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Hydrogen-enhanced cracking of 2205 duplex stainless steel welds

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Abstract

Slow-displacement rate tensile tests were carried out to investigate the effect of hydrogen embrittlement on notched tensile strength (NTS) and fracture characteristics of 2205 duplex stainless steel weld. The hydrogen embrittlement susceptibility of the specimens was correlated with microstructures of the fusion zone. The results indicated that all the specimens were susceptible to gaseous hydrogen embrittlement but to different degrees. The susceptibility decreased with increasing austenite content in the weld metal. The orientation with respect to the rolling direction had a great influence on the impact toughness of the base plate. Preheating before welding or changing the plasma-assisted gas from He to N_2 could raise the γ content of the fusion zone and improve the impact toughness. In case of the post-weld heat-treated weld (PW), the presence of randomly oriented acicular and blocky γ in the fusion zone led to the highest impact energy and NTS among the specimens being tested. Scanning electron microscopy (SEM) fractographs revealed that all specimens underwent a significant change in fracture mode from ductile in air to quasi-cleavage fracture in H_2.

Keywords: Duplex stainless steel; Laser welding; Gaseous hydrogen embrittlement; Notched tensile test; Charpy impact; Quasi-cleavage

1. Introduction

Duplex stainless steels (DSSs) belong to a family of stainless steels that consist of comparable amounts of ferrite (α) and austenite (γ). Owing to their high proof strength, in addition to corrosion resistance in wet CO_2 environment [1,2], DSSs have found increasing applications in chemical industries. Meanwhile, DSSs are highly anisotropic because of the occurrence of elongated γ embedded in the α matrix. Additionally, the partition of alloy elements makes the DSS possess complex electrochemical properties [3] and environment-enhanced cracking characteristics [4-8]. For the DSS with low alloy and N content [3], plastic deformation occurs more easily in the austenite, resulting in the initiation and growth of stress corrosion cracks in the austenite, while in highly alloyed DSS, the strength of austenite is higher and cracking in the ferrite in chloride solution is promoted [3]. Pitting corrosion is known to assist the initiation of stress corrosion cracking in chloride solution at high anodic potential [8]. When charging 2205 DSS in hydrogen, ferrite is more favorable for cracking and propagation than austenite [8-10]. The longitudinal specimen showing lower sensitivity to hydrogen embrittlement than the transverse one with respect to rolling direction, was accounted by the presence of austenite stringer, to retard the crack growth effectively during straining [11]. In previous work, 2205 DSS was found to be susceptible to environment-assisted crack growth in the low ΔK range, especially for specimens with the crack growth transverse to the rolling direction [12].

Modern DSSs have good weldability and can be welded by conventional welding processes [13]. In general, preheat and post-weld heat treatments of a DSS weld are not rec-

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ommended [13]. However, careful control of heat input and interpass temperatures during welding are required to correct the α/γ ratio in the DSS weld. The low energy input gives high cooling rate, preventing the transformation of primary α into γ in the weld [14]. The low γ content in the fusion zone is responsible for its poor impact toughness [15,16]. Besides, excessive amounts of α enhance the precipitation of Cr-nitrides in the α together with Cr-carbides mainly along the α/γ boundaries [2,17]. The depletion of Cr in the regions around those precipitates decreases the corrosion resistance of the weld metal and heat-affected zone [2,9]. In contrast, a high energy input allows more time for the formation of γ phase. But, too high energy input or interpass temperature will deteriorate the mechanical and corrosion properties owing to the precipitation of intermetallic particles inside [18].

Laser welding offers many advantages over the conventional arc welding process. However, the unbalanced α/γ ratio in the fusion zone and HAZ limits its application on the joining of DSSs by laser welding. Laser surface treatment is reported to be able to restore the correct α/γ ratio in a DSS laser weld [19]. In this study, variations in laser welding parameters were made to try to increase the γ content in the fusion zone of a 2205 DSS weld. Little research has been carried out to investigate the microstructures and mechanical properties of a DSS laser weld. Accordingly, this paper focused on investigating the influence of microstructures on the mechanical behavior of the DSS weld metal. Fracture surfaces of the various specimens were examined by scanning electron microscopy (SEM) to identify typical fracture features and correlate those features with mechanical characteristics.

2. Material and experimental procedures

The chemical composition of the 5 mm thick 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 DSS using a Rofin-Sinar 5 kW CO_2 laser connected with a computer-controlled working table. Laser welding parameters used in this work are listed in Table 1. In order to increase the amount of transformed γ in the weld metal, preheating the steel plate at 250 or 400 °C, or changing the plasma-assisted gas from He to N_2 was carried out. In order to identify the welds according to welding conditions, some abbreviations are used to reveal previous welding conditions, e.g., HP250 represents He gas (H) used as the plasma-assisted gas and preheat (P) of the steel plate at 250 °C, while NP400 stands for the specimen preheating at 400 °C and N_2 applied to blow the plasma plume away during laser welding. To understand the influence of post-weld heat treatment (PW) on the mechanical properties of the weld, some of the welds were heated to 1000 °C for 20 min and then quenched in water. In order to evaluate the influence of N_2-charging, instead of He, on the enhanced phase transformation during laser welding, the N content of the fusion zone was measured by an oxygen/nitrogen analyzer (Leco-TC 136).

Fig. 1 show the three-dimensional microstructure of the laser-welded steel plate and the cutting plane for the notched

Table 1
Laser welding parameters used in the experimental

Laser power	3700 W
Travel speed	600 mm min^{-1}
Focal lens	Cu mirrior
Focal length	200 mm
Focal point	0.5 mm below the surface
Plasma-assisted gas flow rate	18 L min^{-1} N_2 or 30 L min^{-1} He
Shielding gas flow rate	15 L min^{-1} N_2 or 15 L min^{-1} Ar
Backing gas flow rate	10 L min^{-1} Ar

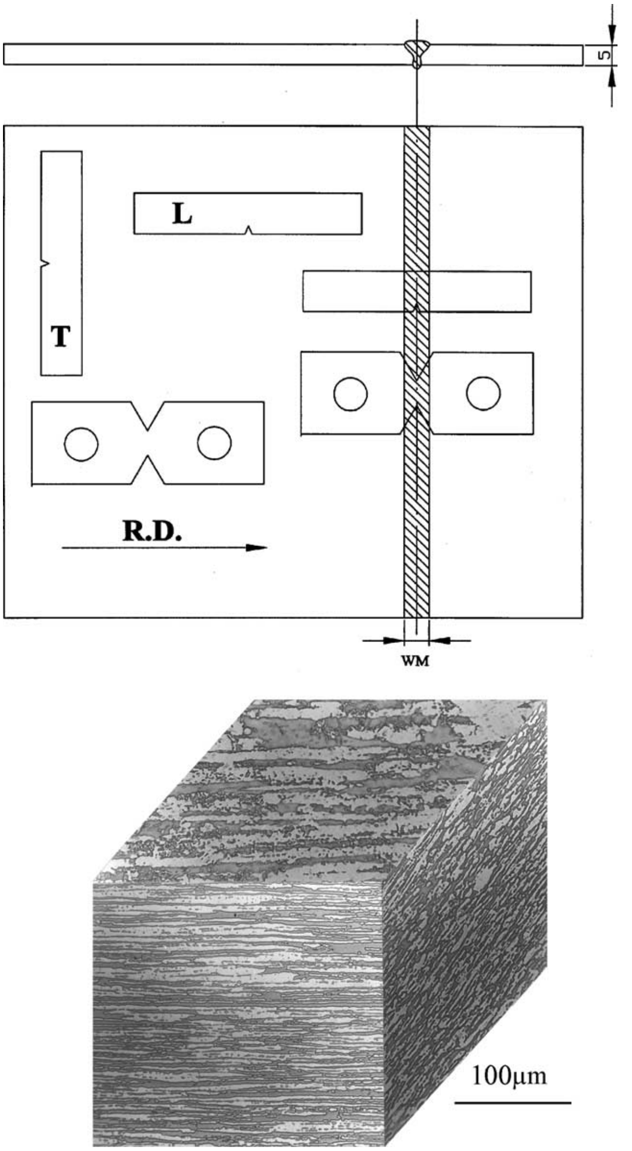

Fig. 1. Schematic diagrams showing the notched tensile and Charpy impact specimens sectioned from the welded steel plate with metallographs revealing the microstructures of the three mutually perpendicular planes of the steel plate.