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Citation	Transactions of JWRI. 2012, WSE2011, p. 101-104
Version Type	VoR
URL	https://doi.org/10.18910/23066
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A Study of Impact Toughness of Intercritically Reheated Coarse-grain Heat Effected Zone of Two Type X80 Grade Pipeline Steel

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ABSTRACT: The impact toughness of intercritically reheated coarse-grain heat-effected zone (ICCGHAZ) of ordinary X80 pipeline steel and X80 pipeline steel with excellent deformability with (Bainite +Ferrite) dual-phase microstructure was studied by means of thermal simulation technique、microscopic analysis method and impact toughness testing, especially discussed the embrittlement mechanism of impact toughness and microstructure of ICCGHAZ. The result indicate that impact toughness of the pipeline steel with excellent deformability and the ordinary pipeline steel have the same variation in different welding second thermal cycle peak temperature conditions. When the second peak temperature was in two phase (α+γ) temperature range, ordinary X80 pipeline steel and X80 pipeline steel with excellent deformability all show local embrittlement of ICCGHAZ. The local embrittlement in critical coarse grained region was caused mostly by grains growth and the increase in the number and size of Martensite /Austenite-constituent (M/A).
KEY WORDS: (X80 pipeline steel with excellent deformability), (ordinary X80 pipeline steel), (intercritically reheated coarse-grain heated-affected zone), (impact toughness), (M-A constituent)

1. Introduction

Pipeline steels with excellent deformability (EDPS) is the first choice of materials of pipeline with transiting geological disaster such as landslide, earthquake, etc. In recent years, it is also an important research direction in the field of pipe materials [1-3]. However, current research focus more on the method of obtaining EDPS and properties study, changes of microstructure and properties of EDPS after welding heat process involves rarely. In welding process, because heat affect zone (HAZ) of pipeline steel endures different thermal cycle, the microstructure of each HAZ region changes different, therefore it has different property. In these HAZ regions, especially in the CGHAZ, properties are the worst. For ordinary pipeline steels, in the process of secondary thermal cycling, the local brittleness of ICCGHAZ is common phenomenon [4-5]. So whether EDPS is also follow this rule has yet to be seen in the relevant reports. This article studied CGHAZ of ordinary X80 pipeline steel and X80 EDPS which is obtained by ICAC method, and emphatically discussed the influence rules of different welding second thermal cycle peak temperatures on the microstructure and properties of CGHAZ of X80 pipeline steels.

2. Test material and the Experimental procedures

2.1 Test material

The material used in this study is a 18.4mm thick plate of X80 steel. The chemical composition of the steel is 0.049C-0.23Si-1.80Mn-0.011P-0.0025S-0.018Cr-0.28Mo-0.25Ni-0.064Nb-0.0065V-0.013Ti-0.17Cu-0.027Al and balance Fe (wt.%). Its mechanical properties were: $R_{t0.5}$ = 575 MPa, R_m = 685 MPa, A = 26.3%, UA =5.8%, $R_{t0.5}$ /R_m = 0.84, CVN = 350J, Hv_{10} =281, n = 0.10.

2.2 Obtain EDPS (ICAC method)

According to the phase transition point (Ac1=770°C; Ac3=910°C) that obtain in the continuous cooling transformation study of experimental steel, 840°C were chosen as the heating temperature. The heat treatment process parameters that produce ferrite and bainite dual-phase pipeline steels is shown in Table 1. The heat treatment schedule is schematically shown in Fig.1. This heat treatment consisted of the following sequential steps: soaking in the salt-bath at the heating temperature for 11 minutes and finally quenching in water.

The specimens for the heat treatment were cut from the X80 plate in the transverse direction (T). The specimens with a 80×11×11mm size for the impact test. Heat treatment process was at the DM-135-25 salt-bath furnace.

Table 1 Heat treatment process parameters

Heating temperature / °C	Holding times / min	Cooling method
840	11	Water cooling

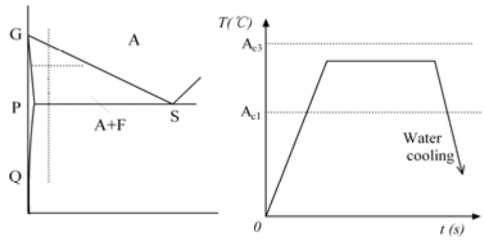


Fig.1 Schematic representation of the heat treatment schedules

2.3 Welding thermal simulation test

In order to obtain the microstructure of HAZ of second thermal cycling process of double-side welding or multi-pass welding, the thermal simulation samples had experienced twice thermal cycle in the test process. The thermal simulation parameters in the first thermal cycle were: the heat input was 20kJ/cm, heating rate was 130°C/s, peak temperature is 1300°C and $t_{8/5}$ was 20 seconds. In the secondary thermal cycle: the heat input and heating rate same as first cycle, but peak temperature was 1200°C, 1000°C, 800°C, 600°C, respectively, to simulate different zone of reheated HAZ, and $t_{8/5}$ still remain 20s.

Among them, the 4 kinds of second thermal cycle peak temperatures chosen are equivalent to the different zones of HAZ of multi-pass welding (see Fig. 2): Subcritically Reheated Coarse-Grained HAZ (SCGHAZ, 600°C), Intercritically Reheated Coarse-Grained HAZ (ICCGHAZ, 800°C), Supercritically Reheated Coarse-Grained HAZ (SCCGHAZ, 1000°C), Unaltered Reheated Coarse-Grained HAZ (UCGHAZ, 1200°C). The chosen $t_{8/5}$ is the welding cooling specification of obtaining the best properties of CGHAZ.

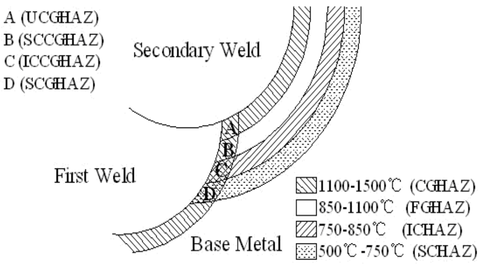


Fig.2 The schematic diagram of HAZ of multi-pass welding of pipeline steel

Thermal simulation tests were conducted on the Gleeble-2500 Thermo-Force Simulation System after duplex treatment. The determined thermal simulation parameters were input in Gleeble-2500 Thermo-Force Simulation System to implement thermal cycle simulation test on the samples under different norms.

2.4 Mechanical properties test and microstructure observe

After the thermal simulation test, the test samples were machined to standard Charpy V-notch impact specimens 55×10×10mm, then take them for mechanical properties test. The V-notch was at thickness direction of Impact specimen. Impact toughness was measured by standard impact electronic force test machine (JBC-500) at -20°C.

The samples used for Optical microstructure observation were mechanical polished, then etched by 3% nitric acid alcohol solution, then were observed by RECHART MEF3A optical microscope. Electronic scanning microscopic analysis and fracture analysis were at JSM-6390A type scanning electron microscope (SEM). For transmission electron microscopy (TEM) observation, the thin foils were mechanically thinned from 500μm to 50μm, and then electropolished by a twin-jet electropolisher in a solution of 10% perchloric acid and 90% acetic acid. Foils were examined by JEM 200CX TEM operated at 120kV.

3. Experimental results

3.1 Impact toughness test

The relationship between CVN impact energy and the peak temperature of secondary thermal cycle are shown in Fig.3 for ordinary X80 pipeline steel and X80 EDPS.

The results of Fig.3 show that the X80 EDPS and ordinary X80 pipeline steel have the same toughness CGHAZ variation at different secondary peak temperatures. When the peak temperature of secondary thermal cycle is in two phase region (α and γ), the CVN energy of ICCGHAZ is the lowest. Due to the sharp decline in toughness, ICCGHAZ became the weakest zone of whole CGHAZ, showing ICCGHAZ local brittleness [4-6].

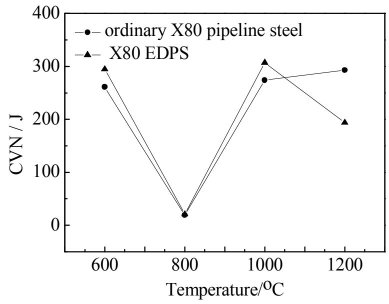


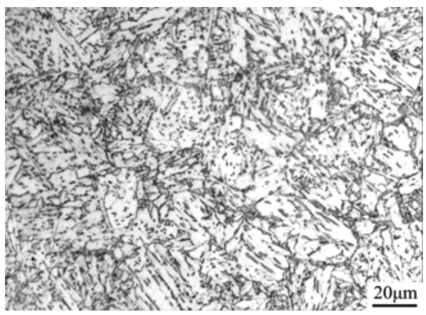
Fig.3 Impact toughness at different secondary peak temperatures

3.2 Microstructure of ICCGHAZ

The change rules of impact toughness of the test steel can be described with the microstructure which is obtained in welding thermal simulation tests. What the Fig.4 shown is the optical microstructure of ICCGHAZ of ordinary X80 pipeline steel and X80 EDPS when secondary peak temperature is 800°C.

The Fig.4 shows, in the process of second thermal cycle of multi-pass welding, ICCGHAZ of X80 EDPS and ordinary X80 pipeline steel present similar changes in the type, shape, size and distribution of microstructure composition phase. After second thermal cycle, the coarse parent austenite grain boundary of ICCGHAZ is visible. Parent austenite grain boundary, boundary of laths of granular bainite and lath boundary distribute big M-A constituent [6-8].

(a) Ordinary X80 pipeline steel



(b) X80 EDPS

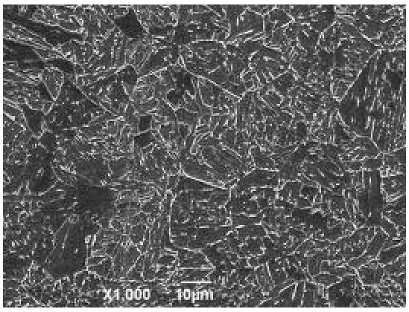
Fig.4 Optical microstructure of CGHAZ of ordinary X80 pipeline steel and X80 EDPS

4. Discuss

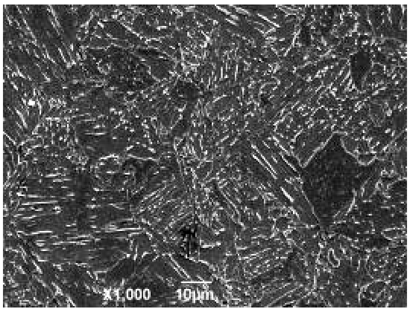
By analyzing the microstructure of test steels, it can be known that there are various factors causing local brittleness of ICCGHAZ of pipeline steel. The local embrittlement in critical coarse grained region was caused mostly by grains growth and the formation of M/A.

4.1 Coarse-grain

When the CGHAZ in ordinary X80 and X80 EDPS is reheated to temperature between A_{c1} and A_{c3}, austenite grains recrystallization occurs partial, the grains of ICCGHAZ have not be fined (Fig.5b,6b).

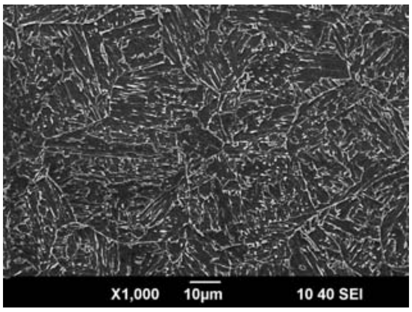


(a) CGHAZ

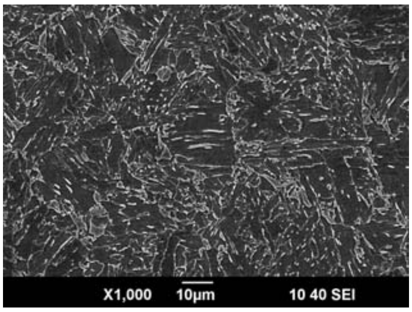


(b) ICCGHAZ

Fig.5 SEM micrographs of CGHAZ and ICCGHAZ of ordinary X80 pipeline steels



(a) CGHAZ



(b) ICCGHAZ

Fig.6 SEM micrographs of CGHAZ and ICCGHAZ of X80 EDPS

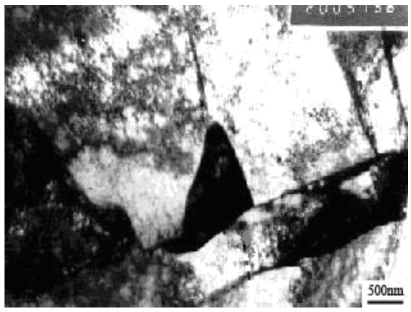
It is the point of the theory of materials phase transformation that the microstructure of CGHAZ is non-equilibrium microstructure of acicular ferrite (AF). This AF transformation occurs through shear phase-transformation process on the $\{111\}_\gamma$ of austenite, and keeps *K-S* relationship with parent phase [10]. When this non-equilibrium microstructure of CGHAZ is reheated to two phases region (α and γ) between of A_{c1} to A_{c3}, the nucleation of new austenite always keeps parallel to close-packed planes and close-packed directions of AF in order to reduce the resistance of phase transformation. Because of this nucleation with orientation, the new austenite inherits the coarse grain of CGHAZ. Although grains recrystallization has occurred partial, the grains is not fined and the toughness of ICCGHAZ is not improved. When the peak temperature of secondary thermal cycle is high up to 1000°C over the two phases region (α and γ), the full recrystallization of austenite in CCHAZ occurred, to lead to microstructure fined and combination of strength-toughness improved [6-8].

4.2 M-A constituents

The local brittleness of ICCGHAZ is related to grain size as well as the M-A constituents that form in the secondary welding thermal cycle process. SEM micrographs of CGHAZ and ICCGHAZ of experimental steels are shown in Fig.7 and Fig.8(b, c). It can be found that the M-A constituents of CGHAZ and ICCGHAZ are different. The shape, content and size of M-A constituents are very important factors for local brittleness of the ICCGHAZ [8-10].

Fig.7 presents that the M-A constituents of ICCGHAZ.

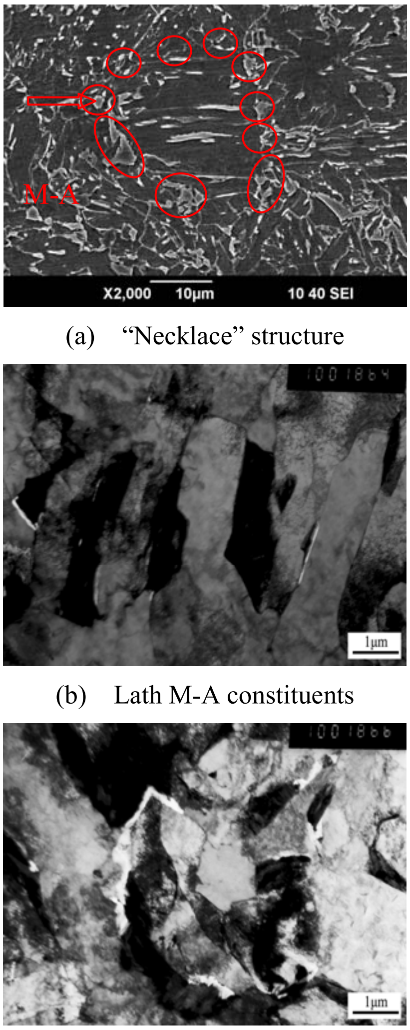
(a) Lath M-A constituents



(b) Blocky M-A constituents

Fig.7 TEM micrographs of M-A constituents in the ICCGHAZ of ordinary X80 pipeline steels

There are two types of M-A constituents: lath and block. Coarse grains of CGHAZ provide thermodynamic conditions for the formation of M-A constituents, so that M-A constituents are formed preferably at the boundaries of blocky prior austenite grain. According to the observation of OM, M-A constituents can be observed as “necklace” structure along with the boundaries of prior austenite grain (Fig.8a). Sometimes, the M-A constituents are also formed at packet interfaces and lath boundaries of AF. In general, the shape of M-A constituents is different when formed at different position. Lath M-A constituents (Fig.8b) is formed at packet interface of AF, small massive blocky M-A constituents (Fig.8c) are formed at lath boundaries of AF.



(a) "Necklace" structure

(b) Lath M-A constituents

(c) Blocky M-A constituents

Fig.8 M-A constituents in the ICCGHAZ of X80 EDPS

Although some research results showed that lath M-A constituents maybe induced crack more easily, however, a few research results also showed that the main influencing factor of local brittleness was not the shape of M-A constituents, but the content and size of M-A constituents. The measurement results of content, size and hardness of M-A constituents in the X80 pipeline steels are listed in Table 2.

Table 2 Content, size and hardness of M-A constituents

	Ordinary X80		X80 EDPS	
	CGHAZ	ICCGHAZ	CGHAZ	ICCGHAZ
Content / %	10.9	12.5	9.2	12.9
Average length/μm	0.8	1.2	1.2	1.8

It can be found that, both ordinary X80 and X80 EDPS, M-A constituents in the ICCGHAZ is much more and bigger than that in CGHAZ, which are easy to constitute the critical size of Griffith crack, so ICCGHAZ more easily lead to local brittleness. Therefore, M-A constituents is the main reason resulting in the local brittleness of ICCGHAZ.

5. Conclusions

(1) Under the secondary thermal cycling process of double-side welding or multi-pass welding, the X80 EDPS and ordinary X80 pipeline steel have the same toughness CGHAZ variation at different secondary peak temperatures, exhibit local brittleness of ICCGHAZ.

(2) When the peak temperature of secondary thermal cycle is in the temperature range of two phase region(α and γ) of experimental steels, the grains of ICCGHAZ do not be fined although austenite partial recrystallized, so that the toughness do not improved.

(3) Larger size and higher hardness of M-A constituents are main factor resulting in the local brittleness of ICCGHAZ, in ordinary X80 pipeline steel and X80 EDPS.

Acknowledgements

The authors acknowledge the supported by National Natural Science Fundation of China(50874090) and Materials Processing Engineering key subject of Shaanxi province at the Xi'an Shiyou University.

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