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Effect of Heat Input on Cleavage Crack Initiation of Simulated Coarse Grain Heat-affected Zone in Microalloyed Offshore Platform Steel

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Abstract: The combined effects of martensite-austenite (MA) constituent and pearlite colony on cleavage crack initiation in the simulated coarse-grained heat-affected zone (CGHAZ) of V-N-Ti microalloyed offshore platform steel under different heat inputs were investigated. The results of welding simulation, instrumented impact test, and quantitative analysis indicated that the size of the MA constituent decreased with the increase in cooling time, and by contrast, the size of the pearlite colony increased. According to Griffith theory, the critical sizes of cleavage microcracks were calculated. With the increase of cooling time, the calculated microcrack size could be characterized by the size of the MA constituent first, and then fitted with the size of the pearlite colony. Moreover, the calculated microcrack size variation was opposite to the microcrack initiation energy. This phenomenon is probably due to the combined effects of the MA constituent and pearlite colony with increasing the cooling time of the specimen's temperature from 800 to 500 ℃.

Key words: simulated coarse-grained heat-affected zone; martensite-austenite constituent; pearlite colony; cleavage fracture; V-N-Ti microalloying

One of the development prospects of microalloyed steel with high mechanical properties for modern offshore platform application is to improve the high heat input weldability[1]. High heat input welding could promote the welding efficiency as well as minimize the construction period of offshore platforms[2]. However, severe toughness deterioration could occur on the heat-affected zone (HAZ) of the welding joint. Specifically, the coarse-grained heat affected zone (CGHAZ) shows conspicuous embrittlement, which is also referred to the local brittle zone (LBZ), has drawn the attention of numerous researchers[3-5]. During welding simulation, the CGHAZ experiences a peak temperature near the melting point and subsequently a medium cooling rate range. High peak temperature causes the failure of the particle pinning effect, thereby resulting in prior austenite grain coarsening. The brittle microstructures, including grain boundary ferrite, side-plate ferrite, coarse lath-/granular-bainite, and second phases (MA constituent, pearlite colony, etc.) are formed eventually in the CGHAZ because of the medium cooling rate and coarse-grained prior austenite[6,7].

The V-N-Ti microalloyed offshore platform steel is specially designed for high heat input welding through precipitation strengthening and grain refining strengthening to guarantee the toughness of CGHAZ. However, many aspects of CGHAZ toughness still deserve further investigation. According to the study of Li and Baker[8], the presence of MA constituent rather than carbide nor inclusion, plays a major initiation role of cleavage fracture in the intercritically-reheated coarse-grained heat-affected zone (ICCGHAZ). Lan et al.[9] stated that the size of MA constituents can characterize the nucleation size of cleavage cracks, which further confirms the deterioration effect of MA constituent on the HAZ toughness. Hu et al.[10] noticed that the pearlite colony is also the crack source, which could significantly decrease the crack initiation energy and crack

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propagation energy of CGHAZ. Chen and Yan[11] pointed out that the pearlite colony could act as the nucleus of cleavage fracture in CGHAZ. Although the MA constituent and pearlite colony are often preferred as the nucleus of cleavage fractures in CGHAZ or ICCGHAZ, quantitative studies of both the MA constituent and pearlite colony as cleavage microcrack nucleus are rarely reported. Moreover, the combined effects of aforementioned second phases on the cleavage microcrack in the CGHAZ under different heat input conditions still remain unknown.

The present work aimed to determine the influence mechanism of MA constituent and pearlite colony on cleavage crack initiation, and to ascertain their combined deterioration effects of MA constituent and pearlite colony on the toughness in CGHAZ of V-N-Ti microalloyed steel.

1 Experimental

Table 1 shows the chemical composition of the V-N-Ti microalloyed steel. The specimens for the welding thermal simulation were cut from an experimental steel plate and machined into samples with dimensions of 10.5 mm×10.5 mm×65 mm. This thermal simulation experiment was conducted on a Gleeble 3800 thermomechanical simulator. The welding thermal circle curves are illustrated in Fig. 1. The specimens were heated to 1350 ℃ at 100 ℃ • s^{-1} and held for 1 s, then cooled with $t_{8/5}$ (the cooling time of the specimen's temperature from 800 to 500 ℃) of 10, 30, 60, and 100 s, which were determined by the 2D Rykalin mathematical model to characterize the corresponding heat inputs.

Table 1 Chemical composition of V-N-Ti microalloyed steel mass%

C	Si	Mn	P	S	Al_s	Ni	Ti	V	N
0.147	0.28	1.55	0.009	0.001	0.036	0.005	0.011	0.074	0.009

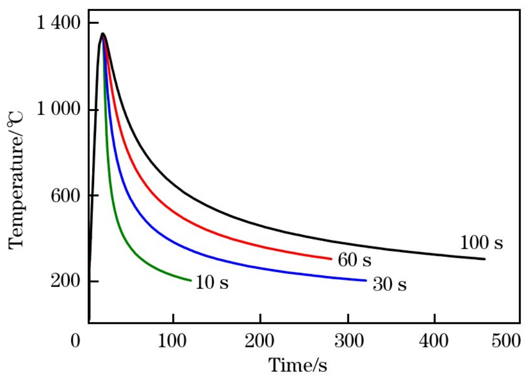

Fig. 1 Schematic illustration of welding thermal cycle curves for CGHAZ simulation

The specimens for the microstructural studies were wire-cut from the simulated specimens along the transverse direction, right on the thermocouple spots, and then prepared by standard mechanical polishing procedures and etched in a 4 vol. % nital solution. The processed specimens for the microstructure were observed using a Hitachi S4300 scanning electron microscope (SEM). Thin foil specimens of CGHAZ for the FEI Tecnai G^2 F30 transmission electron microscope (TEM) investigation were sliced and mechanically thinned to 50 μm, and then electropolished by a twin-jet electropolisher in a solution of 10 vol. % perchloric acid and 90 vol. % ethanol.

Quantitative microstructure examination was also conducted by SEM to clearly identify the MA constituent and pearlite colony[12]. The size and area fraction of at least 1000 MA constituents and 100 pearlite colonies were measured with SEM micrographs using the ImagePro Plus software. These micrographs were appropriately selected from 70 random fields for each specimen[13].

Standard Charpy V-notch (CVN) samples were obtained from the simulated CGHAZ specimens. Impact tests were conducted using an instrumented impact tester, and at least three impact test results for each of the heat inputs were recorded. The fracture surface of the CVN samples were etched with 4 vol. % nital solution for the SEM observation to reveal the location of the cleavage microcrack initiation. The CVN samples were cut, polished, then etched for secondary microcrack observation after the impact test, as illustrated in Fig. 2.

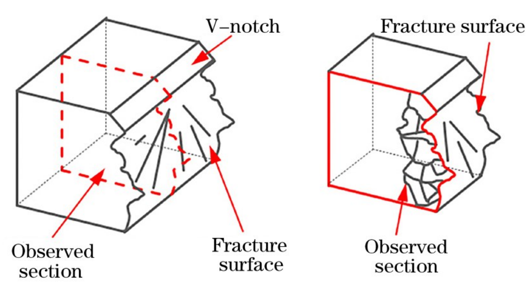

Fig. 2 Schematic of specimen cutting for secondary crack observation