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SMALL-SIZED PROCESS TEST FOR THE EVALUATION OF COLD CRACKING SUSCEPTIBILITY OF WELD METAL

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ABSTRACT

A new weldability test has been developed that allows experimental determination of the critical preheating temperature necessary to prevent the formation of cold cracks in welded joints. The new geometry of the welding unit allows combining the bending stresses with normal transverse and longitudinal ones, increasing the test stiffness. The proposed test sample design has lower metal content and allows its repeated use. The weldability of hardening steels with different degrees of alloying was tested with application of the new test. The obtained test results are comparable to the results obtained in other studies of steel weldability and they have been recommended for use under production conditions.

KEYWORDS: welded joints, cold cracks, welding tests

INTRODUCTION

The most dangerous defect of the welded joints is cold cracks, occurring in welding the hardening steels. Their formation is due to the action of a complex of factors, in which some of the main ones are the structural stresses arising as a result of martensitic or bainitic transformation and presence of hydrogen in the metal. Appearance of cold cracks can be also promoted by formation of segregation interlayers, nonmetallic inclusions, etc.

The cold cracking process is essentially influenced by the welding modes, as the width of the HAZ, cooling rate of the weld and HAZ and level of postweld stresses depend on the welding mode. Diverse process tests are used to assess the susceptibility of the welded joint metal to cold cracking. Such process tests have their advantages over the full-scale tests of the welded structures, first of all, due to a lower metal content and cost [1].

Research on development of the methods for assessment of the cold cracking susceptibility of the welds began as far back as in the thirties of the last century and continues to this day [2–6]. Process tests differ by their design, dimensions, conditions and technology of welding, method of detection of the presence or absence of cracks, and crack resistance index. Each test envisages intensive development of one or several factors, causing the cold cracking. Such factors can be: hydrogen concentration; accelerated cooling to increase the degree of hardening; and higher stress level. Test samples of different design have different effectiveness of evaluation of the cold cracking susceptibility of the materials.

A large number of tests for assessment of the cold cracking susceptibility of steels and alloys are known in the world practice of studying their weldability [7]. Most of the tests, as well as the methods for calculated assessment of the cold cracking resistance were developed and tried out on the classical high-strength low-alloyed steels. Recently, however, the high-alloyed martensitic steels have been ever wider used, which often differ considerably by their reaction to the loads arising during welding.

The main feature of the high-chromium martensitic steels is the fact that their multiphase composition is at the junction of the austenitic, ferritic and martensitic structures. This causes significant difficulties in their welding, as, depending on the temperature and duration of heating and the cooling rate, the austenite and martensite can have “good” and “bad” modifications: lath or plate martensite; residual, reversed or allotriomorphic and Widmanstatten austenite, etc. In many cases when controlling the weldability it is necessary to use different variants of test stiffness.

For instance, study [8] showed that during testing of a weld of the modified martensitic 9Cr–Mo steel greater stiffness is required that for the standard tests. Contrarily, in the case of the martensitic-austenitic weld metal, which has higher ductility, cold cracks are observed at a low stiffness of the joint [9]. A similar tendency was revealed during application of welding consumables of Cr–Ni type [10].

Cold cracking tests provide qualitative (cracks/no cracks) or quantitative results (determination of test parameters for welds without cracks) for the studied combinations of the base material, filler material and welding parameters. Alongside the above-mentioned criteria, it is important to take into account the labour intensity of machining the blanks for the test samples, metal content and possibility of their further application. Many different testing methods have been developed to determine the potential risk of cracking by creating special conditions of the weld restraint, as is shown in numerous reviews on the subject [11].

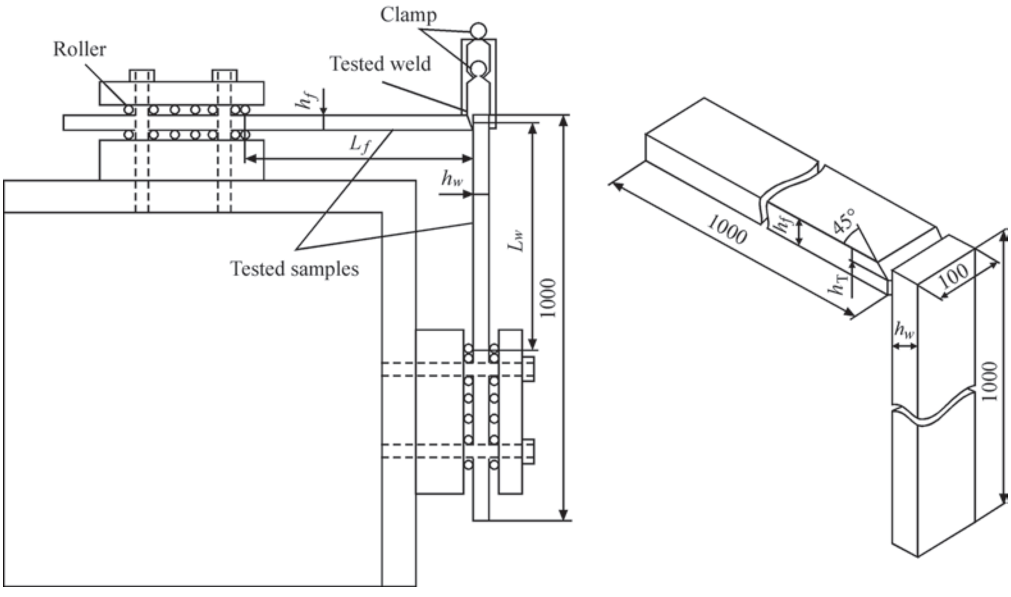

Figure 1. Design of CJC-test

The main part of the laboratory tests consists of a particular individual form of the fillet or butt weld, where higher stiffness is ensured either by the rigidity of the test samples proper, or by using anchor welds, bolts, jigs and other holding devices or their combination [12]. At the same time, it was established [13] that for a valid assessment of the influence of some factors on cracking in the welded joints and selection of an optimal procedure of structure welding during fabrication, the intensity of restriction during bending should be added during testing. However, the availability of laboratory tests, which best correspond to the probability of cold cracking, as the welds are simultaneously subjected not only to tension, but also to bending, is very limited.

Additional measurement of bending stresses together with the normal transverse and longitudinal stresses in the 3D testing facility BAM 2-MN [14] demonstrated a noticeable increase in the bending moment based on the restriction of angular deformation, particularly in the critical root zone, with accompanying risk of cracking. Values have been determined which exceed similar parameters of the slot test several times [15]. This is indicative of the fact that the bending stresses rise in welding and cause higher local residual stresses. Unfortunately, the complex design limits the application of such a test.

Sufficiently informative is the CJC-test [16], in which the stress-strain state of the joints is regulated by a special device, which allows combining the angular stress with the transverse one (Figure 1). A significant drawback of this test is its high metal content and the need to apply a complex jig.

The small-size test, in which bending stresses are recorded during welding, is the WIC test [1], which is used in welding pipelines from high-strength steels (Figure 2). Changing the height of the base plate stiffener, it is possible to model the high intensities of out-of-plane bending of the weld. The intensity of restriction in the transverse direction of welding can be changed, depending on the length of anchor welds between the WIC sample and the base plate [7]. As shown by practice, the test is sufficiently informative. However, the high metal content, significant cost of the unit mounting, complex fixation of the gap between the plates and one-time use of the unit should be noted.

THE OBJECTIVE

of the work is to develop a simplified design of the test sample to assess the weld metal susceptibility to cold cracking.

DEVELOPMENT OF THE DESIGN OF A SIMPLIFIED PROCESS TEST AND ITS PRACTICAL APPLICATION

We have conducted investigations on development of a cost-effective small-sized process test for the weld susceptibility to cold cracking. Both the plates

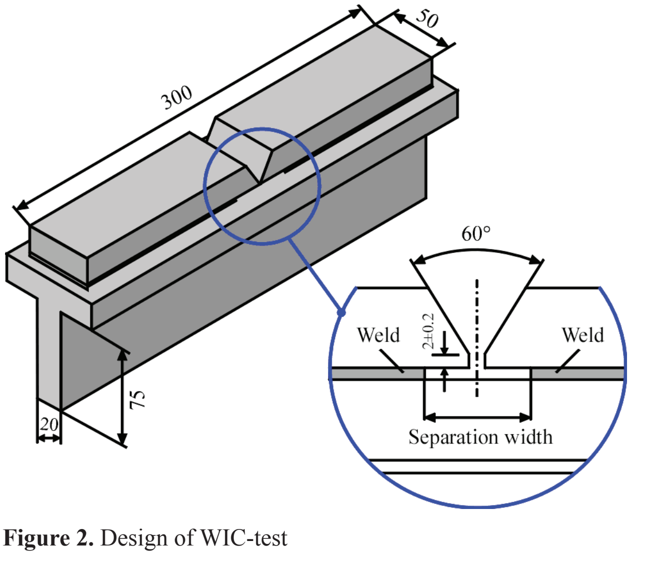

Figure 2. Design of WIC-test

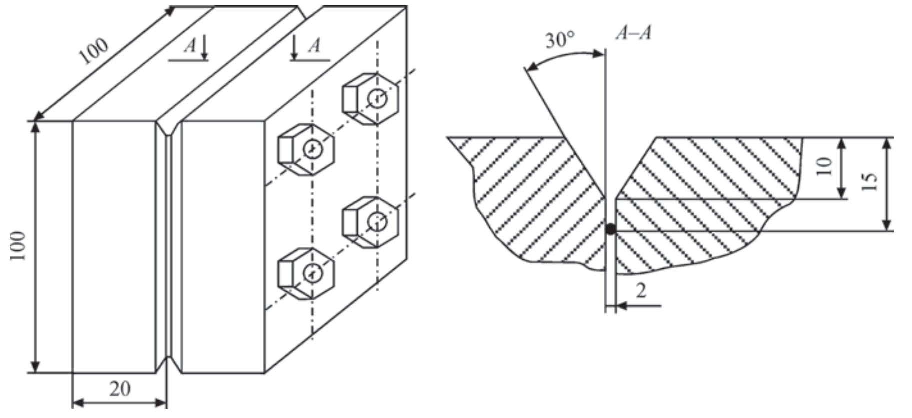

Figure 3. Design of the developed test sample

are fastened vertically in order to record the bending moment. It allows combining the bending stresses with the normal transverse and longitudinal ones. Test plates 20 mm thick are fastened using anchor bolts or jig (Figures 3, 4). The testing slots are located at the plate end faces. The slot geometry can be selected as required: *Y*, *V*, *U*-shaped and others. We selected the *V*-shaped groove, as cracks in the HAZ of the modern martensitic steels are practically absent.

The length of the reference weld in small-sized tests is selected within the range of 50–100 mm. The length of 85 mm was chosen, because in this case as it was determined [17], the highest both longitudinal and transverse residual stresses are ensured in the weld. The width of the slot between the plates is fixed with an insert of 2 mm diameter at 15 mm distance from the surface (Figure 1). If required, the test stiffness can be regulated by changing the distance from the fixing insert to the root zone. When making the test unit using anchor bolts, the groove can be made around its perimeter, which allows using one unit four times. In case of application of the jig (Figure 4), with a fixed width of the test plates it is possible to increase their length indefinitely, which also allows using one test unit many times.

The test joint design allows eliminating complex edge preparation, as for instance, in Tekken sample, which is particularly important with a large thickness of the materials being welded. More over, cutting out templates for metallographic analysis is greatly simplified. The sample metal is almost completely preserved for further use in multiple tests.

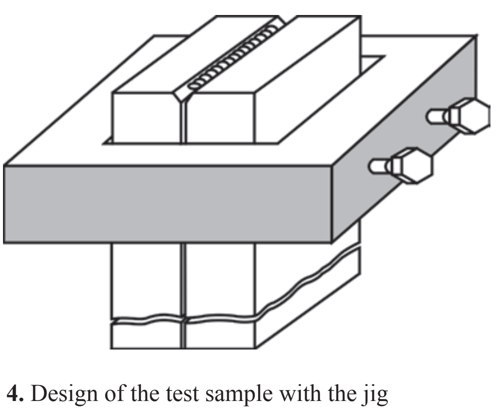

Figure 4. Design of the test sample with the jig

The requirements to sample preparation and procedure to be performed during application of the developed simplified process test were established by the recommendations of DSTU EN ISO 17642-2:2019 [18].

The test is used predominantly, but not exclusively, for martensitic alloyed and high-alloyed steels in coated-electrode arc and semi-automatic gas-shielded welding with solid and flux-cored wires. The plates are joined by bolts 20 mm in diameter. Under the condition of ensuring a uniform compression of the test sample elements and impossibility of the thread destruction, the tightening torque of all the bolts should be the same, being in the range of 100–184N·m, which is controlled by a torque wrench. Welding is performed in the downhand position, presence of cracks in the samples is controlled visually, or using a magnifying glass with ×2–4 magnification. The absence of cracks can be also confirmed during examination of transverse macrosections with magnification of approximately ×100–200.

Based on the proposed test, experiments were conducted to assess the cold cracking susceptibility of welded joints of martensitic 25Kh2MNFA, 15Kh5M and Kh10CrMoVNb91 (P91) steels 20 mm thick. Welding was performed with 3 mm electrodes. The material chemical composition is given in the Table 1.

Welding was conducted at reverse polarity direct current. The welding current source was VDU-505. Welding current was equal to 100 A. Before the start of welding, the electrodes were baked in the furnace at the temperature of 300 °C for 2 hours.

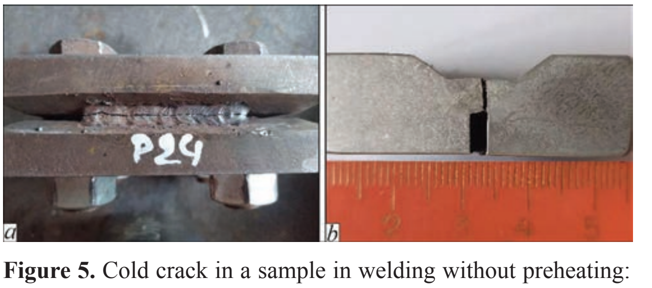

Figure 5. Cold crack in a sample in welding without preheating: top view (*a*), transverse section (*b*)

Table 1. Chemical composition of the used materials

Variant No.	Material grade	Weight fraction of elements, %						
		C	Si	Mn	Cr	Ni	Mo	V/Nb
1	Steel 25Kh2NMFA	0.24	0.17	0.50	2.20	1.50	0.50	0.2 V
	Electrodes Thernanit P 24 (EZ CrMo2VNb B42H5)	0.11	0.24	0.62	2.52	–	0.98	0.24 V
2	Steel 15Kh5M	0.11	0.4	0.6	4.8	0.6	0.34	–
	Electrodes TsL-17 (E 10Kh5MF)	0.07	0.45	0.90	4.5	–	0.65	0.25 V
3	Steel 10Kh9MFB (R91)	0.10	0.3	0.6	8.9	0.63	0.85	0.06 Nb
	Electrodes ANL-8 (E9018-B9)	0.09	0.13	0.72	9.15	0.52	0.83	0.05 Nb

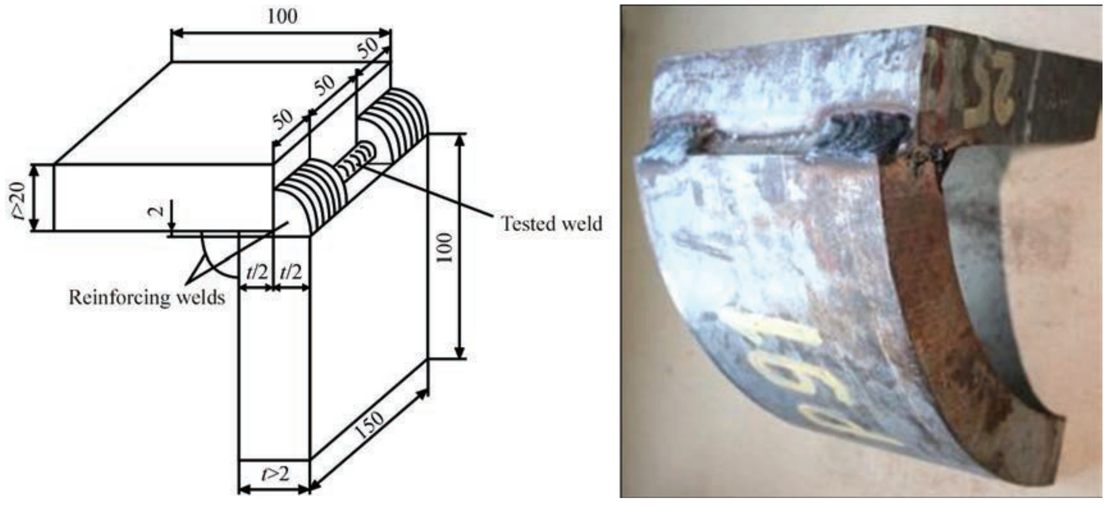

Figure 6. Angular sample design

Plate preheating before welding was conducted in a muffle electric furnace of SNOL type. Then the unit was moved to the welding table. Welding was begun after the planned temperature of the sample metal had been reached, which was controlled using a contact thermocouple. The test blocks were welded without preheating and with preheating with a step of 50 °C. The units welded without preheating cracked completely during testing of all the three steel grades (Figure 5).

Investigations conducted with application of the proposed test, showed that in the joints of the welded steels the cracks form solely in the weld metal. Cracks in the HAZ are absent with all the testing parameters.

Depending on the steel grades, the lowest critical preheating temperature to prevent cold cracking was determined as follows:

- in welding 25Kh2NMFA steel — 150 °C;
- in welding 15Kh5M steel — 300 °C;
- in welding R91 steel — 200 °C.

Critical preheating temperature derived in welding R91 steel, correlates well with the results of testing this steel using G-BOP test (200 °C) [19], which is considered the stiffest among the laboratory tests in the investigations. It is also noted there that in application of the Tekken test, a lower critical temperature of 150 °C was obtained. Similar results were derived in work [20].

To check the informativeness of the proposed test, a semi-scale testing of a higher stiffness was conducted. Plates of P91 steel 45 mm thick were welded at 90° angle with a 2 mm gap (Figure 6). It allowed eliminating the complex edge preparation, which is particularly important with large thickness of the materials being welded. More over, weld cutting out and preparation of templates for metallographic analysis are greatly simplified, the sample metal being preserved almost completely for further use.

The test weld was deposited after making the anchor welds from the inner and outer sides. Crack resistance was assessed by the critical preheating temperature. Performed testing showed that cracks in the reference weld, similar to application of the proposed test, are absent at the preheating temperature of 200 °C.

The considered approaches to testing the cold cracking susceptibility have been accepted in the research practice, and the obtained individual results have been used in development of the technologies of welding the elements of boiler, turbine, and hydroelectric power equipment from hardening bainitic and martensitic steels.

CONCLUSIONS

The design of a small-sized simplified process test for weld metal testing for cold cracking susceptibility was proposed. The test allows combining the bending stresses with the normal transverse and longitudinal stresses, providing a high stiffness of the experimental welded joints. A special feature of the test is its low metal content and the possibility of multiple application. The thermal conditions of welding of hardening heat-resistant steels with bainitic and martensitic structure determined by the developed method, have been recommended for manufacturing the welded components of power equipment.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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