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Laser cleaning of sulfide scale on compressor impeller blade

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ABSTRACT

Sulfide scale on the surface of a compressor impeller blade can considerably reduce the impeller performance and its service life. To prepare for subsequent remanufacturing, such as plasma spraying, it needs to be removed completely. In the corrosion process on an FV(520)B stainless steel, sulfide scale is divided into two layers because of different outward diffusion rates of Cr, Ni and Fe. In this paper, the cleaning threshold values of the upper and inner layers and the damage threshold value of the substrate were investigated using a pulsed fiber laser. To obtain experimental evidence, scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS) and 3D surface profilometry were employed to investigate the two kinds of sulfide layers on specimens before, during, and after laser cleaning.

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1. Introduction

In transporting of natural gas by using a compressor impeller, the surface of integral impeller blades is often covered by sulfide scale, which causes abrasive wear and corrosive pitting because of the impurities that exist in gas such as water vapor and hydrogen sulfide [1]. These sulfide layers increase friction and reduce product's service life [2]. Formation and the removal of sulfide corrosion were analyzed in previous studies [3–5]. Yagi investigated the mechanism of sulfide scale formation and found that the process is the outward diffusion of corrosion [6]. The thickness of sulfide scale is mainly influenced by time, temperature and pressure [7]. The most common method for removal of corrosion layers is using chemicals, such as nitric acid or other acids. However, these chemicals are hazardous and environmentally destructive and acid pickling also removes some materials from the substrate [8]. Sandblasting is another way to remove the sulfide scale. This process requires more time and energy than laser cleaning when large impeller is used, but only a small part needs to be cleaned.

Among multifarious surface preparations, laser cleaning is an environmentally friendly technique for direct removal of contaminants without altering or affecting bulk properties in numerous applications [9]. Common applications of laser cleaning in industries include surface preparation [10–13], coating [14] and cultural heritage restoration [15,16]. Researchers have demonstrated that laser decontamination helps convert microns to sub-micron sized surface particulates, artificial corrosion spots as well as thin contamination layer on the surface [9]. However, previous research focused on laser cleaning of oxide corrosion because the sulfide scale is not as common as oxide corrosion in industrial manufacturing [17].

The laser used in this work was a nanosecond pulsed fiber laser with a focusing lens, which is suitable for laser cleaning because of a wide range of high power density. This study aims to remove sulfide corrosion by using an effective and environmentally friendly technique without causing serious degradation of essential performance of the substrate. The surface before and after laser cleaning was investigated by scanning electron microscopy, energy dispersive spectroscopy and 3D surface profilometry.

2. Experimental

2.1. Sample preparation

FV(520)B, containing Cr ($\geq$13 wt.%), Ni ($\geq$5 wt.%) and Mn ($\sim$1 wt.%), is a kind of martensitic stainless steel with good corrosion resistance. This material is widely used in manufacturing long pipeline compressor impeller. In this study, sulfide scale was generated at the surface of FV(520)B specimens with the dimensions of 10 mm × 10 mm × 12 mm, which has a double-layer structure because of the different outward volume diffusions of Ni and Cr. The sulfide scale hindered the outward diffusion of Ni ions in the substrate, when Cr content exceeds a certain value in the corrosion layer. Meanwhile Ni ions in the sulfide scale outward diffuse

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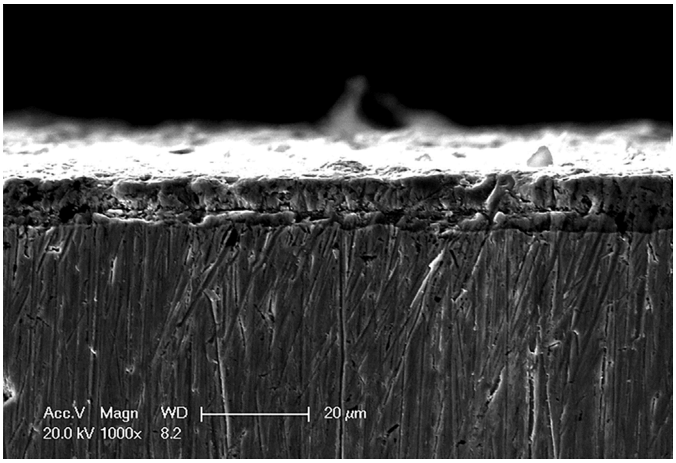

Fig. 1. Cross-sectional images of the specimen.

continuously. Cross-sectional image of the specimen, which has double-layer sulfide corrosion, was obtained using SEM (Fig. 1). In addition, the schematic of this study before and after laser cleaning is described in Fig. 2. The sulfide scale on the surface of specimen has a similar composition and structure to that induced under working condition on the compressor impeller blade.

2.2. Laser cleaning

A schematic diagram of the laser cleaning system is shown in Fig. 3. Laser beam movement on the surface of specimens was controlled by the directional control system along *X*-axis and *Y*-axis. High power density was guaranteed by the *F*–θ lens, which focuses the laser beam on a small spot. Specimens were irradiated with pulsed fiber laser (1064 nm). The following parameters were employed for the fiber laser: 20 W average power, 4.3×10^8 W/cm^2 power density, 82.5 J/cm^2 maximum fluence value, 60 kHz repetition rate, 200 ns pulse duration, 1000 mm/s scanning speed, 0.02 mm scanning step length and using a square beam spot of 0.02 mm side length. Repetition rate is greater than the scan rate, which ensures the complete coverage of laser cleaning. Meanwhile, that scanning rate is similar to the repetition rate ensures a small overlap rate (20%), which reduces the influence of energy accumulation. Fluence values were adjusted by varying the power density while preserving the repetition rate and pulse duration. The sulfide scale was cleaned several times based on thickness of sulfide scale. To identify the threshold fluence, different fluence values were chosen to determine the optimal condition for sulfide scale removal. A small quantity of residues on the surface is acceptable because it can be removed during post processing. The laser-irradiated area was 2 mm × 2 mm in the progressive scanning mode. No inert gas protection device was applied to the irradiated area when the laser was turned on.

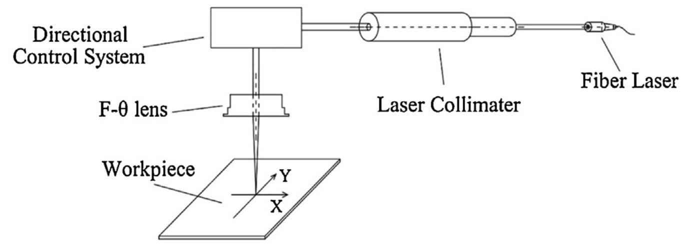

Fig. 3. The schematic of the laser cleaning setup.

3. Results and discussion

Sulfide scale, including the upper layer and inner layer, must be removed completely (Fig. 4). SEM analysis showed that many irregularly large particles were detected on the sulfide scale surface of the specimen before laser cleaning (Fig. 4a), which are part of upper layer. S content of these particles is similar to the other place of the surface. In multiple sets of tests using a fiber laser for cleaning, the surface of specimen changes, when the power reached 5‰. Therefore, the threshold fluence value for the removal of the upper layer is 0.41 J/cm^2. The cleaning effect is proportional to the fluence value. Fig. 4b shows the cleaning result of 6% power for one exposure. The surface becomes slightly smoother than that before laser cleaning. Given two exposures of 6% power, many jagged traces can be seen clearly on the surface (Fig. 4c) and the inner layer surface was revealed preliminarily. Laser cleaning using 6% power for several times resulted in complete removal of the upper layer. However, the inner layer was not removed by this process. Fig. 4d shows the inner layer surface. A lot of obvious pits and cracks can be seen on the inner layer surface. The pits exist because S was not able to enter after Fe and Ni diffusion outwards. In addition, cracks indicate the high Cr content in the inner layer because Cr increases the material hardness, but reduces the material plasticity. The spallation phenomenon appears proceeding with the increase in power to 10% (Fig. 5). This finding indicates the threshold fluence value for the removal of inner layer is 8.25 J/cm^2. Fig. 4e shows the unbroken part on a surface that covered the cleaning traces again which are different from the previous one. By contrast, Fig. 4f shows the new and rougher exposed surface. Continued cleaning for several times removed the sulfide scale completely (Fig. 4g). The substrate damage implies that the damage threshold value of FV520B stainless steel is 9.90 J/cm^2 with further increase in fluence to 12%. Fig. 4h shows the substrate surface after damage by high fluence value. High power pulsed laser radiation leads to formation of regular rectangular pits (3 μm × 20 μm) on the surface because of 1000 mm/s scanning speed and 60 kHz repetition rate.

Cleaned and uncleaned surfaces at each stage were examined by EDS. Fig. 6a–c shows the EDS result of the original surface, inner layer and substrate surface after laser cleaning respectively. EDS

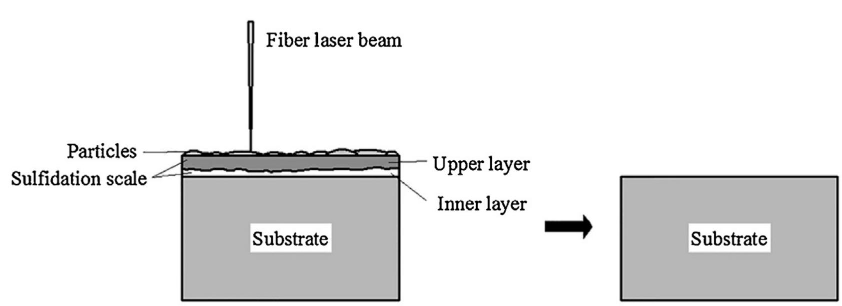

Fig. 2. Schematic diagrams showing experiment objective after laser cleaning.

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