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The effect of short time post-weld heat treatment on the fatigue crack growth of 2205 duplex stainless steel welds

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Abstract

The influence of γ content and its morphology on the impact and fatigue crack growth behavior of 2205 duplex stainless steel (DSS) welds were studied in this work. Short time post-heating was able to effectively raise the γ content and the impact toughness of the weld. The variation in microstructures showed less influence on the fatigue crack growth rate (FCGR) of the steel plate and weld except in the low ΔK regime. In contrast, residual welding stresses played a more significant affection on the FCGR of the DSS weld than microstructural factors did. Plastic deformation induced martensitic transformation within a definitely thin layer was responsible for the difference in crack growth behavior between specimens in the low ΔK range. Coarse columnar structure was more likely to have tortuous crack path in comparison with the steel plate.

Keywords: Duplex stainless steel; Laser welding; Fatigue crack growth rate; Charpy impact; Post-heat treatment

1. Introduction

DSSs (2205 duplex stainless steels) consist of comparable amounts of ferritic (α) and austenitic phases (γ). This gives the DSS the superior strength and stress-corrosion cracking resistance of ferritic stainless steels, as well as good ductility and toughness of austenitic stainless steels [1,2]. With these excellent properties, DSSs are used increasingly in chemical industries such as pressure vessels, heat exchangers and line-pipes. DSSs are highly anisotropic because of the elongated γ phases embedded in the α matrix [3]. As shown in the previous work [4], the anisotropy had little influence on the fatigue crack growth rate (FCGR) of 2205 DSS in air.

Modern DSSs have good weldability and can be welded by conventional welding processes under careful control of heat input to ensure a correct α/γ ratio in the weld [5]. Preheat and post-weld heat treatments of a DSS weld are in general not recommended [5]. Laser welding process offers many advantages over conventional arc welding process. However, the low-energy processes accompanying with fast cooling rates produce welds with higher α contents, which is responsible for its poor impact toughness [6,7]. As a result, the electron beam and laser beam welding processes are not recommended for joining DSS welds [8].

To alter the unbalanced α/γ ratio in the fusion zone and HAZ of a DSS laser weld, laser surface treatment is used to restore the correct α/γ ratio [9]. An addition of little amount of nickel powder [10] or assist-charging of nitrogen into the fusion zone during laser welding [11], may restore the correct α/γ ratio. According to the literature survey,

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little investigation has been carried out on the fatigue crack growth behavior of a DSS laser weld. In this study, short time post-weld heat treatments were performed after welding to increase the γ content in the fusion zone of a 2205 DSS weld. The effects of γ content and its morphology on the impact and fatigue behavior of the DSS weld metal were evaluated. A magnetic technique and quantitative image analysis were used to determine the α/γ ratios of the base plate and weld metal. Fatigue- and impact-tested specimens were examined by scanning electron microscopy (SEM) to identify fracture features, which were further correlated with their properties accordingly.

2. Material and experimental procedures

The chemical composition of the 2205 DSS plate in weight percent was 21.1 Cr, 5.8 Ni, 2.7 Mo, 0.052 C, 1.42 Mn, 0.45 Si, 0.025 P, 0.022 S, 0.02 Cu, 0.165 N and balance Fe. Laser welding was performed on the as-received 5 mm thick DSS plate, using a Rofin-Sinar 5 KW CO_2 laser integrated with a computer-controlled working table. Laser welding parameters used in this work are listed in Table 1.

Fig. 1 is the schematic diagram showing Charpy impact and compact tension (CT) specimens sectioned from the laser-welded steel plate. The relative direction between crack growth and rolling direction (RD), named according to the ASTM E399 specification, is also indicated in Fig. 1. Both fatigue crack growth and impact tests were carried out at room temperature in laboratory air. The fatigue crack growth tests were conducted on an MTS 810 model servo-hydraulic testing machine under a constant amplitude sinusoidal loading. Fatigue data were analyzed using the MTS 790.40 fatigue crack growth software. The load ratio was set at 0.1 throughout the test. The crack length was determined by a compliance method [12] and confirmed by a traveling microscope at 30× magnification. The welded CT specimen was designated as CW when the fatigue crack propagated along the weld metal, as shown in Fig. 1. The stress intensity factor corresponding to the crack opening stress (K_{op}) was measured by compliance method using crack mouth clip gage. The degree of crack closure, U, was defined as the fraction of the load range for which the crack is open, $U = \Delta K_{eff}/\Delta K$.

Austensite is known to be the stable phase in the temperature range from 900 °C to 1100 °C [1]. Therefore, a high α content resulting from the high cooling rates in the as-welded (AW) DSS laser weld, or unbalanced phase ratio in the steel plate, can be corrected by a proper heat treatment. In this work, post-heat treatment was carried out at 1050 °Cover different periods of time from 15 to 60 min, followed by cooling in air to raise the γ content of the material. High soaking temperature not only restore the correct α/γ ratio but also help to release welding residual stresses. Welding residual stresses were determined by the modified hole-drilling strain gage method according to the specification of ASTM E837-92. Similar experimental procedures had been conducted in previous studies for the determination of residual stresses [13,14]. The soaking time in minute was indicated as a number appending the specimen designation. For example, W15 or W60 indicates that the post-heating time was 15 or 60 min for the weld, respectively.

Table 1
Laser welding parameters used in the experiment

Laser power	3700 W
Travel speed	600 mm/min
Focal lens	Cu mirrior
Focal length	200 mm
Focal point	0.5 mm below the surface
Plasma-assisted gas flow rate (He)	30 L/min
Shielding gas flow rate (Ar)	15 L/min
Backing gas flow rate (Ar)	10 L/min

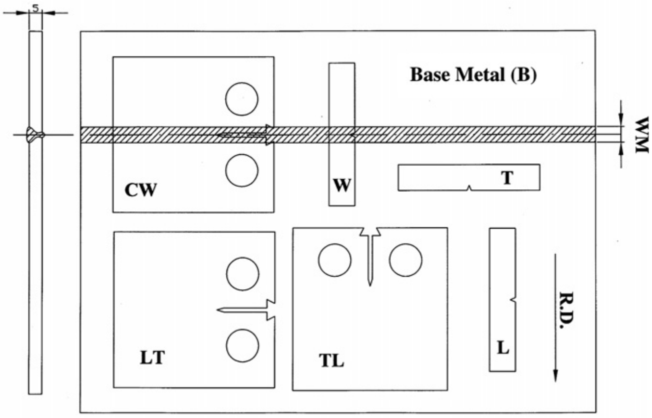

Fig. 1. The schematic diagram showing Charpy impact and compact tension specimens sectioned from the laser-welded steel plate.

Due to the existence of fine and irregular α in the fusion zone of the weld, the α/γ ratio as determined using traditional image analysis was hard to be conducted sometimes. A magnetic technique was used to assist the measurement of the α/γ ratio of the base plate and weld metal. The magnetic technique, by means of the Ferrite scope, registered an average volume content of ferromagnetic phases present in the examined region. Murukami reagent was used to reveal the microstructures of the specimens; α phase appeared in gray and γ was white in the metallograph. Fatigue fracture surface was examined by a Hitachi S4100 SEM, with attention being paid to the changes in fracture features. Fracture surface roughness and profile were measured by the height of the irregularities with respect to an average level. R_a is the arithmetic average of the absolute values of the roughness profile ordinates. Besides, R_z is the sum of the mean height of the five highest peak profiles and the mean depth of five deepest valley profiles measured from the mean line.

3. Results and discussion

3.1. Microstructural observations

Table 2 lists the α/γ ratio of various specimens measured by Ferrite scope. For the as-received base plate (B), the α/γ