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Krzysztof Pańcikiewicz

Assessing the Susceptibility of Welded Joints to Cold Cracking in the CTS Test

Abstract: The article presents the CTS tests used when assessing the susceptibility of welded joints to cold cracking as well as test results related to steel 7CrMoVTiB10-10. The research work involved macro and microscopic metallographic tests performed using light and scanning electron microscopy. The macro and microscopic metallographic tests were used to assess the nature of cracking. It was demonstrated than an increase in thermal severity was accompanied by an increase in the average length of cold cracks.

Keywords: cold cracking, CTS test, steel T24, steel 7CrMoVTiB10-10

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Introduction

Cold cracks belong to the group of four primary types of cracks occurring in steel welded joints. Because of the fact that cold cracks are formed during cooling following welding performed at a temperature where austenite is transformed into non-equilibrium structures, materials most susceptible to the formation of cold cracks include steels characterised by higher hardenability [1]. Assessments aimed to identify the degree of susceptibility to cold cracking comprise technological tests [2] including those specified in PN-EN ISO 17642. The above-named standard indicates two groups of methods varying in the manner in which stress is applied, i.e. adjusted tests (e.g. Implant Test) or tests determined by the geometry of the test joint, i.e. where joint geometry determines the manner in which the joint is fixed (Tekken, Lehigh or CTS).

The analysis of related reference publications revealed that the controlled thermal severity (CTS) tests are successfully used when assessing the susceptibility of unalloyed structural steels, high strength steels or steels used in the power sector to cold cracking [3-14]. The article presents the performance and exemplary results of a CTS test obtained in relation to low-alloy steel 7CrMoVTiB10-10 (T24) used in the conventional power engineering. The modification of the chemical composition and of the heat treatment of the above-named steel in relation to steel 10CrMo9-10, constituting the design basis for the new grade, led to the obtainment of higher mechanical properties at the cost of weldability. Experience related to the fabrication and operation of tight walls provide information about the high susceptibility of steel 7CrMoVTiB10-10 to cracking, which was described in detail in related reference publications [15-25].

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Controlled Thermal Severity (CTS) Test

The CTS test, described in PN-EN ISO 17642-2, involves the making of two test welds using specific thermal severity in a specifically prepared lap joint. The dimensions of test plates and their schematic fixing are presented in Figure 1. Where the direction of the rolling of both plates is known, the plates should be situated parallel to each other. In both plates it is necessary to make an opening having a diameter of 13 mm. In addition, in the lower plate (in the area where test welds will be made), near the edges, it is necessary to make two grooves, each having a depth of 1.6 mm and a width of 10 mm. The plates should be bolted together using a torque of 100±5 Nm. Afterwards it is necessary to make two auxiliary fillet welds along the edge perpendicular to both grooves. The filler metal used when making the test welds should have a yield point not lower than that of a test base material. If the yield point of a base material exceeds 895 MPa, it is possible to use a filler metal characterised by a lower yield point (but not lower than 895 MPa) or an austenitic corrosion-resistant filler metal. The auxiliary welds should be started and finished 10 mm away from the corner of the smaller sheet. The thickness of the auxiliary welds should amount to 6 ± 1 mm in relation to plates having a thickness of 15 mm and 13±1 mm in relation to thicker plates. After making the auxiliary welds it is necessary to verify the value of torque and wait for 12 hours before making the test welds.

Test welds should be made in the flat position, in one run. After the making of the first weld, the specimen should be subjected to cooling for a maximum of 60 s by immersing the specimen end opposite the end with the weld in a container filled with water up to a height of 60±5 mm. After cooling to ambient temperature and waiting for a minimum of 48 hours the second test weld is made on the opposite side (using the same procedure).

The crack susceptibility in the CTS test can include the analysis of the pre-weld preheating / interpass temperature or the effect of a diffusive hydrogen input to a joint, where the amount of supplied hydrogen should be determined in accordance with PN-EN ISO 3690. Thermal severity depends on the thickness of elements being joined. CTS tests require the use of plates having a minimum thickness of 6 mm.

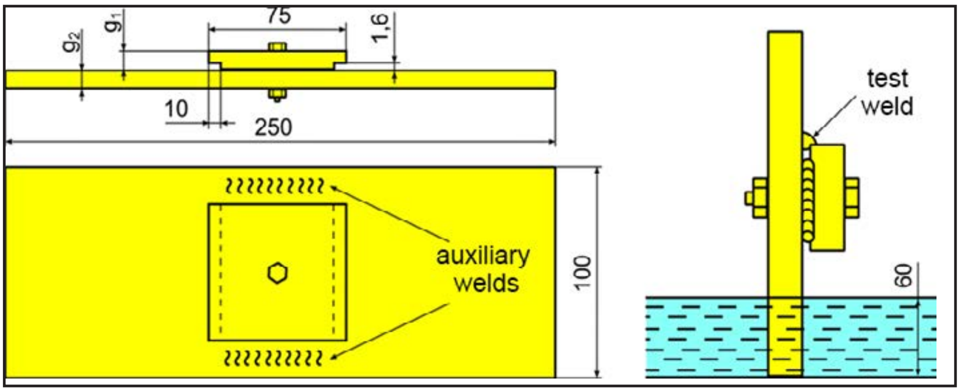

Fig. 1. Schematic CTS test

Determination of Thermal Severity Number (TSN)

The thermal severity number (TSN) is a parameter describing thermal severity. The TSN strictly depends on the number of heat discharge directions. The TSN is identified using a unitary sheet thickness of 6 mm (0.25 inch). If a plate is thicker or thinner than 6 mm, calculations are performed using the multiplicity of a unitary thickness [1].

The primary cases determining the thermal severity number are presented in Table 1. In relation to the lap joint referred to in PN-EN ISO 17642-2, the TSN value can be determined using the following dependence (1):

$$TSN = \frac{1}{2}\left(\frac{g_1}{6} + \frac{g_2}{6}\right) \cdot 3 \qquad (1)$$

where g_1, g_2 – thicknesses of elements to be joined (mm).

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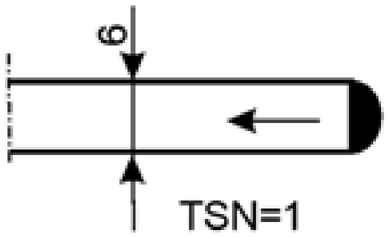
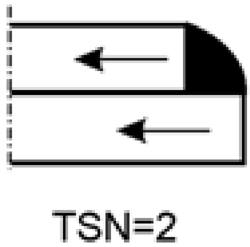
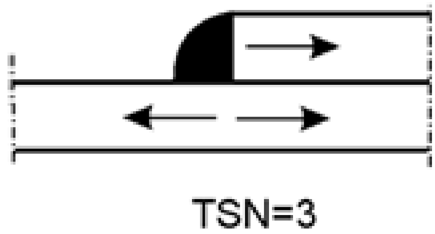
Table 1. Primary cases when determining the thermal severity number (TSN) [1]

No.	1	2	3
Scheme			

Assessment of Test Results

The test welds are sampled for 4 specimens used in metallographic tests to be performed in accordance with the recommendations specified in PN-EN ISO 17639. The weld and the HAZ should be subjected to microscopic observations performed at a magnification of 50x. Where there is a lack of cracks, observation results should be confirmed using a magnification of at least 200x. Where cracks identified in the weld have the total length representing more than 5% of the weld thickness and/or if the lower plate revealed a crack, the test should be recognised as invalid. If the HAZ of the upper plate contains a crack having a length constituting more than 5% of the mean value of the weld legs, the test should be recognised as valid with the negative result ("crack"). Hardness measurements in the weld and in the HAZ should be performed under a load of 2.5 kg, 5 kg or 10 kg, in accordance with PN-EN ISO 9015-1.

Methodology and Tests

The assessment of the susceptibility of steel 7CrMoVTiB10-10 (1.7378, T24) to cold cracking and the identification of the effect of diffusive hydrogen on the intensification of the above-named susceptibility required the performance of CTS tests. The tests were performed using specimens sampled from a 6 mm thick flat bar made of steel 7CrMoVTiB10-10. The tests were performed in relation to various TSN values. Flat bars made of steel S235J2G3 and having thicknesses of 10, 14, 16 and 25 mm were used as the lower plate, increasing thermal severity. One test was made in relation to one value of thermal severity. Fillet welds were made in the flat position, using method 111 and a straight polarity DC of 110 A. The filler metal used in the tests had the form of low-hydrogen electrodes covered Thermanit P24 (EN ISO 3580-A: E Z CrMo2VNb B 4 2 H5) in two states, i.e. after drying in a furnace (350°C/2 h) and after artificial hydrogenation. The amount of diffusive hydrogen was measured using the glycerine method [26, 27]. Metallographic specimens were analysed using light and scanning electron microscopy.

Test Results and Discussion

Figure 2 presents the pre-weld preparation of the elements and an exemplary joint after a CTS tests. Two welds were compared within one thermal severity test, i.e. one made using the dried electrode (5 ml HD/100 g of the weld deposit) and the other made using hydrogenated electrode (23 ml HD/100 g of the weld deposit). Figure 3 presents selected macrostructures of the joints obtained in the CTS test. The microscopic observation results along with TSN-related calculations are presented in Table 2. The test performed using TSN = 3 did not reveal the presence of cracks. An increase in the TSN to 4 resulted in the formation of cracks in the joint made using the hydrogenated electrode. As regards the dried electrode, cracks were formed when the TSN exceeded 5.5. In each case a crack was formed in the interface on the root side and propagated through the coarse-grained heat affected zone (CGHAZ) to the fine-grained HAZ (FGHAZ).

The cross-sectional microscopic observations revealed that, regardless of the TSN and

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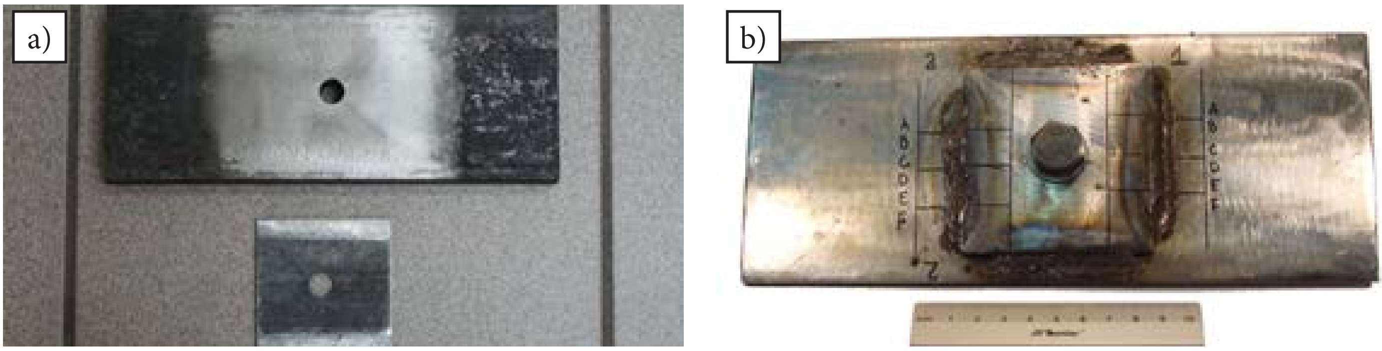

Fig. 2. Elements composing the test specimen and the test joint: a) flat bars prepared for the CTS test; TSN = 7.75; b) joint after the CTS test; TSN = 3

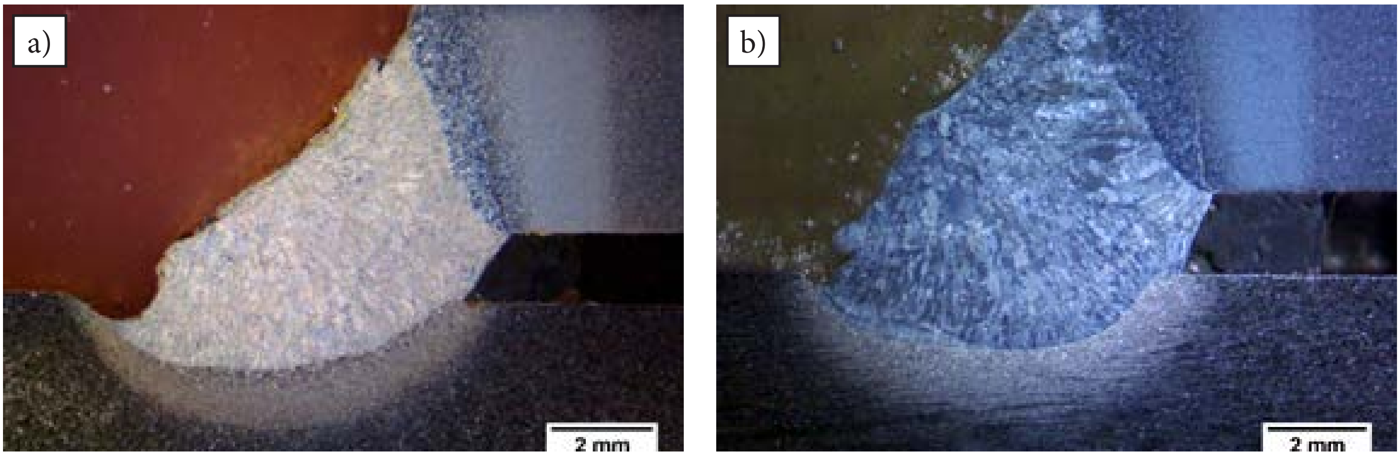

Fig. 3. Macrostructure of the joint made in the CTS test using the hydrogenated electrode: a) TSN = 5.5, b) TSN = 7.75; cracks are marked with the arrows; the metallographic specimen was etched using Nital

electrode condition, cracks were primarily transcrystalline (Fig. 4, 5). The cracks propagated both along and across martensite/bainite laths and, locally over short distances, along former austenite grains (intercrystalline), often changing directions. The foregoing resulted in the "stepped" nature of cracks, which could imply their non-continuous development (Fig. 4-6), characteristic of post-weld cold cracks.

Another conventional criterion identifying cold crack susceptibility is the length of cracks.

Table 2. Metallographic test results after the CTS test

No.	Flat bar thickness		TSN	Test result	
	g_1, mm	g_2, mm		Dried electrode	Hydrogenated electrode
1	6	6	$\frac{1}{2}\left(\frac{6}{6}+\frac{6}{6}\right)\cdot 3 = 3$	No cracks	No cracks
2	10	6	$\frac{1}{2}\left(\frac{10}{6}+\frac{6}{6}\right)\cdot 3 = 4$	No cracks	Crack
3	14	6	$\frac{1}{2}\left(\frac{14}{6}+\frac{6}{6}\right)\cdot 3 = 5$	No cracks	Crack
4	16	6	$\frac{1}{2}\left(\frac{16}{6}+\frac{6}{6}\right)\cdot 3 = 5{,}5$	No cracks	Crack
5	25	6	$\frac{1}{2}\left(\frac{25}{6}+\frac{6}{6}\right)\cdot 3 = 7{,}75$	Crack	Crack

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Figure 7 present the dependence of the mean length of cracks in the function of thermal severity number (TSN) in relation to the joints made using the dried electrodes and those made using the hydrogenated electrodes. Each weld was subjected to observation involving 4 metallographic specimens. The observations revealed an increase in the length of cracks along with an increase in the TSN as well as the presence of secondary cracks (in addition to principal ones). The presence of hydrogen in the weld material significantly increased brittleness in the heat affected zone (HAZ). The use of electrodes supplying a limited amount of hydrogen resulted in the obtainment of relatively shorter cracks than those revealed after welding performed using hydrogenated electrodes under the same thermal severity conditions (in relation to TSN > 5.5) or in the prevention of crack formation (in relation to TSN = 5 ÷ 5.5). In relation to TSN ≤ 4, crack formation was not observed regardless of the electrode condition.

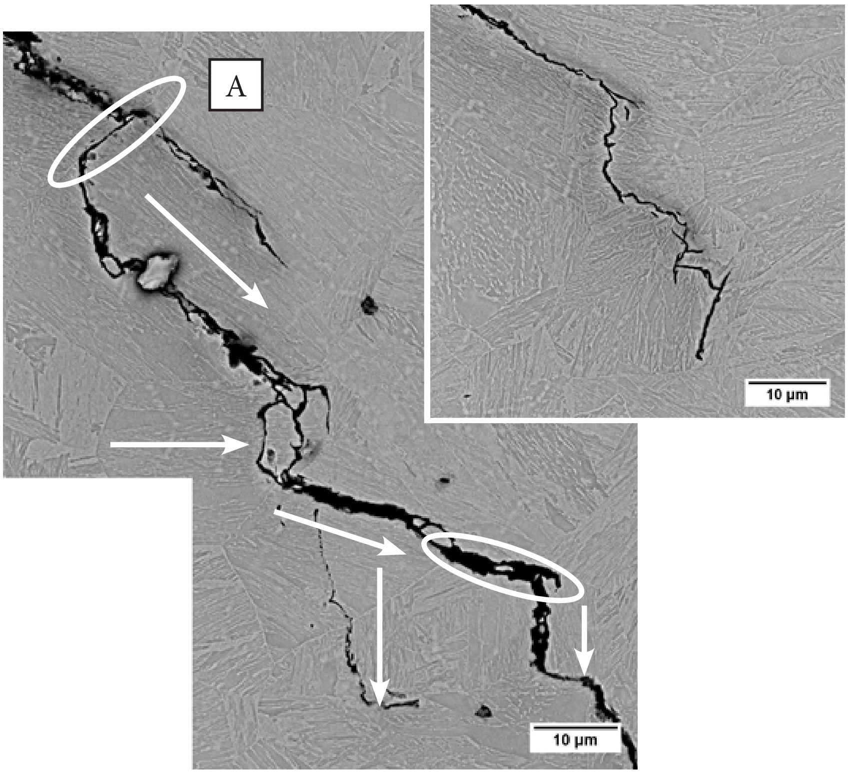

Fig. 4. Transcrystalline cold crack; crack direction parallel in relation to martensite/bainite laths (marked with arrows); area A represents the local change in the crack nature into the transcrystalline cold crack; welding performed using the hydrogenated electrode; TSN = 7.75; SEM (BSE)

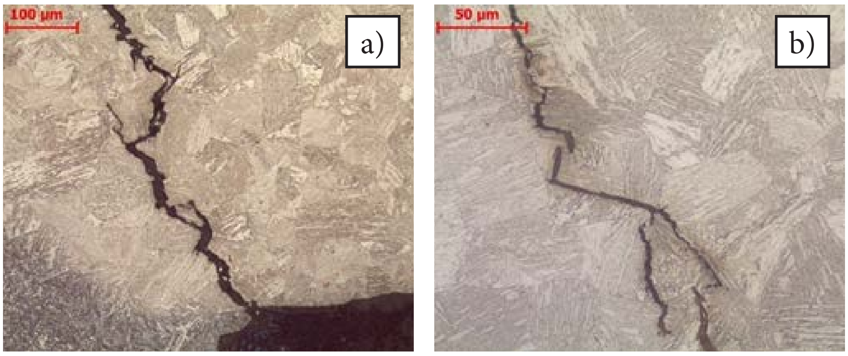

Fig. 5. Transcrystalline cold crack; welding performed using the hydrogenated electrode; TSN = 5.5; etching performed using Nital

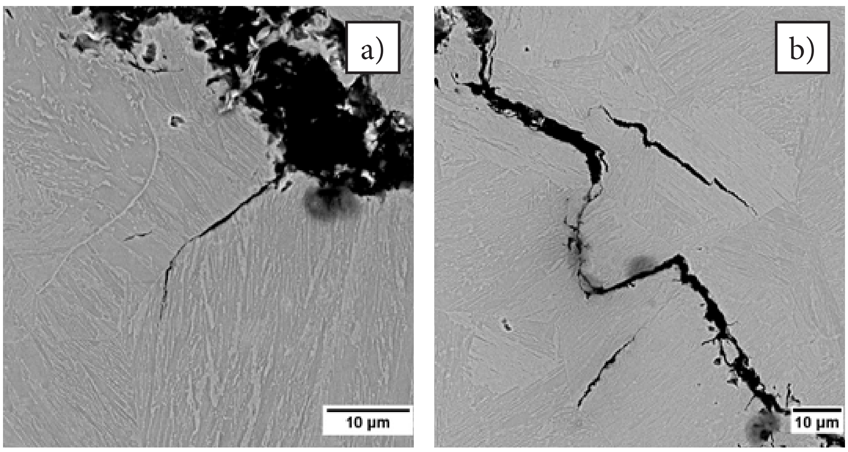

Fig. 6. Cold cracks: a) secondary transcrystalline, b) transcrystalline – primary and neighbouring of a subcritical length; welding performed using the hydrogenated electrode; TSN = 7.75. SEM (BSE)

Summary

The tests enabled the determination of the value of thermal severity, the exceeding of which triggered the formation of cold cracks in the HAZ of steel T24. As regards the dried electrodes (providing 5 ml HD/100 g of the weld deposit), crack formation was not identified up to TSN = 5.5 inclusive. In turn, in terms of hydrogenated electrodes (providing 23 ml HD/100 g of the weld deposit), crack were formed above TSN = 4. The characteristic “stepped”

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cracks propagated in the HAZ in a non-continuous manner at various levels. Principally, the cracks were transcrystalline and situated both along and across martensite/bainite laths and, locally and over short distances, along former austenite grains (intercrystalline). The obtained results confirmed the susceptibility of steel T24 to cold cracking, increasing along with increasingly high cooling rates (represented by TSN) and an increasingly high content of diffusive hydrogen in the joint.

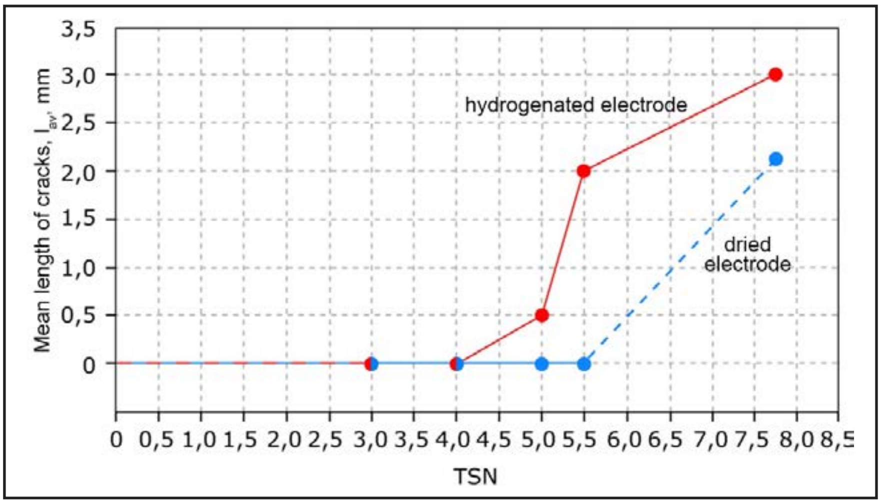

Fig. 7. Effect of the covered electrode condition on the mean length of cracks in the function of TSN obtained in the CTS test

The research works were performed within statutory research work no. 11.11.110.299.

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