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Microstructure, mechanical properties and residual stress of a 2205DSS/Q235 rapidly formed LBW joint

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A R T I C L E I N F O

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A B S T R A C T

Welding seam (WS) of a 2205DSS/Q235 laser-beam welded (LBW) joint consisted of a martensitic phase and a small amount of residual austenite. The microstructure of the heat-affected zone (HAZ) of the 2205DSS side was ferrite-dominated. The HAZ of the Q235 side consisted of a coarse-grained zone (near the WS) and a fine-grained zone which was a result of the thermal cycling. The WS had the was highest hardness, and the hardness value of the HAZ was slightly higher than that of the respective base metal. The strength of these welding joints was approximately 460 MPa. The residual stress was investigated using a finite element method, hole-drilling method, and X-ray diffraction analysis. The results revealed two high stress regions on either side of the WS. The residual stress of the WS was relieved substantially because of the martensitic transformation at 400 °C.

1. Introduction

Duplex stainless steel (2205DSS) consists of ~50 vol. % austenite and ~50 vol. % ferrite. Moura et al. (2010) showed that compared to steels of conventional austenitic grades (AISI 304L, 316L, 317L), 2205DSS steels present higher strength levels and are more resistant to Cl^- environments. Owing to these characteristics, 2205DSS have been widely employed to manufacture pressure pipes and vessels for the in oil, gas, and chemical industries. Recently, the welding process used in joining 2205DSS steels has attracted increasing attention. Many welding methods, such as gas tungsten arc welding (GTAW), laser beam welding (LBW), and friction welding, have been employed to join 2205DSS steels. Badji et al. (2011) characterized the texture evolution of the base metal, HAZ, and weld metal during welding (via GTAW) and annealing. Subsequently, an optimal annealing treatment was determined based on a micromechanical model. Zhang et al. (2017) studied the effects of the addition of nitrogen to the shielding gas used during GTAW on the microstructural evolution and localized corrosion behavior of duplex stainless steel (DSS) welds. Lai et al. (2016) also showed the beneficial effect of the addition of nitrogen to the shielding gas on the corrosion resistance. Mourad et al. (2012a, b) compared welds formed via LBW and GTAW. The results showed that welds formed using LBW offer superior corrosion resistance, small HAZ, and high efficiency. Meinhardt et al. (2017) also joined 2205DSS steels via friction welding. The results showed that this welding technique is adequate for maintaining satisfactory microstructural, corrosion, and toughness properties, when considering the required specifications required for the equipment used in oil and gas exploration. The above investigations show that 2205DSS steels can be joined using many methods. However, in the case of dissimilar joints of 2205DSS, a relatively traditional welding method is used. Moteshakker and Danaee (2016) joined the 2205DSS and 316L steels via GTAW and investigated the microstructural and corrosion properties of the dissimilar joints. The use of an ER 309L welding wire was determined to be most appropriate for such dissimilar joints. Verma and Taiwade (2016) joined 2205DSS and 316L steel via shielded metal arc welding (SMAW). Bettahar et al. (2015) joined 2205DSS and 13Cr supermartensitic stainless steel (SMSS) via GTAW and investigated the microstructural and mechanical properties of the dissimilar joint. An investigation on the dissimilar joint of 2205DSS and 16MnR steel (low-alloy high-strength steel) was conducted by Wang et al. (2011). Here, GTAW and submerged arc welding (SAW) methods were used, and the weld metals of ER2209 and E2209 were employed. Based on the results, GTAW was considered to be the most suitable method for the joining of 2205DSS and 16Mn steel. Based on previous studies, the GTAW method is considered the most appropriate for the joining of 2205DSS with other steels. However, the welding efficiency of GTAW is found to be very poor. In the study by Moteshakker and Danaee (2016) and Wang et al. (2011), the welding speeds for GTAW were determined to be only 60 mm/min and 100–120 mm/min, respectively.

In the present study, the LBW method, without the use of a filler metal, was employed to join 2205DSS and Q235 steel plates. A welding

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Table 1
Chemical compositions of the 2205DSS and Q235 steels (wt. %).

Steel	C	Si	Mn	Ni	Cr	Mo	N	S	P
2205DSS	0.025	0.570	1.250	5.300	22.570	3.040	0.140	0.002	0.030
Q235	0.16	0.21	0.55	–	–	–	–	0.02	0.030

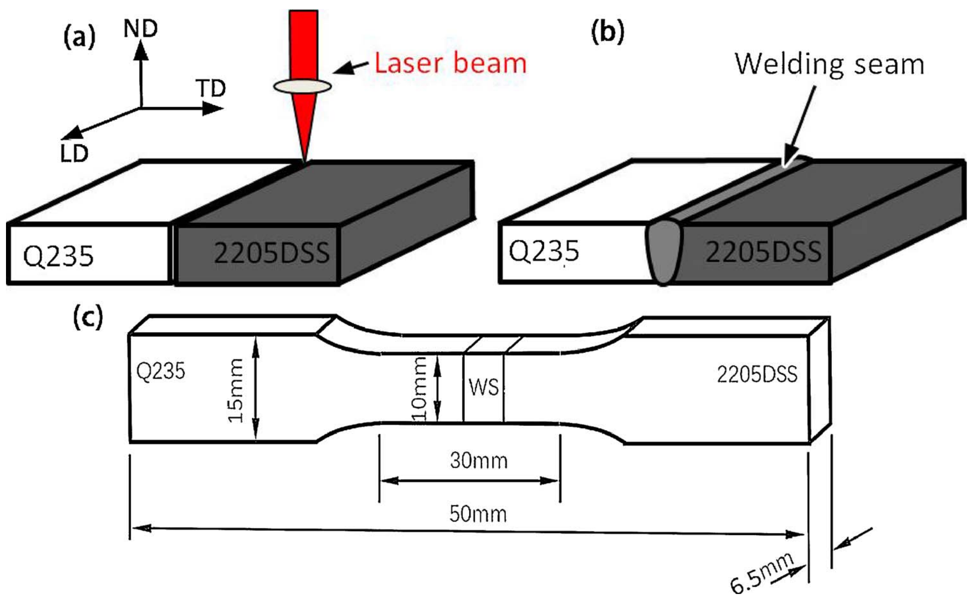

Fig. 1. (a) Assembly of the Q235 steel and 2205 duplex steel plates; (b) Schematic of the Q235 steel and 2205DSS dissimilar joint formed via LBW; (c) dimensions of the tensile samples used in this study.

speed of 1200 mm/min was used. The microstructures of the WS and HAZ were investigated. The residual stress of the dissimilar joint, and stress evolution of the WS were also investigated.

2. Materials and experiments

The compositions of the 2205DSS and Q235 steels used in this investigation are shown in Table 1. The prepared 2205DSS and Q235 steel plates had identical dimensions of 200 mm × 150 mm × 6.5 mm. A diagram showing the assembly of the 2205DSS and Q235 steel is shown in Fig. 1(a). The longitudinal direction (LD), transverse direction (TD), and normal directions (ND) are also defined in Fig. 1 (a). Laser powers of 3.2 kW, 3.7 kW, and 4.2 kW, and a welding speed of 1.2 m/min were employed. The defocusing distance was 0 mm. Moreover, the Ar gas with a flow rate of 25 L/min, was employed as a shield gas. A schematic of the joint following LBW is shown in Fig. 1(b). It can be observed that the WS constitutes the melted 2205DSS and Q235 steel. The macro morphology and microstructure of the 2205DSS/Q235 dissimilar joint were observed by optical microscopy (OM) and transit electron microscopy (TEM). The composition of WS was analyzed by energy dispersion spectroscopy (EDS). The phases of the WS were analyzed using X-ray diffraction (XRD). The strengths of these joints were measured using a universal mechanical tester. The dimensions of the tensile samples used are shown in Fig. 1(c). The tensile speed was 2 mm/min. The hardness values of these joints were measured using a micro-hardness tester with a load of 200 g, and a holding time of 5 s. The hardness values of the austenite and ferrite were measured using a nano-indentation tester. The loading/unloading rate and maximum load used during the nano-indentation tests were 160 mN/min and 80 mN, respectively (Table 1).

The temperature field of the 2205DSS/Q235 dissimilar joint was calculated using ABAQUS software (Version 6.13). The physical parameters of the 2205DSS and Q235 steels were acquired from a study by Zeng (2003). The physical parameters of the WS are discussed in Section 3.3. The stress field of the joint was calculated based on the temperature field shown in Section 3.3. The residual stress was measured using the hole-drilling method and XRD method, which were demonstrated by Li et al. (2017).

3. Results and discussion

3.1. Microstructure of LBW joint

The cross-sectional morphologies of the 2205DSS/Q235 joints are shown in Fig. 2. The WS was narrow, and was present throughout the base-metal plate. The central width of the WS was approximately 1 mm. The top and lower portions of the WS were wider than the central width. The width of the top portion was ~2.4 mm. The width of the lower portion increased from 1.2 mm to 2.2 mm as the laser power was increased from 3.2 kw to 4.2 kw, respectively. Moreover, an obvious HAZ was observed on the Q235 side of every joint as shown in Fig. 2. The width of the HAZ was less than 1 mm. The microstructures of the 2205DSS/Q235 joints obtained via LBW with a laser power of 3.7 kW were investigated in detail.

The microstructures of the 2205DSS/WS are shown in Fig. 3(a) and (b). The HAZ, which contained large quantities of ferrite, was very narrow (~30 um) as shown in Fig. 3(b). During welding, the peak temperature of the HAZ of the 2205DSS/WS was very high. The duplex phases microstructure (ferrite and austenite) transformed in to a single phase (ferrite) (Nowacki and Łukojć, 2005). Owing to the rapid cooling rate of the HAZ, there was insufficient time for the ferrite to transform into austenite. Therefore, a large quantity of ferrite remained in the HAZ of the 2205DSS/WS.

The microstructure the of WS/Q235 is shown in Fig. 3(c) and (d). A coarse-grained region (coarse-grain heat-affected zone, CGHAZ) and a fine grain region (fine-grain heat-affected zone, FGHAZ) can be