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Influence of welding thermal cycles on microstructure and pitting corrosion resistance of 2304 duplex stainless steels

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ABSTRACT

Different welding thermal cycles from single-pass to triple-pass were performed on two kinds of 2304 duplex stainless steel through Gleebe thermal–mechanical simulator. The corresponding microstructure was observed, while the pitting corrosion resistance was investigated in 1.0 M NaCl by potentiostatic critical pitting temperature (CPT). The results showed that single-pass welding deteriorated microstructure and pitting corrosion resistance significantly. As the welding pass increased, the ferrite content decreased and CPT increased. However, CPT was still lower than that of the base metal. Nitride precipitated at the boundary between ferrite and austenite phase for low-alloyed 2304 after the single-pass welding thermal cycle.

1. Introduction

Duplex stainless steels (DSS) are widely used as alternatives to austenitic stainless steels and nickel-based alloys recently. They represent an important and expanding class of steels with an outstanding combination of mechanical strength and corrosion resistance in chloride-ion containing environments. Their good properties rely on the duplex microstructure, which consists of approximately equivalent amounts of γ and δ-ferrite without other undesirable precipitates [1–4].

However, when DSS are welded, the experienced thermal history may severely impair their performances, especially local pitting corrosion resistance and toughness. These degradations were resulted from the unbalanced duplex phase fraction with excess of ferrite phase and the precipitation of deleterious secondary phases such as chromium nitrides, secondary austenite (γ_2), sigma (σ), chi (χ) etc. The most typical problems of welded DSS are associated with heat-affected zone (HAZ), not with weld metal zone (WMZ), since the properties of WMZ could be modified by using high-alloyed filler metal and N_2 containing shield gas [5–13]. A great number of investigations have been carried out on the HAZ of DSS [14–21], most of which were concerned on the single-pass welding. Study on the HAZ of multi-pass welding is scarcely reported, although multi-pass welding is more common during the practical industrial fabrication, especially for the plate or pipe of middle thickness. The thermal experience of HAZ during multi-pass welding is more sophisticated compared with that of single-pass welding, resulting in more complicated microstructure evolution in HAZ during multi-pass welding. The corresponding corrosion resistance and mechanical properties of duplex stainless steel multi-pass HAZ are also influenced. Therefore, it is of great scientific and industrial significance to investigate the influence of multi-pass thermal cycle on corrosion resistance and mechanical properties.

Thermal simulation in thermo-mechanical simulator is an effective method to investigate welding process, which has been applied in the study of duplex stainless steel welding [6,8,16,17,21]. The variation of practical welding parameters can be reflected on the parameter of thermal simulation. Since different location exhibits different thermal cycle during welding, thermal cycle of the whole welded joints is very complicated. The advantage of thermal simulation is to simulate the thermal cycle of the specific location of welded joints accurately, which is convenient for investigation.

In current work, welding thermal cycles with different welding passes (from single-pass to triple-pass) were performed on two kinds of DSS2304 (high-alloyed and low alloyed) through Gleebe thermal–mechanical simulator. After the simulation, the microstructure was observed and the corresponding pitting corrosion resistance was investigated by potentiostatic critical pitting temperature (CPT) in 1.0 M NaCl solution.

2. Experimental procedures

2.1. Materials

The materials were two kinds of DSS 2304 with different chemical composition as shown in Table 1. They were melted in a 50 kg

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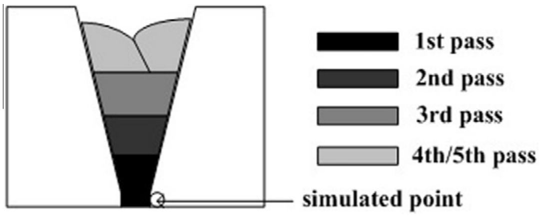

Fig. 1. Schematic diagram of multipass welded joints. The point for the thermal simulation was the heat-affected zone at the joint bottom, marked with a cycle in this figure.

Table 1
Chemical composition of two kinds of duplex stainless steel 2304 (wt.%).

Element	Cr	Mo	N	Ni	Cu	C	Mn	Si	P	S	Fe
2304-A	23.06	0.31	0.13	4.03	0.29	0.021	1.56	0.40	0.010	0.004	Bal.
2304-B	23.82	0.91	0.18	4.50	0.35	0.025	1.52	0.38	0.008	0.004	Bal.

vacuum furnace and then cast as a single square ingot. After removing the oxide skin, the ingot was forged into square bloom at the temperature ranging from 900 to 1200 °C and divided into several blooms with a dimension of 150 mm × 100 mm × 42 mm. The blooms were reheated at 1250 °C for 2 h and hot-rolled, using a laboratory hot-rolling mill, into 12 mm thick plates. After hot-rolling, DSS 2304-A was solution-annealed at 1020 °C while 2304-B was solution-annealed at 1050 °C, and quenched in water. The annealed time was 12 min.

2.2. Thermal simulation

The specimens for the multi-pass welding simulation, with the dimensions of 10 mm × 10 mm × 55 mm, were cut from the 12 mm thick solution-annealed plates. Their longitudinal direction was parallel to the rolling direction. Since different location in the HAZ suffers different thermal experience during multi-pass welding, the exact location simulated must be pointed out. Fig. 1 shows a model of the multi-pass welded joint, and the investigated zone was the high temperature HAZ near the weld pool at the bottom. The simulated thermal cycle of multi-pass welding was established according to Rosenthal's solution of heat transfer equation [22], performed by Gleebe 3800 thermal–mechanical simulator. Fig. 2 shows the relationship between elapsed time and temperature registered during Gleebe simulations. Only three-pass welding thermal cycle was simulated because the peak temperature during the fourth-pass welding thermal cycle was lower than 400 °C, which had little influence on the microstructure and properties

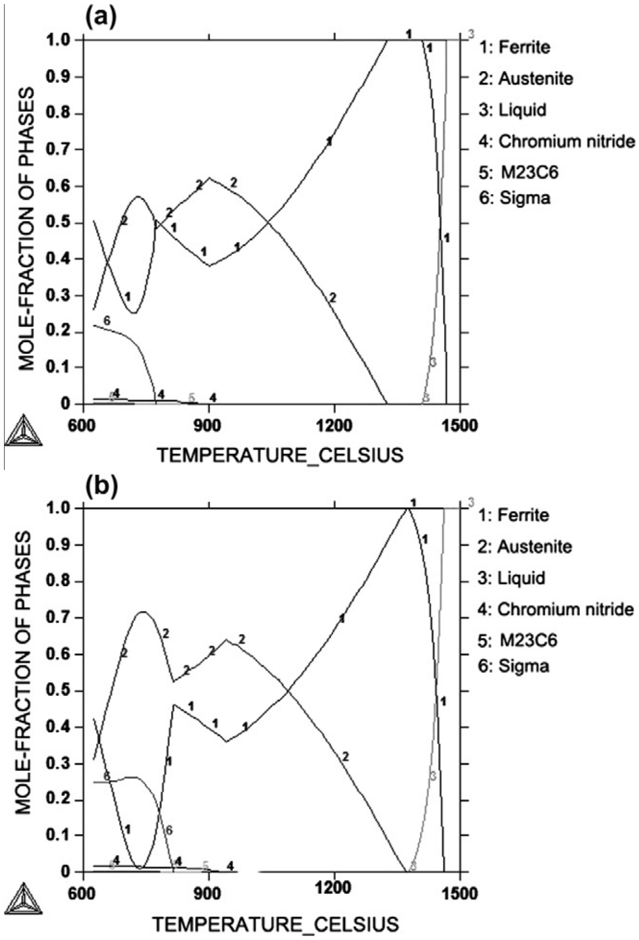

Fig. 3. Equilibrium diagrams of 2304 duplex stainless steels calculated by Thermo-Cal software. a. 2304-A, b. 2304-B.

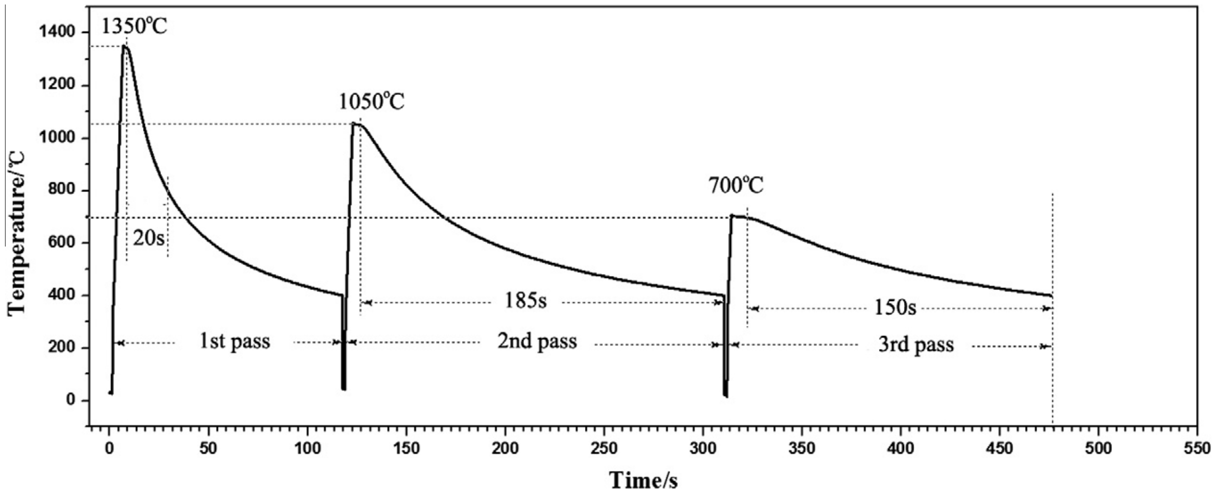

Fig. 2. Curve of temperature with time during multipass welding thermal simulation. The single-pass HAZ specimen has only experienced the 1st pass welding thermal cycle; the double-pass HAZ specimen has experienced the 1st pass and the 2nd pass welding thermal cycle; the triple-pass HAZ specimen has experienced the 1st pass, 2nd pass, and 3rd pass welding cycle.