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Effect of weld thermal cycle on microstructure and fracture toughness of simulated heat-affected zone for a 800 MPa grade high strength low alloy steel

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ABSTRACT

In the present investigation, thermal simulated specimens were used to investigate the effect of welding cooling time and peak temperature on characteristic fracture toughness and microstructure feature of heat-affected zone (HAZ) for an 800 MPa grade high strength low alloy (HSLA) steel. It is found that the fracture toughness is the best for the simulated coarse-grained HAZ, when the cooling time of $t_{8/5}$ is 18 s. In addition, the size of prior austenite grain, and the volume fraction of bainitic ferrite and M/A constituent increase with increasing the cooling time. However, the volume fraction of martensite decreases with increasing the cooling time. Remarkable decrease of toughness is observed with increasing the size of austenite grain and the volume fraction of M/A constituent. Moreover, there exists the effect of orientation on fracture toughness for the specimens subjected to weld thermal cycle. Generally, the fracture toughness of simulated HAZ with L–T orientation is higher than that with T–L orientation. The reason may be related to that the strip structure formed during rolling is remained after the thermal simulation. Furthermore, the investigation shows that the toughness of coarse-grained zone is higher than that of fine-grained zone for the simulated HAZ. The reason may be related with the microstructure evolution of the HAZ during the complete thermal cycle used in the simulation. For the fine-grained HAZ, the shorter cooling time of $t_{8/5}$ may be not benefit for the self-tempering and decomposition of M/A constituents, then the toughness of the fine-grained HAZ is lower. For the coarse-grained HAZ, however, the longer cooling time of $t_{8/5}$, may promote the decomposition of M/A constituents, then the toughness of coarse-grained HAZ is improved. The fracture toughness deteriorated drastically for the partly phase transformed HAZ may be related with the formation of mixture microstructure, in which the M/A constituent is distributed in shape of network.

1. Introduction

With the development of engineering constructions, large-scale and heavy-duty construction equipments such as bulldozer, excavators, loaders, etc. are extensive requisite for various construction works, mine production or even for disaster salvation. Moreover, it should be mentioned that working condition of the construction equipments is rather

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severe. Besides complex impact and fatigue loading, the equipments may be subject to low temperature in winter. Thus, the strength matching and toughness of welded joints are important except exact selection of welding consumables and welding procedure.

Nowadays, high strength low alloy (HSLA) steel is widely used in engineering structures. The reason is due to many attractive properties of the steel, such as higher strength/weight ration, formability, and weldability. Despite these useful properties, the welding of this steel, when not critically controlled, has often posed problems, particularly in the shop condition.

Under thermal effect of welding, evident change of microstructure and property occurs in the base metal adjacent to the weld metal. Sometimes, the change of the microstructure may lead to local brittleness in heat-affected zone (HAZ). In addition defects, stress concentration and higher residual stresses are easy to coexist in the welded joint. Thus, fracture failure of weldment cannot be completely prevented till now.

HAZ of welded joint is very narrow in width, and the HAZ consists of many fine regions having different structures. When the fracture toughness is measured using true weldment, the results may represent a global property of HAZ. The measured results cannot be used to describe the property of the fine region of HAZ. Thus, it is very difficult to analyze the effect of a characteristic microstructure on fracture toughness using the true weldment. Since the thermal simulation technique has generated with representation of Gleeble, the research on the relation between microstructure and property for the welded joint becomes easy. Of course, the weld thermal simulation technique has disadvantage like other simulation techniques. For example, the grain size of simulated specimen is slightly larger than that of true welded joint when experiencing the identical thermal profile. The reason is that the thermal pinning is not considered in the thermal simulation process. Even though the simulated result may not fully reflect the true welded joint, the thermal simulation technique becomes an important tool in the field of current weld physical metallurgy and steel rolling.

According to the metallurgical characteristics of the HSLA steel, heat input of welding process significantly affects the mechanical property of heat-affected zone. In the present study thermal simulated specimens were used to investigate the effect of welding cooling time and peak temperature on fracture toughness and microstructure feature of HAZ for an 800 MPa grade HSLA steel. The results will be available for determining welding procedure and evaluating fracture safety for large-scale construction equipments.

2. Materials and experimental procedure

2.1. *Materials*

The test material was a 800 MPa grade high strength low alloy steel plate of 16 mm thickness produced by Wuhan Steel Company. The plate was heat-treated by water-cooling at 923 °C at 2.5 min/mm, the tempering at 600 °C at 3 min/mm. The chemical composition expressed in wt% was as follows: 0.11C, 0.23Si, 0.87Mn, 0.012P, 0.009S, 0.32Cu, 0.46Ni, 0.59Cr, 0.30Mo, 0.04V, 0.04Al, 0.003B, remainder ferrite. The mechanical properties of the plate were: yield stress, $\sigma_y = 845$ MPa, tensile strength, $\sigma_u = 880$ MPa, elongation = 15%, and average value of Charpy Vee-notch tests were 115 J and 98 J at −20 °C and −40 °C, respectively.

2.2. *Specimens preparation*

The thermomechanical simulation was conducted in a Gleeble 1500. Square bas specimens (11 mm × 11 mm × 105 mm) were prepared and subjected to thermal cycles. The maximum temperature, holding time and cooling rate of the thermal cycle parameters were selected according to possible procedures during metal arc welding. After the thermo-mechanical process, the simulated specimens were cut and ground to the standard Charpy size of 10 mm × 10 mm × 55 mm. The test specimens were prepared in the L–T and T–L orientation, in which the first letter designates the direction of loading, while the second letter designates the direction of crack propagation. L represents the longitudinal rolling direction of the sheet, and T represents the long transverse direction.

The main parameters of the thermal cycles are given in Tables 1 and 2, respectively, for simulating various cooling rate and peak temperature. In the experiments the thermal cycle parameters are selected on a basis of actual GMAW weld experiments and swing a range. Actually, in this work the peak temperature and cooling rates in the thermal cycles are well designed to simulate possible heating history and possible HAZ microstructures occurred in real welding production. The thermal cycling parameters given in Table 2 would produce microstructures evolution occurred in different zones of the HAZ.

Table 1 – Time intervals for thermal simulation cycle parameters (time: s)

Heating time from ambient to 1300 °C	Holding time at 1300 °C	Cooling time from 1300 °C to 800 °C	Cooling time from 800 °C to 500 °C	Cooling time from 500 °C to ambient	Heat input, Q (kJ/cm)
3	2	10	6	40	10.7
3	2	15	9	65	14.1
3	2	20	18	80	22.3
3	2	25	27	95	29.2
3	2	32	45	110	41.1
3	2	55	100	140	70.0
3	2	110	240	260	125.5