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Study on the Localized Preheating Effects on Crack Resistance of Welded Joints

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Abstract

It is proved from the experimental results and analyses that localized preheat plays a duplex role in the crack resistance. On one hand, localized preheat improves the micro-structure and properties of welded joints and speeds up the escaping of the diffusible hydrogen and thus, enhances the crack resistance; on the other hand it increases the welding restraint stresses and then reduces the crack resistance. It is obvious that under a certain restraint condition an "optimum temperature renge for localized preheat" may exist, within which no cracking would occur in welded joints on account of the duplex role.

KEY WORDS: (Localezed Pewheating)(Welded Joints)(PRRC Test)
(Crack Resistance)

1. Introduction

It is known that preheat is one of the most commonly used ways to enhance the crack resistance of welded joints of HSLA steels. Unfortunately it is usually not as easy to adopt in commercial welded structures the overall preheating technique as in diminutive specimens for experiments such as the slit type cracking test and so on. Therefore the study of localized preheating effects on the crack resistance of welded joints is regarded as a research of essential significance for welding engineering. In our project, the localized preheating effects on restraint stresses and crack resistance of welded joints were studied through the plate Rigid Restraint Cracking Test (PRRC) and is supposed to be of great significance to the fabrication of welded structures in engineering.

2. Experimental Material and Procedure

(1) Experimental Material

The material adopted in this study was 14MnMoNbB which was a Chiness-made HSLA steel whose yield strength was 70Kgf/mm^2 and it had ever proved successful in the manufacture of installations such as muticoated high pressure vessels, forked high pressure pipes for power stations and so on [1]. Its chemical composition and mechanical properties are given in table 1 and 2.

14MnMoNbB was supplied in thermal refining state and its original micro-structure was Bainite and the Vickers diamond hardness HV10Kg = 268. The electrodes adopted were H14, the match for the steel, and had been baked for 2 hours at 400°C before the operation. The heat input E was 14.88 KJ/cm.

(2) Procedure of Plate Rigid Restraint Cracking Test

(a) Preparation of Specimens:

The specimens were sized according to shape requirements, the thickness h being 28 mm and the width B 100 mm. The restraint length L ($L = l_1 + l_2$) was determined on each separative experiments. Its should be pointed out that the groove of the specimens could be shaped and sized significantly in accordance with that of a commercial engineering structure in order to obtain more accurate and practical experimental results. The groove geometry adopted in this study is as shown in Fig.1.

(b) Calculation of the Restraint Intensity:

In this study, the formula calculating restraint intensity of the specimens was derived from the finite element method of elasticity as the following:

$$R = \frac{R_{RRC}}{1+1.757 \times 10^{-8} \times R_{RRC}} \ (\text{Kgf/mm.mm})$$

wherein:

$$R_{RRC} = \frac{E \cdot h}{l_1 + l_2}$$

E ---- Modulus of elasticity (Kgf/mm^2)

h ---- Thickness of the specimens (mm)

l_1 , l_2 ---- Half the length of the specimens (mm)

(c) Specimen Fix:

Contaminants and dirts were thoroughly removed from around the groove and end tabs were tacked on the specimen before it was installed between the two restraint plates and fixed with fix stoppers to make its axis concord with that of the restraint plates. Then primary and ultimate fastening were conducted with high strength bolts to ensure a rigid fixing. This restraint state should be kept over 16 hours after the welding operation.

(d) Preating:

The localized preheat to specimen was carried out with a diminutive flat electric heater through the window in the restraint plates.

(e) Measurement of Weld Thermal Cycle:

The weld thermal cycle was measured and recorded through the blind hole method with a chart recorder for the analysis after the experiment.

(f) Measurement of Weld Restraint Stress:

The restraint stress was measured through a resistance strain gauge installed on the restraint plates and recorded through a dynamic resistance strain gauge with a DQX-76 long chart self-balanced recorder.

(g) Calculation of the Weld Restraint Stress:

Average welding restraint stress of a PRRC weld specimen σ_w was calculated as the following:

$$\sigma_w = \frac{P}{\frac{1}{N} \sum_{i=1}^{N} h_{wmin}}$$

wherein:

P ---- welding restraint force

N ---- number of the cross-sections measured (commonly N = 3)

h_{wmin} ---- minimum thickness of weld cross-sections

(h) Cracking Detection:

The initiation and development of cracking in the PRRC specimens were detected with a sonic cracking detector and a weld restraint force recorder. The specimens were dissected after welding and the cracks were examed by metaloscopy. External cracks could be checked before the dissection through a magnetic particle examination.

3. Analysis and Discussion on the Experimental Results

The experimental results of localized preheating effects on the crack resistance of the welded joints of 14MnMoNbB steel obtained in this project are shown in Fig.3 and table 3 and those on the hardness of HAZ are shown in table 4.

n ---- the number of cross-sections with cracks
N ---- the number of dissected cross-sections
This datum is calculated with the average thickness of fractures measured.

It can be known from the experimental results that the crack resistance of 14MnMoNbB steel welded joints is not only related with the conditions of restraint but also with that of the localized preheat. Besides, it is obvious as well that the crack resistance is not simply linear with the localized preheating conditions and the restraint intensity of welded joints, namely, high localized preheating temperature does not surely result in great crack resistance. Factors influencing the complication of cracking probability under localized preheating conditions are many-sided. It is known to all that the three principle factors that affect the initiation and development of cold cracking in welded joints are the content of hydrogen, the structure and properties of HAZ and the welding restraint stresses. Since localized preheat influences these three factors separately, it does influence the crack resistance.

(1) Effects on the Hydrogen in Welded Joints

The distribution and diffusion of the hydrogen in welded joints are influenced by many factors. The initiation and development of cracks are directly related with the hydrogen diffusion, which is affected by the temperature. Generally, the structure and properties of HAZ are influenced by the cooling time $t_{8/5}$ while the distribution and escape of hydrogen by t_{100}. It was proved from the experimental results that $t_{8/5}$ and t_{100} became longer as the localized preheating temperature being raised up. But the t_{100} increased greater than $t_{8/5}$. From the First Fick's Law it is known that difference in temperature T results in a indexical variation in diffusion coefficient. Preheating can increase the remaining time at relatively high temperature and thus it helps the hydrogen escape from welded joints, meanwhile, the space lattice increase at high temperature while the diffusion energy of hydrogen decreases, which made it difficult for hydrogen to accumulate to a great content at some lattice defects. All this results in a difficult crack initiation and development. It is apparent from this point that localized preheat can enhance the crack resistance of welded joints.

(2) Effect on the Structure and Properties of Welded Joints

One of the essential approaches through which the crack resistance is improved by preheat is the accomendation of structure and properties of welded joints. The quantity of the hardened structure in HAZ is decreased as the localized preheating temperature rises up and the cooling time $t_{8/5}$ becomes longer. It was known from the analysis on the micro-structure in the HAZ of 14MnMoNbB steel welded joints under various localized preheating temperature that the structure of the welded zone was improved with the increase of localized preheating temperature, which promoted the refincing of the originally coarse Martensite lath, the increasing of Bainte and the presenting of Ferrite. This conclusion can be well proved through the hardness analysis given in table 4. It was known from the scanning electron microscope analysis on the fracture of

14MnMoNbB steel with localized preheat and without preheat that with localized preheat, the morphology appeared principally fine hackly fracture, as shown in Fig.4(a) while without preheat the fracture was principally intercrystalline fracture, pseudo-cleavage fracture, as shown in Fig.4(b) and Fig.4(c). It can be learnt from this that localized preheat not only reduces the hydrogen content in the welded joints but also accomendates the structure and properties of the welded zone and thus improves the morphology of the fracture. This compline with the Hydrogen Induced Cracking Theoty of Beachman.[4]

(3) Effect on Welding Restraint Stress

Another essential way through which localized preheat influences the crack resistance of welded joints is its effect on the restraint stress. Under localized preheat condition, the welding restraint stress is determined not only by restraint intensity of the welded joint but also by the factors such as the temperature and width of the localized preheated zone and so on.[2]

A calculation with the welding experimental data of this study showed that the welding restraint stress doubled when the localized preheat temperature got over 200°C. Therefore as the localized preheating temperature was held higher up, the welding restraint stress would considerably increase until the weld metal and the HAZ reached the yield point. It is shown in Fig.3 that although the cold cracking in the experimental songle-V groove with broad root face welded joint whose restraint stress R = 901.0Kgf/mm.mm was successfully prevented, the restraint stress increased from 37.31Kgf/mm^2 up to 60Kgf/mm^2.

It can be known from the above analysis that the localized preheat plays a duplex role to the crack resistance of welded joints. Localized preheat on one hand improves the thermal cycle and promotes the escape of hydrogen from inside welded joints, thus it raises the crack resistance of welded joints, on the other hand it induces the additional restraint stresses and increases considerably the welding restraint stresses which implies a better mechanical condition for the initiation and development of cracking, thus it decreases the crack resistance. This duplex effect results in complication of the cold cracking trend in the welded joints of structures. In the welded joints of little restraint intensity, the advantage of localized preheat from improving the micro-structure and promoting hydrogen escape is greater than its disadvantage from increasing restraint stress, therefore, the crack resistance increases. For instance, a 14MnMoNbB steel structure of restraint intensity R = 901Kgf/mm.mm which cracked in welded joints when without preheating proved no cracking when preheated at 100°C. From the data in table 3 and Fig.3 it is known that with the identical preheat consition the welded joints of great restraint intensity cracked because the disadvantage of localized preheat from the increase of restraint stress was greater than its advantage. For example, the 14MnMoNbB steel welded joints of restraint intensity R = 1117.4Kgf/mm.mm cracked when the preheating temperature T_0 = 100°C. When the temperature was raised with the restraint condition remained the same, the improvement of the structure and properties of the welded joints and the promotion of hydrogen escape by preheat overwhelmed the decrease of crack resistance caused by the increase of welding restraint stress, therefore ensured the quality of the welded joints. The 14MnMoNbB steel welded joints of R = 1117.4Kgf/mm.mm no longer cracked when preheated at 150°C.

If the localized temperature is further raised, the welding restraint stress will increase immencely even over the tensile strength of weld metal and the base metal, therefore the crack potentiality will increase greatly and the crack resistance will considerably decrease. Under the experiment condition adouped in this study, the 14MnMoNbN steel welded joint of restraint intensity 1117.4Kgf/mm.mm cracked at 183 minutes after having been welded, (while no cracking occurred when preheated at 150°C) which proved the disadvantage of over-temperature preheat.

It is apparent from the above analysis that with localized preheat, a proper localized preheating temperature, with which no cracking occurrs, exists for the welded joint of certain restraint condition, namely, the optimun localized preheating temperauture. Under the experiment conditions adopted in this study, this temperature was about 150°C for 14MnMoNbB steel structure of restraint intensity 1117.4Kgf/mm.mm.

It should be pointed out that the optimum localized preheating temperature does not remain constant but varies with the effect of many factors. In the procedure of practical welded structures, the localized preheating temperature should be determined with great care. As long as the satisfactory structure and properties of welded joints and the sufficient hydrogen escape can be achieved, the width and temperature of localized preheat should be decreased as much as possible and strictly controlled in fabriation. It is necessary, both for increasing crack resistance and ensuring the safety of welded joints in operation, to make proper subsequence for welding operation and structure assembly to decreace the restraint intensity of the welded joints.

4. Conclusion

(1) It is proved by metallographic analysis and scanning electron microscope examination on fracture that localized preheat can improve the structure and properties of welded joints and benefit the crack resistance.
(2) Localized preheat improves the thermal cycle and promotes the hydrogen escape from inside the welded joints.
(3) Localized preheat increases welding restraint stresses greatly and decreases the crack resistance severely.
(4) Localized preheat plays a duplex role to the crack resistance of the welded joints under a rigid fixing condition. With certain localized preheating width, an optimum localized preheating temperature exists for the welded joints of relative restraint intensity.

Reference

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[2] Hou Wenkao "The Study on the Plate Rigid Restraint Cracking Test of High Strength Low Alloy Steel" Graduation Thesis of Postgraduates of Tianjin University, Jan. 1983, P.33,58,82
[3] Li Guangyuan "Finite Element Method" Calculation Programm for PSLF-2 Plate Elasticity, June 1982.
[4] C. D. Beachman "A Model for Hydrogen Established Cracking (Hydrogen Embrittlement)" Metallurgical Transactions 1972, No.2

Table 1. Chemical Composition of 14MnMoNbB Steel (%)

C	Mn	Si	S	P	Mo	Nb	B	IIW C_{eq}	Ito. Bysso P_{cm}
0.141	1.41	0.21	0.011	0.020	0.52	0.050	0.0028	0.48	0.2711

Table 2. Mechanical Properties of the Experimental Material

Material	σ_s (Kgf/mm^2)	σ_b (kgf/mm^2)	δ (%)	ϕ (%)
14MnMoNbB	82.2	98.6	19.0	68.0

Table 3. The Effects of Localized Preheat on the Crack Resistance of the Welded Joints of 14MnMoNbB

T_0 (°C)	restraint intensity R (Kgf/mm.mm)	$t_{8/5}$ (sec)	t_{100} (sec)	σ_w (Kgf/mm^2)	n/N *
room temperature	901.0	6.5	10.3	37.31	1/8
100	901.0	7.75	35.9	60.0	0/8
100	1117.4	7.75	35.9	70.1	2/8
150	1117.4	10	498	75.418	0/8
150	1117.4	10	498	77.16	0/8
200	1117.4	15	1175	89.8**	fracture

Table 4. The Effects of Localized Preheat on the Hardness of the Welded Joints

preheat temperature T (°C)	hardness of welded joints (HV10Kg)	hardness of HAZ (HV10Kg)
No	297, 274, 297	381, 101, 383
100	297, 285, 297	390, 401, 383
150	297, 274, 285	383, 351, 366
200	285, 274, 254	285, 285, 286

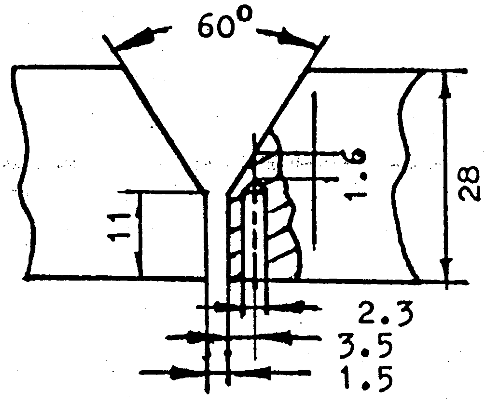


Fig. 1
Single-V groove with broad root face adopted in the experiment

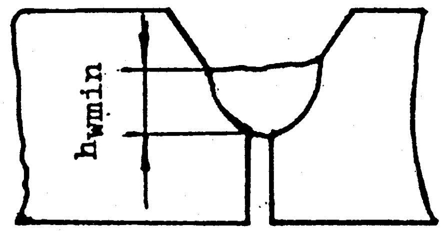


Fig. 2
Determination of the cross-section dimension of welded joints

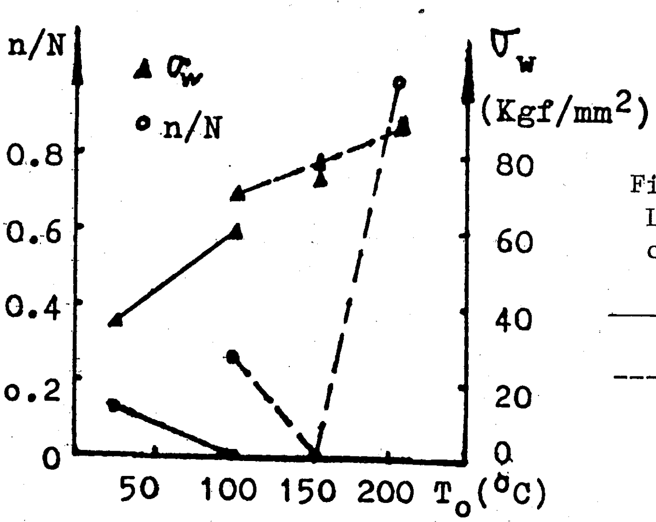
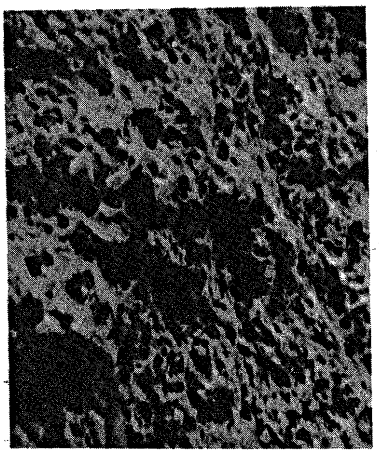


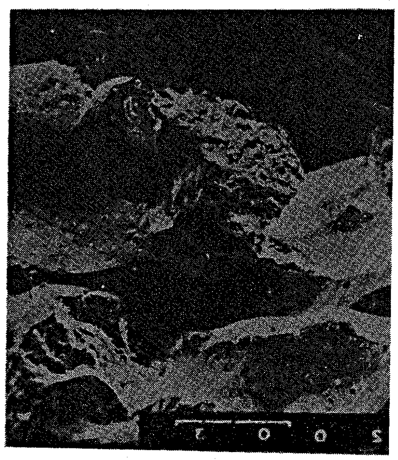
Fig. 3
Localized Preheating effect on the crack resistance of welded joints

——— R = 901 Kgf/mm.mm

----- R = 1117.4 Kgf/mm.mm

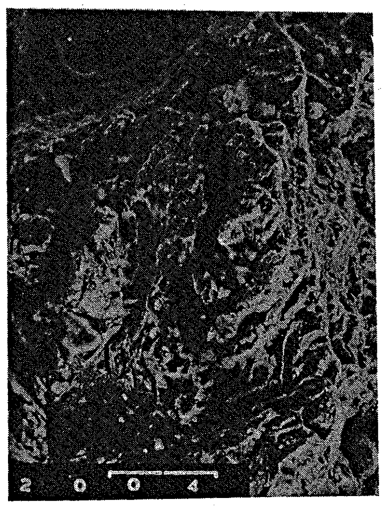


(a)×640 DR
preheat temperature
T_0 = 200°C



(b)×320 IG

not preheated



(c)×320 QC

not preheated

Fig. 4
Fracture of the PRRC specimen of 14MnMoNbB steel