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Microstructure influence on crack resistance of steels welded structures operated in an extremely cold environment

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Abstract

The weld joints are characterized by microstructure inhomogeneity and defects due to non-uniform heating and cooling particularly at service while operating in extremely cold environment. Vickers micro hardness measurement was done on hard probes of welded samples of low-alloyed 14H2GMR and low-carbon St3sp steel. Experimental study was carried out to see the thermal cycling influence on the heat-affected zone properties. It was discovered that, welding at -40°C does not lead to a significant increase of steel micro hardness as compare to welding at +20°C despite the large difference in cooling rates. It was also discovered that, the crack grows mainly along the grain boundaries of martensite and bainite (as over chilled austenite), but in some cases passes through the grain body and cuts across it at 14H2GMR for pipe steel. For structural St2sp steel the inter granular cracks are revealed both in weld metal and in the heat affected zone nevertheless of milder test conditions against hard technological probes.

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1. Introduction

The formation of cold cracks is often connected with the overheating in the heat affected zone (HAZ) of a part or a sample in which the adverse combination of structural factors, such as intensive growth of grains with high level residual stress and strain, and rather high content of hydrogen observed. Therefore one of the relevant directions of actual researches is the assessment of structural heterogeneity, mechanical properties and damage of HAZ in a weld joint, as pointed by Markashova et al (2019). This is very important especially when welding equipments are operating in extreme climatic conditions such as the North of Russsia, the Arctic and the Subarctic regions.

The most widely applied in-process tests of weld joints of low-alloyed high-strength steels for the assessment of cold cracking sensibility are the hard tests named "Likhaysky" and "Tekken", suitable standardized in Industrial Welding Handbook (1979). Revelation of cracks from these tests occurs as a result of action of high shrinkable tension in a root pass of a weld joint by the stress concentration due to lack of fusion. However if in the "Likhaysky" test the crack resistance criterion serves the maximum depth of cuts with which the cracks do not appear, then in the "Tekken" test criterion serves a critical cooling speed, as shown by Derlomenko et al (2010). Tough in-process test with a unilateral bevel of one edge causes the high stress concentration in a weld root. In this case the crack usually arises in the large grain area located directly abroad fusion weld and extends both on weld metal and HAZ.

Nomenclature

B	bainite, an aggregate of iron carbide and ferrite
C	hydrogen content, cubic cm per 100 grams of metal
C_H	cold cracking susceptibility indicator forweld vertical section, %
C_R	cold cracking susceptibility indicator for weld root, %
C_S	cold cracking susceptibility indicator for weld surface, %
d	diagonal of a print of a diamond pyramid in microns
F	ferrite, bcc form of pure iron
HAZ	heat affected zone
H_C	heat affected zone
HV	Vickers hardness (diamond pyramid hardness)
HV_{max}	maximum value of Vickers hardness
I_W	welding current, A
L	weld length
M	martensite, a hard and very brittle solid solution of carbon in iron
T_{pr}	preheating temperature, Celsius degrees
U_W	welding voltage, V
V_W	welding speed, mm/s
$W_{600/500}$	weld cooling rate from 600 to 500 Celsius degree, °C/s

2. Materials and equipment

In order to study the influence of cooling speed in the temperature range between 600 to 500 Celsius on the microstructure of metal and its hardness in a weld joint and its tendency to formation of cold cracks, the hard tests were chosen for steel 14H2GMR at the probes sized of 200×150×16 mm. The weld was done by ∅4 UONI-13/55 electrodes. Before welding, the electrodes were annealed at a temperature of 420 Celsius within two hours that provided hydrogen level in a metal, approximately equal $C = 3$ cm^3/100 g. Hydrogen content was determined by a glycerine method.

The welding conditions were chosen as follows: $I_W = 180$ A, $U_W = 22$ V, speed of welding of $V_W = 2.5$ mm/sec. One sample was performed by austenitic weld and OZL-18 electrode. Control of a thermal cycle of HAZ was done by means of the chromel-alumel thermocouple, with a diameter of 0.4 mm. For the micro analysis, the area along the weld joint across the crack was chosen.

The measurement of microhardness on a cross section of a welded sample is executed with intervals of 0.5 mm between the neighboring measurement of the PMT-3 device and after 5÷8 sec endurance under loading.

The analysis of a microstructure of base metal, weld metal and HAZ was carried out by means of a Neophot-32metalgraphic microscope. The structure of various zones of 14H2GMR steel welded samples studied by means of etching 4% Nita composition. The reactant which compose of water solution of picric acid, Syntol, sulfoamidoparaffin and sodium chloride is applied to identify the grain boundaries.

For the comparison of microhardness, the structure and crack resistance of St3sp steel weld joint after the low-cyclic fatigue tests were also carried out by Saraev et al (2016). The phase components of the St3sp steel probe structure was revealed by etching previously grinded by an emery paper in decreasing granularity order and polished by diamond paste; composition of the reagent for etching is four percent nitric acid solution of ethanol.

3. Results and discussions

Assessment of the weld joint cold cracking susceptibility has been made by three indicators, as established in Industrial Weld.Handbook (1979):

$$C_S = \frac{L_S}{L} \times 100\%. \tag{1}$$

$$C_R = \frac{L_R}{L} \times 100\%. \tag{2}$$

$$C_H = \frac{H_S}{H} \times 100\%. \tag{3}$$

Where ΣL_S and ΣL_R are the sum of the crack lengths respectively on a surface and in a weld root; L – total weld length; H and H_S are the weld height and the sum of the crack lengths in a vertical cross-section (an arithmetic average value on four sections).

Determination of the parameters (1-3) was made after 10 days from the end of welding (see Table 1).

Table 1.Results of the toughness tests for 14H2GMR steel probs.

T_{pr}, °C	Cs,%	C_R,%	C_H,%	HV_{max}	$W_{600/500}$, ℃/s	Phase components
-40	100	100	100	380	16.0	58% M, 35% B
20	100	100	100	380	15.5	55% M, 36% B
65	100	100	100	375	16.5	59% M, 35% B
80	0	37	20	375	15.5	55% M, 36% B
90	100	100	100	370	13.5	54% M, 37% B
90	100	100	100	360	11.8	52% M, 37% B
120	0	100	40	325	12.2	52% M, 37% B
160	0	36	56	310	7.8	49%M, 37% B, 10%F
20	0	29	52	360	30.0	65% M, 35% B

Calculation of Vickers microhardness was made by a formula:

$$HV = 1854\frac{100}{d^2}. \tag{4}$$

Microhardness measurements results calculated according (4) for 14H2GMR steel probes are shown in fig.1. The maximum hardness of HV_{max} is revealed in HAZ directly behind the weld metal that is confirmed by other research authors also, for example by Saraev et al (2016), Khanna and Maheshwari (2017), Pang et al (2011). Preheating at

90 °Csmoothened the hardness distribution on weld joint section, however the maximum hardness value does not change, so the 100 °Cpreheating only leads to significant decrease in HV_{max}.

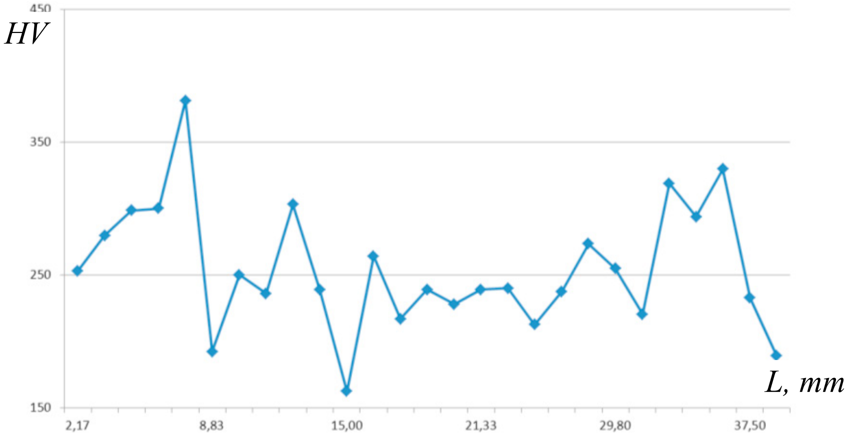

Fig. 1.HV microhardness distribution forHAZ of 14H2GMR weld steel probe.

The microhardness measurement revealed that welding at -40 °C ($W_{600/500}$ =17 °C/s) does not leads to significant increase in HV_{max}value in comparison with the welding at 20 °C ($W_{600/500}$ =10-12 °C/s).

In fig. 2, the micro Brinell HB distribution (the scale of HB corresponds to about 3*HV [1]) has been presented in weld and HAZ for the weld joint of St3sp steel probe after the low-cyclic fatigue tests, made by Bisong et al (2017). Microhardness distribution showed the uniformity of phase structure, and the maximum values quantitatively characterized the mechanical strength of phase terms. Therefore, it is possible to estimate the crack resistance of the weld joint, because the more the uniformity of structure, the higher the resistance to crack formation and growth also.

It should be noted that the microhardness distribution on fig. 2 is not typicalfor most of weld joints, as shown by Saraev et al (2016), Khanna and Maheshwari (2017), Harish Arya (2013),because the high inhomogeneity of structural components distribution corresponds to hard weld toughness tests. The cold cracks susceptibility of steel is much easier revealed in such conditions.

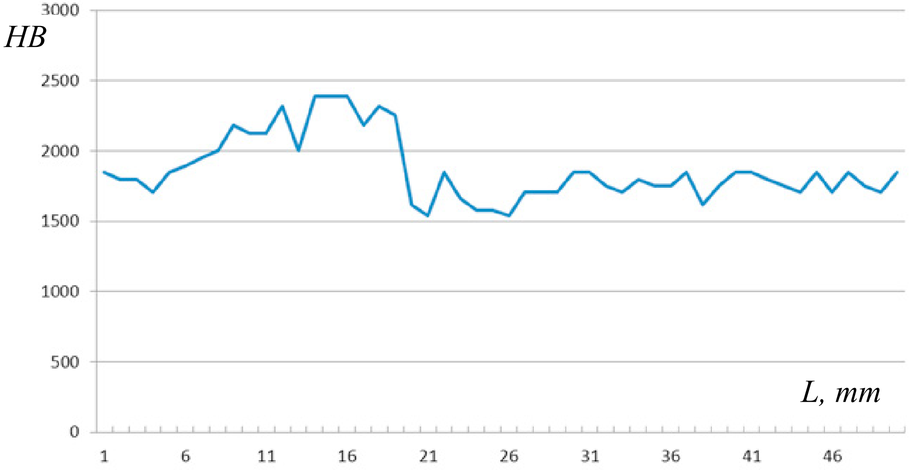

Fig. 2.HB microhardness distribution for HAZ of St3sp weld steel probe after low-cycling fatigue test.

The structure of the base metal in 14H2GMR steel probes is martensite with a score of 7÷8 grains (by Russian standard GOST 5639-82) and with 252-268 HV hardness. The incomplete recrystallization weld potion consists of sorbite-like structure with 373-380 HV hardness. The fine grain area is characterized by presence of the mixture of martensite and intermediate transformation products with 380-387 HV hardness. In a large grain area the score changes from 8÷10 to 4÷5 grains, and the bainite-martensitic structure with 376-390 HV hardness in the overheating zone is revealed also. Observations on cold cracks growth in the micro section in the weld joints for low-alloyed high-strength steels showed that the most sensitive to delayed fracture is an area with the large grains located at 0.1-0.4 mm distance from the fusion border of HAZ. The heat in the Metal increases right up to 1350 ^{0}C here and the crack grows mainly on the bainite (as an overcooled austenite) grain borders, but can pass through and cuts the grain body in some regions of the micro structure.

For St3sp steel probe the base metal microstructure represents the ferrite and pearlite with the score of 11-12 grains that corresponds to an average diameter about 7 microns. The weld joint metal structureis ferrite and perlite (the column crystals of cast metal). In HAZ of the Widmanstätten figures has been slightly observed to score 1 grain by scale of Russian standard GOST 5640-68. HAZ width is about 1.5 mm. At different areas of HAZ the fine-grained ferrite-perlite structure with the various dispersibility has been observed. The cracks formed primarily in HAZ, but also observed in the weld zone.

4. Conclusion

The observations of cold cracks formation process in low-carbon and low-alloyed steel weld joints showed that the most sensitive to delayed fracture area is the heat affected zone with the coarse-grained structure located at 0.1-0.4 mm distance from the heating up to 1350 °C fusion boundary. Steel weld joint microstructural research and microhardness distribution analysis showed that the crack growth in the HAZ depends on the stiffness of stress-strain state and does not depend on the welding temperature, Cold cracks occurred permanently on grain boundaries of overheated bainite for low-alloyed 09H2GMRsteel, and on martensite grain boundaries for low-carbon St3sp steel probes so. Thus the toughstress-strain state included caused by operation at low temperature conditions causes the high heterogeneity of mechanical properties in HAZ that provokes the cold cracks formation and delayed fracture of structural members.

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