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Microstructure and mechanical properties of hot wire laser clad layers for repairing precipitation hardening martensitic stainless steel

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ABSTRACT

Precipitation hardening martensitic stainless steel (PH-MSS) is widely used as load-bearing parts because of its excellent overall properties. It is economical and flexible to repair the failure parts instead of changing new ones. However, it is difficult to keep properties of repaired part as good as those of the substrate. With preheating wire by resistance heat, hot wire laser cladding owns both merits of low heat input and high deposition efficiency, thus is regarded as an advantaged repairing technology for damaged parts of high value. Multi-pass layers were cladded on the surface of FV520B by hot wire laser cladding. The microstructure and mechanical properties were compared and analyzed for the substrate and the clad layer. For the as-cladded layer, microstructure was found non-uniform and divided into quenched and tempered regions. Tensile strength was almost equivalent to that of the substrate, while ductility and impact toughness deteriorated much. With using laser scanning layer by layer during laser cladding, microstructure of the clad layers was tempered to fine martensite uniformly. The ductility and toughness of the clad layer were improved to be equivalent to those of the substrate, while the tensile strength was a little lower than that of the substrate. By adding TiC nanoparticles as well as laser scanning, the precipitation strengthening effect was improved and the structure was refined in the clad layer. The strength, ductility and toughness were all improved further. Finally, high quality clad layers were obtained with equivalent or even superior mechanical properties to the substrate, offering a valuable technique to repair PH-MSS.

1. Introduction

Precipitation hardening martensitic stainless steel (PH-MSS) is particularly attractive to manufacturing load-bearing parts like turbines and shafts in power plant, oil and chemical industry due to its excellent service performance. Cr13 and 17-4PH steels are typical PH-MSS widely used. Despite that, some parts are found damaged because of severe working conditions, which brings to giant economic loss and much worse safety hazard [1]. It was reported that it costs $1.32 million for one day of outage in terms of lost revenue in a 350 MW combined cycle power plant [2]. It is economical and flexible to repair those parts instead of changing new ones.

The repairing quality is always in the first priority. The overall properties of repaired parts should be equivalent to the substrate to assure service performance and life, especially for load bearing parts. For PH-MSS, precipitated phases, like carbides and ε-Cu etc., play a significant role to mechanical properties [3]. Heat treatment of solution and aging are generally used to obtain the required mechanical properties. For example, the tensile strength, elongation and hardness of Cr13 steel were reported to be in the range of 813–1070 MPa, 10–21% and 21-32 HRC respectively with different heat treatment [4]. Therefore, post-weld heat treatment is usually necessary for the repaired parts to guarantee the equivalent mechanical properties of the clad layer and heat affect zone [5–7]. However, it takes much cost and time, and also results in problems like residual stress and distortion. It is significant to develop repairing methods with low requirement of heat treatment.

Davoodi used GTAW to repair 17-4PH steel with ER630 electrode. The microstructure in as-cladded layer was coarse, and the width of heat affected zone was about 3 mm. The mechanical properties and corrosion resistance dropped a lot compared with those of base metal [8]. Bhaduri used GTAW with different wires like ER410 and ERER NiCr-3 to repair 13Cr and 410SS martensitic stainless steel. He found that the ductility of repaired layers was difficult to reach that of base metal even after a deliberately designed heat treatment for GTAW [9,10]. Due to merits like low

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heat input and high flexibility, laser cladding is regarded as a high quality repairing method. Lin used laser cladding to repair 17-4PH steel with powder of the similar composition of base metal. The width of heat affect zone decreased to only 0.6 mm. The strength of as cladded layer was comparable to that of base metal, but the ductility dropped much. By applying heat treatment, the overall mechanical properties of cladded layer reached to the similar level of base metal [11].

The deposition efficiency has been a key issue for most laser cladding processes. If the volume of filler metal is increased, more laser energy is needed to melt the additional filler metal, bringing to problems like excessive heat damage to base metal and poor processing stability, as well as high cost due to the use of high power laser source. In laser hot wire welding, substrate metal and filler wire are respectively heated by laser and resistance heat. The wire can be preheated near to the solidus temperature. The process has both merits of high deposition volume and small heat damage to substrate. It is regarded as an advantaged repairing method with high quality and high deposition efficiency [12–16]. However, there are few reports involved in microstructure and mechanical properties for this repairing method.

In this study, microstructure of as-cladded layer using hot wire laser cladding for PH-MSS was discussed. Mechanical properties, including tensile strength, yield strength, elongation and impact toughness, were tested and compared between the clad layer and the substrate. Two approaches of laser scanning and nanoparticles addition, rather than post-weld heat treatment, were proposed to improve mechanical properties of the clad layer in order to match those of the substrate. Consequently, it is hopeful to develop an efficient method to repair PH-MSS parts with hot wire laser cladding technology.

2. Experimental method and materials

The schematic of hot wire laser cladding is shown in Fig. 1. An IPG fiber laser with the maximum power of 2000 W and the wavelength of 1.07 μm was used. The focal length was 200 mm. With moving the lens, a defocused spot of 3.5 mm was used to heat the substrate. The filler wire was supplied via a lateral feed torch and was preheated by a Panasonic YC-400TX power source. When the wire touches the substrate metal, a circuit forms and heats the electric part of wire. The electric length was set as 35 mm; the wire angle 70°. Argon gas with flow rate of 20 L/min was used to shield the molten pool from oxidation. The preheated wire was fed into the tail of the molten pool without direct irradiation from laser. The distance between the wire tip and the center of laser spot was set as 1 mm. The experimental setup is shown in Fig. 2.

The substrate metal was FV520B, cut from a blower part made by a domestic factory. It had been heat treated with solution (1050 °C) and aging (650 °C) in service status. The size of test piece was $100 \times 60 \times 8$ mm^3. The surface was cleaned with absolute

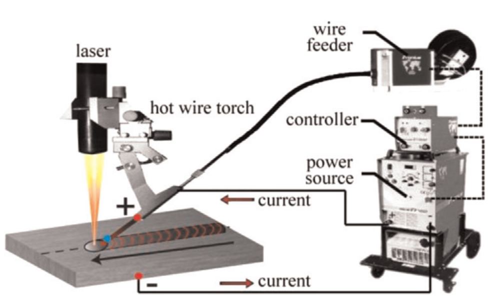

Fig. 1. Schematic of hot wire laser cladding process.

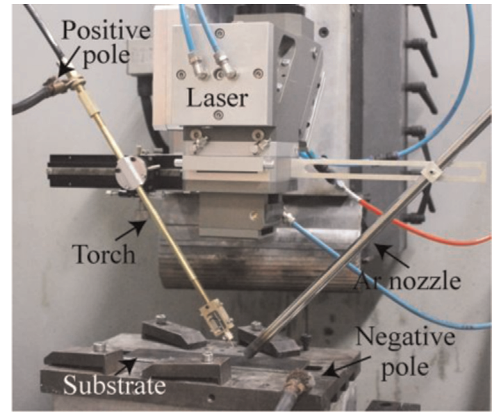

Fig. 2. Experimental setup of laser hot wire cladding.

ethyl alcohol before cladding. The filler wire was martensitic stainless steel ER410NiMo with 1.2 mm diameter. The chemical compositions of the substrate metal and the filler wire are shown in Table 1.

Multiple passes and layers were deposited to form the clad layer. Preliminary experiments were carried out to optimize processing parameters [15,16]. The main parameters were set as: laser power 1810 W, scanning speed 9.5 mm/s, wire feed rate 2.3 m/min, overlap ratio 39.5%, and wire current 95 A. The cross section of the clad layer was polished and etched by Fry's etchant. Microstructure was observed by optical and scanning electron microscopes (SEM). Samples were cut from both the substrate and clad layer to measure mechanical properties by tensile test and Charpy U-notch impact test at room temperature. Vickers micro hardness was measured using a load of 100 g with a dwell time of 10 s.

3. Results and discussion

3.1. Microstructure of as-cladded layer

Fig. 3a shows the cross section of as-cladded layer of 4 passes in a single layer. No defect, like porosity, crack and lack of fusion, was found. All the results show that the formation quality was quite good [16]. Since the thermal cycle of the next pass had reheated the adjacent part of the previous pass, non-uniform microstructure was found in multi-pass clad layers during hot wire laser cladding. The dash lines in Fig. 3a distinguish areas enduring single and double thermal cycles. Fig. 3b is an enlarged picture of the two sides at the line. The difference of microstructure can be clearly seen. For the area with double thermal cycles, shown as the left side in Fig. 3b, it is named as the tempered region; for the area with single thermal cycle, the right side in Fig. 3b, named as the quenched region. The quenched region shows average hardness about 340 HV, higher than that of the substrate 300 HV. The hardness of the tempered region is 300 HV, just as the similar as that of the substrate. The non-uniform microstructure of the as-cladded layer is detrimental to mechanical properties, which will be discussed later.

Fig. 4 shows the SEM picture of microstructure of the substrate, the quenched and the tempered region of the clad layer. For the substrate in Fig. 4a, it shows fairly fine tempered martensite. Some parallel martensitic laths compose a bundle, and those bundles make up a grain. Many precipitate ion particles can be observed in the enlarged image in Fig. 4b. It has been reported that these secondary phase particles are mainly carbides and Cu-rich particles, which play a role of precipitation strengthening [17].