieces after the tests. Energy dispersive spectroscopy (EDS) analysis was carried out at six different locations at the surface of the laser treated workpieces. The error related to the EDS analysis is estimated based on the repeatability of the data, which is on the order of 3%. A Bruker D8 Advance having Cu Kα radiation was used for X-ray diffraction (XRD) analysis. The XRD equipment settings were 40 kV and 30 mA.

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