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Analysing the Effect of Changes in Overlay Weld Geometry on Test SEP 1390

Abstract: The article presents issues related to the assessment of the weldability of thick-walled materials used when making welded steel structures. The article also discusses the analysis of test results based on the technological test concerning the weldability of thick-walled structural materials according to the guidelines of SEP 1390. The tests took into consideration the effect of the change in overlay weld geometry on the technological test, and, as a result, the final result of weldability assessment.

Keywords: weldability, properties of structural materials, bend test, crack assessment, destructive tests

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Introduction

The making of thick-walled welded structures continues to pose numerous difficulties in spite of continuous developmental progress in many areas of manufacturing technologies, including welding and metallurgical processes. Thick-walled welded joints require being particularly carefully made, following the development of appropriate technological conditions. One of the key factors affecting the successful making of good quality joints is the proper determination of base material weldability, usually based on both analytical and simulations methods, often involving technological tests [1, 2]. Technological tests serving the above named purpose are usually used to verify analytical methods and confirm quality assumptions required by related standards and guidelines. Recommended technological tests are related to crack mechanics, i.e. the initiation and propagation of cracks in structural materials and joints [3]. Technological test SEP 1390 recommended by the German Institute of Steel and Iron (ABV) and used for assessing the weldability of thick-walled structural materials also serves the purpose mentioned above.

The objective of this study includes analysing the results of tests performed on the basis of SEP 1390 guidelines and taking into consideration the effect of a change in overlay weld geometry on the proper course and result of test SEP 1390 when assessing the weldability of thick-walled structural materials. Provided that technological test SEP 1390 is performed properly, the analysis of test results should provide valuable information concerning the proper determination of material weldability.

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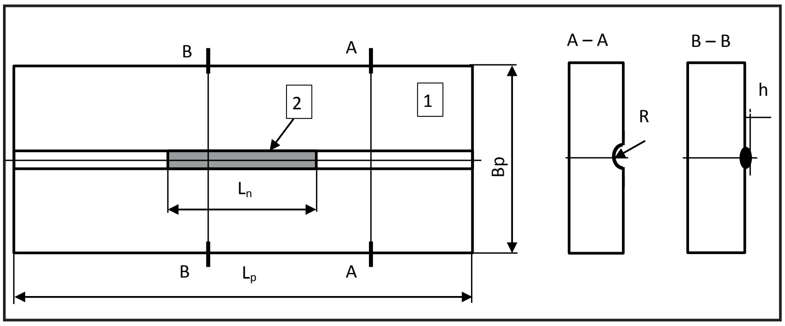

Fig. 1. Scheme of the specimen subjected to test SEP 1390
1: material, 2: overlay weld [4]

Table 1. Dimensions of the specimens in relation to the thickness of tested material [4]

Material thickness *g* [mm]	**Specimen length L_p [mm]**	**Specimen width B_p [mm]**	**Overlay weld length L_n min [mm]**	**Groove radius *R* [mm]**
$30 \leq g \leq 35$	410	200	175	4
$35 < g \leq 40$	440	200	190	4
$40 < g \leq 45$	470	200	220	4
$45 < g \leq 50$	500	200	220	4
$g > 50$	500	200	220	4

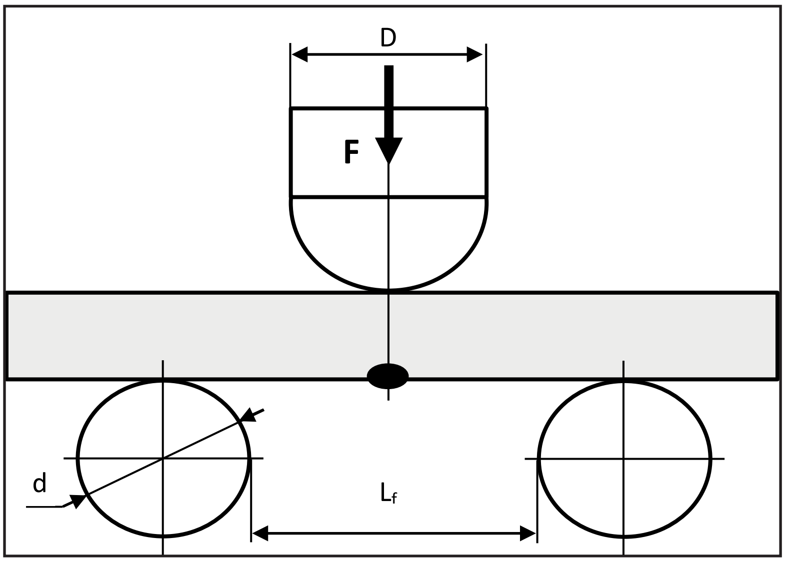

Fig. 2. Scheme of the weldability test performed within the bend test [4]

Table 2. Dimensions of the scheme involving the bend tests of the specimens [4]

Material thickness *g* [mm]	**Mandrel diameter *D* [mm]**	**Distance between supports L_f [mm]**	**Support diameter *d* [mm]**
$30 \leq g \leq 35$	105	190	
$35 < g \leq 40$	120	220	
$40 < g \leq 45$	135	250	≥ 50
$45 < g \leq 50$	150	280	
$g > 50$	150	280	

Characteristics of Weldability Test SEP 1390

Test SEP 1390 is focused on the weldability of materials having a minimum yield point restricted within the range of 235 MPa to 355 MPa and a thickness equal to or exceeding 30 mm [4,5]. The weldability tests consist in bending a specimen sampled from a material with an appropriately made overlay weld located in a groove milled along the specimen axis. The bend test assesses the possibility of blocking a crack induced in a special overlay weld subjected to tension during the bending of the specimen. The shape of the specimen sampled for the tests is presented in Figure 1. The dimensions of specimens in relation to the thickness of a material being tested are presented in Table 1 [4].

When testing thicker materials, it is necessary to remove the excess material to a thickness of 50 mm, leaving one post-roll unprocessed surface. The satisfaction of this condition is necessary because of limitations concerning loads of up to 1000 kN on standard testing machines. The scheme of a weldability test performed in a bend test involving a properly prepared specimen is presented in Figure 2. Important dimensions concerning the specimens are presented in Table 2.

The bend tests are performed using a testing machine having a significantly large load range, preferably up to 1000 kN, using appropriate fixtures according to the test scheme presented in Figure 2.

Preparation of Test Specimens

Material

Material for test specimens was sampled from steel 355J2+N (65×1640×3550 mm). Steel 355J2+N is structural unalloyed steel commonly used in civil engineering structures including halls, containers, bridges, cranes or power engineering structures. According to standard PN-EN 10025-2:2008, the minimum yield point of the above named steel amounts to R_e = 335 MPa, whereas the minimum impact energy at a temperature of -20°C amounts to 27 J. During the production the material was subjected to heat treatment (normalising) [6]. Steel S335J2+N is characterised by good weldability and, according to the manufacturer's certificate of conformity, has a carbon equivalent CEV = 0.44 [7].

According to the above named certificate, the mechanical properties of steel S335J2+N are the following [7]:

- yield point R_e = 358 MPa
- tensile strength R_m = 512 MPa
- elongation A_5= 30%
- impact energy KV = 209 J at a temperature of -20°C

Treatment of Specimens

The specimens were thermally cut out of a plate leaving an appropriate allowance. Afterwards, the specimens were subjected to mechanical treatment to reach dimensions of 500×200×50 mm. In accordance with the requirements of test SEP 1390 the specimens were milled to a thickness of 50 mm on only one side of the plate, leaving the other side with a post-roll raw surface. Afterwards, on the untreated (post-roll raw) surface of the specimen, a groove having a radius *R*=4 mm was milled along the entire length of the plate. The post-treatment view of the specimen is presented in Figure 3.

Overlay Weld

The overlay weld was made in accordance with the guidelines of SEP 1390, using MMA welding (111) and a rutile electrode. The rutile electrode was thick-covered (Fig. 4) and had a diameter of 5 mm; the electrode was made by ESAB under the commercial name of OK Femax 33.80 5.0×450 mm. In accordance with standard EN ISO 2560-A, the electrode was designated with code E 42 0 RR 73). Before overlay welding, the electrodes were subjected to drying (recommended by the manufacturer) performed at a temperature of 250°C for approximately 2 hours.

According to the certificate of conformity, the mechanical properties of the weld deposit were the following [8]:

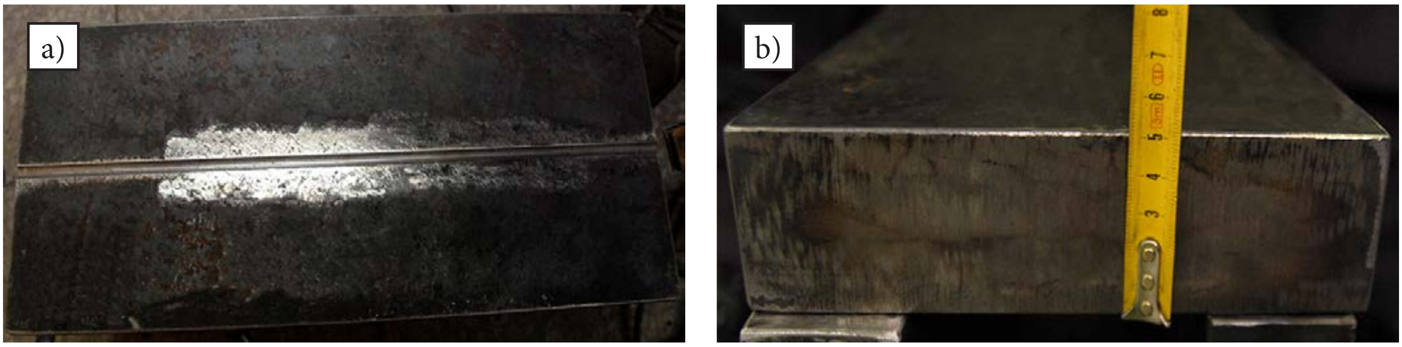

Fig. 3. Post-treatment view of the specimen: a) groove b) front

Fig. 4. Electrodes made by ESAB OK Femax 33.80 5.0x450 mm

– yield point R_{eL} = 480 MPa
– tensile strength R_m = 555 MPa
– elongation A_5 = 26%
– impact energy KV = 60 J at a temperature of 0°C

The preparation of the specimens in accordance with the recommendations contained in SEP 1390 was followed by the adjustment of optimum parameters for surfacing individual specimens. The overlay welds were made in the milled groove using a single run without stopping the process of surfacing. After surfacing, the overlay welds were not subjected to mechanical treatment. All the specimens were subjected to surfacing at a temperature of 19°C and using constant values of welding current and arc voltage (I=246 A, U=29.84 V). In order to test the effect of the change in overlay weld geometry (height of the excess weld metal of the overlay weld) on test SEP 1390, the overlay weld of each specimen was performed using a different welding rate restricted within the range of 2.2 mm/s to 4.9 mm/s. The process of surfacing is presented in Figure 5. The photographs showing the process of surfacing were performed without screening electric arc and using a filter screening arc. The specimens after surfacing and cleaning of the overlay weld are presented in Figure 6.

After cooling, the slag was removed from the specimens using a welding hammer and a wire brush. The removal of the slag was followed by measurements of the widths and heights of the overlay weld faces. Each specimen was subjected to 12 measurements performed every 20 mm. The average heights of overlay weld faces amounted to 0.1; 0.8; 1; 1.2; 2.0 and 2.5 mm respectively, whereas the corresponding heights amounted to 17.9; 18.7; 19.1; 19.4; 24.3 and 24.8 mm.

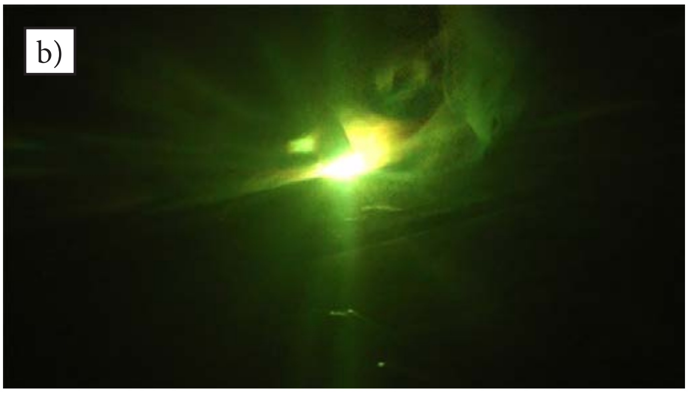

Fig. 5. Surfacing of the specimens: a) without screening arc b) using a filter screening arc

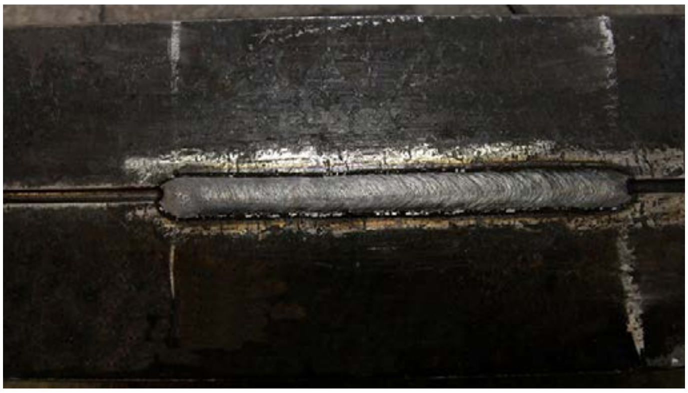

Fig. 6. Test specimen with the overlay weld

Tests

After thorough preparation, the test specimens were individually placed in a testing machine manufactured by Heckert EU 100T and provided with specialist fixtures featuring appropriate mandrel and supports used for the bending of specimens. A given specimen was placed in such a manner that the overlay weld was located in the tension zone during the process of bending. In accordance with the guidelines of SEP 1390, the mandrel diameter related to the test plate having a thickness of 50 mm amounted to 150 mm, the diameters of the supports amounted to 80 mm, whereas the distance between the supports amounted to 280 mm. In order to assess the bend angle of the specimen, the bend tests were continuously monitored by cameras filming the area of the overlay weld subjected to tension; the testing machine dynamometer (clock) indicating the value of the bend force and the specimen subjected to bending. An exemplary image recorded (and edited) using three cameras during the technological bend test is presented in Figure 7 [9].

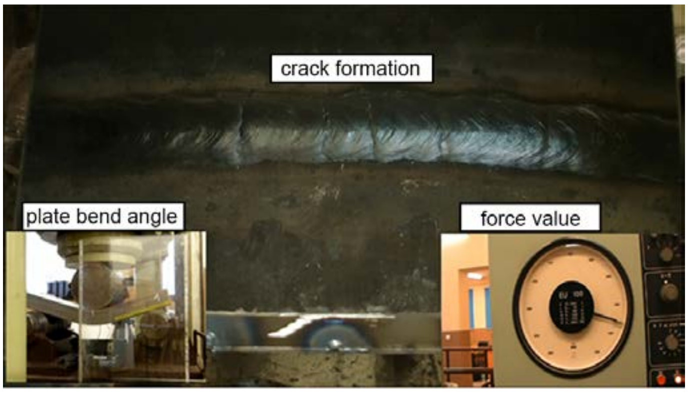

Fig. 7. Image recorded by the cameras during the bend test [9]

The system enabling the continuous monitoring of primary process variables was the basis of the thorough analysis of individual tests.

Test Results

The general characteristics of test results are presented in relation to the individual tests [9].

Test no. 1

In test no. 1 (excess weld metal height of 2.5 mm, bend angle of 65°) 6 cracks were recorded; 4 cracks passed through the heat affected zone and were stopped in the base material. None of the cracks exceeded the boundary value of 80 mm (from the overlay weld centre to the edge of the crack). The test result was positive.

Test no. 2

In test no. 2 (excess weld metal height of 2.0 mm, bend angle of 66°) 6 cracks were recorded; 2 cracks passed through the heat affected zone and were stopped in the base material. None of the cracks exceeded the boundary value of 80 mm (from the overlay weld centre to the edge of the crack). The test result was positive.

Test no. 3

In test no. 3 (excess weld metal height of 0.8 mm, bend angle of 65°) 6 cracks were recorded, all of which cracks passed through the heat affected zone and were stopped in the base material. None of the cracks exceeded the boundary value of 80 mm (from the overlay weld centre to the edge of the crack). The test result was positive.

Test no. 4

In test no. 4 (excess weld metal height of 0.1 mm, bend angle of 67°) 9 cracks were recorded; 7 cracks passed through the heat affected zone and were stopped in the base material. None of the cracks exceeded the boundary value of 80 mm (from the overlay weld centre to the edge of the crack). The test result was positive.

Test no. 5

In test no. 5 (excess weld metal height of 1.2 mm, bend angle of 66°) 7 cracks were recorded; 3 cracks passed through the heat affected zone and were stopped in the base material. None of the cracks exceeded the boundary value of 80 mm (from the overlay weld centre to the edge of the crack). The test result was positive.

Test no. 6

In test no. 6 (excess weld metal height of 1.0 mm, bend angle of 66° 10 cracks were recorded, 6 cracks passed through the heat affected zone and were stopped in the base material. None of the cracks exceeded the boundary value of 80 mm (from the overlay weld centre to the edge of the crack). The test result was positive.

Analysis of Test Results

All the test specimens produced positive results as regards the final assessment concerning the weldability of the material in accordance with criteria presented in the guidelines of SEP 1390. Conditions related to the formation and propagation of cracks within appropriate limits (during bending performed to reach the boundary angle) were satisfied. Table 3 presents the detailed characteristics of the parameters recorded during the bend tests (taking into consideration cracks formed in relation to the height of the excess weld metal of the overlay weld).

metal. A similar dependence referred to a greater number of cracks crossing the HAZ boundary and entering the base material of the specimens characterised by lower heights of overlay welds. The latest criterion is particularly important as regards the essence of technological tests, where

Table 3. Bend test results [9]

Height of excess weld metal [mm]	**2.5**	**2.2**	**1.2**	**1.0**	**0.8**	**0.1**
Specimen no.	1	2	5	6	3	4
Maximum bend angle [°]	65	66	66	66	65	67
Value of force [kN]	945	930	895	900	910	940
Number of cracks formed in the overlay weld	6	6	7	10	7	9
Number of cracks passing outside the HAZ	4	2	3	6	6	7
Total length of the longest crack [mm]	39.6	36.6	25.3	25.0	70.5	30.0
Longest crack from overlay weld axis [mm]	20.9	16.2	17.7	12.5	37.1	18.0
Bend angle related to the formation of crack no. 1 [°]	20	40	20	8	8	12
Bend angle related to the passage of crack no. 1 through the HAZ [°]	56	48	46	28	24	32
Bend angle related to the formation of the longest crack [°]	36	40	28	8	8	12
Test assessment [ok – positive; neg. – negative]	ok	ok	ok	ok	ok	ok

The test results presented in Table 3 were determined for all of the specimens subjected to bending to a boundary angle restricted within the range of 65÷67° using force restricted within the range of 895 to 945 kN. In the specimens having heights of 0.1, 0.8 and 1.0 mm, the first cracks were initiated at small bend angles restricted within the range of 8° to 12° and were characterised by significant dynamics when crossing the HAZ boundary at bend angles restricted within the range of 24° to 32°. In turn, in the specimens containing overlay welds having higher excess weld metal, i.e. 2.5, 2.0 and 1.2 mm, the first cracks were initiated at greater bend angles restricted within the range of 20° do 40° and were characterised by significantly smaller dynamics making it possible to cross the HAZ boundary at bend angles restricted within the range of 46° to 56°.

It was also possible to observe greater amounts of cracks formed in the specimens characterised by lower heights of the excess weld metal of the overlay weld faces in relation to the specimens characterised by higher excess weld

it is absolutely necessary that a crack be generated in the overlay weld, cross the HAZ boundary to finally enter and be stopped in the base material.

Conclusions

The tests and the analysis of the effect of the change in overlay weld geometry on the course of technological testing used when assessing the weldability of thick-walled materials made of steel S355J2+N according to the guidelines of SEP 1390 enabled the performance of the related assessment and the formulation of the following conclusions:

- first cracks were initiated significantly early and related to the lower excess weld metal of overlay weld faces,
- rate of crack propagation was significantly higher in cases of the lower excess weld metal of overlay weld faces,
- number of cracks passing through the HAZ and reaching the base material was greater in cases of lower excess weld metal,
- number of cracks was also greater in cases of

the lower excess weld metal of overlay weld faces,
- recommendation contained in the technological test according to the guidelines of SEP 1390 concerning the excess weld metal height of approximately 1 mm is fully justified in light of the performed tests as the cracks were initiated early (as early as at an angle of 8°) and satisfied the condition of passing from the overlay weld to the base material at an angle of mere 24°,
- all of the tests performed using the specimens having various heights of excess weld metal produced positive results concerning the weldability of 65 mm thick plates made of steel S355J2+N.

Confirming the rightness of the recommendation concerning the height of the excess weld metal of the overlay weld (approximately 1 mm) is justified, as the range of up to 1 mm undoubtedly offers the most favourable conditions as regards the appropriate dynamics of the test and its high sensitivity without affecting the final result concerning the assessment of weldability. Properly conducted tests make it possible to verify the analytically determined assessment of weldability related to thick-walled structural materials used in welded structures. Particularly important is the test when assessing the weldability of thick-walled structural materials used in structures exposed to significant static loads or to loads of lower intensity but being dynamic in nature. For this reason the test is often recommended by various guidelines or standards, e.g. DIN 18800-7 [10].

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