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Additional Requirements Concerning the Fabrication of Welded Structures in Accordance with the EN 1090 Standard

Abstract: The manufacturer of welded structures should meet the requirements set forth in the EN 1090 standard, concerning, in particular, technological processes as well as their control and supervision. Additional requirements are concerned with the selection and evaluation of structural material properties. The so-called Z-test enables the assessment of plastic properties in the direction perpendicular to the material surface, whereas test SEP 1390 is used to evaluate the weldability of thick-walled materials (based on material ability to block the development of initiated cracks). These additional requirements aim to increase the safety and service life of crucial welded structures exposed to dynamic loads.

Keywords: Fabrication, Welded Structure, Material Properties, Weldability Assessment, Test SEP 1390

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Introduction

Long service life and reliability belong to some of the most important features of building structures. All structures should be designed and made in a manner ensuring their operation for a previously specified period. The selection of appropriate structural materials should take into account not only their mechanical strength but also easy and reliable fabrication as well as resistance to a surrounding environment. Many structures made in Poland are commissioned by overseas customers. Structures made, e.g. for the German market, must satisfy requirements effective in this country, where related contractual provisions require the satisfaction of criteria specified in the EN 1090 standard as well as those stipulated in Zusätzliche Technische Vertragsbedingungen und Richtlinien für Ingenieurbauten (Additional Technical Conditions of Contract and Guidelines for Civil Engineering Structures – ZTV-ING).

Requirements for steel structures

All building structures made of steel and aluminium should be fabricated following the requirements of the EN 1090-1–3 [1] series of standards, harmonised by the Regulation (EU) no. 305/2011 of the European Parliament and of the Council [2]. A similar situation is observed in terms of civil engineering structures, where, e.g. road infrastructure or bridges must meet requirements specified in the Additional Technical Conditions of Contract and Guidelines for Civil Engineering Structures (ZTV-ING). Part 4 of the aforesaid requirements contains guidelines concerning steel and composite structures, whereas Part 3 contains requirements concerning the corrosion protection of steel structures [3].

Fabrication of structures in accordance with ZTV-ING

Additional ZTV-ING guidelines concerning the manufacturer require the latter to satisfy the requirements related to the certification of factory production control (in accordance with the requirements of the EN 1090-1 standard), the welding certificate (in accordance with the requirements of the EN 1090-2 or EN ISO 1090-3 standards), in accordance with a related execution class

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(EXC) as well as welding coordination based on appropriate technical knowledge described in the EN ISO 14731 standard [3, 4].

The provisions specified in ZTV-ING approve the use of materials representing strength classes S235, S355 and S460. Materials used in steel structures must satisfy the requirements specified in the EN 10025-1-5, EN 10210 and EN 10219 standards [3, 5, 6, 7]. In addition, load-bearing structures of bridges cannot contain materials, the toughness of which was determined at a temperature of +20°C and that of 0°C (JR and J0). An additional requirement involves the performance of strength tests in the direction perpendicular to the surface, i.e. the so-called tensile test in the z-axis, aimed to verify appropriate plastic properties (in accordance with the requirements of the EN 10164 standard). The above-named test enables the identification of the minimum area reduction, aimed to determine appropriate quality class Z15, Z25 or Z35 [9]. Materials subjected to analyses in the z-axis should first undergo ultrasonic tests performed in accordance with the requirements specified in the EN 10160 standard (to confirm the satisfaction of criteria of required class S1 for flat products).

All required steel properties must be confirmed in inspection certificate 3.2 (in accordance with the EN 10204 standard) and approved by a recognised body. Inspection certificates should be presented before the fabrication of structures. In addition, the ZTV-ING guidelines specify what detailed information should be contained in the certificate (e.g. the chemical composition containing 15 chemical elements including C, Si, Mn, P, S, Al, N, Cr, Cu, Mo, Ni, Nb, Ti, V and B). The ZTV-ING document also requires providing information concerning the carbon equivalent (CEV) as well as confirming the satisfaction of SEP 1390 test-related weldability requirements for materials having a thickness of 30 mm and above as well as a strength of up to S355. Additional tests such as SEP 1390 or the Z-test (in accordance with the EN 10164 standard) should be taken into account when ordering steel rather than upon the delivery of materials (due to the risk of negative test results) [3, 8, 9, 10].

The above-named regulations are also concerned with the quality level of welded joints, supervision over the fabrication of a given structure, the performance of non-destructive tests and corrosion protection. However, the aforesaid guidelines do not exhaust the entire list of requirements contained in ZTV-ING.

Characteristics of weldability test SEP 1390

Weldability test SEP 1390 referred to in ZTV-ING is used for examining the weldability of materials, the minimum yield point of which is restricted within the range of 235 MPa to 355 MPa and having a thickness of 30 mm or greater [11]. The weldability test consists in bending an appropriately prepared specimen sampled from a material subjected to the test. Weldability test SEP 1390 aims to assess the ability of a given material to block the development of a propagating crack, where the crack is triggered by the deposition of an overlay weld on a specimen subsequently subjected to bending. The shape of a specimen sampled for the test is presented in Figure 1, whereas the dimensions of the specimen (depending on the thickness of a material subjected to the test) are presented in Table 1.

As regards tests of materials having thicknesses in excess of 50 mm, it is necessary to remove the excess material (from one side) to a thickness of 50 mm, leaving one surface unprocessed after rolling.

A schematic diagram concerning the performance of weldability test SEP 1390 including a

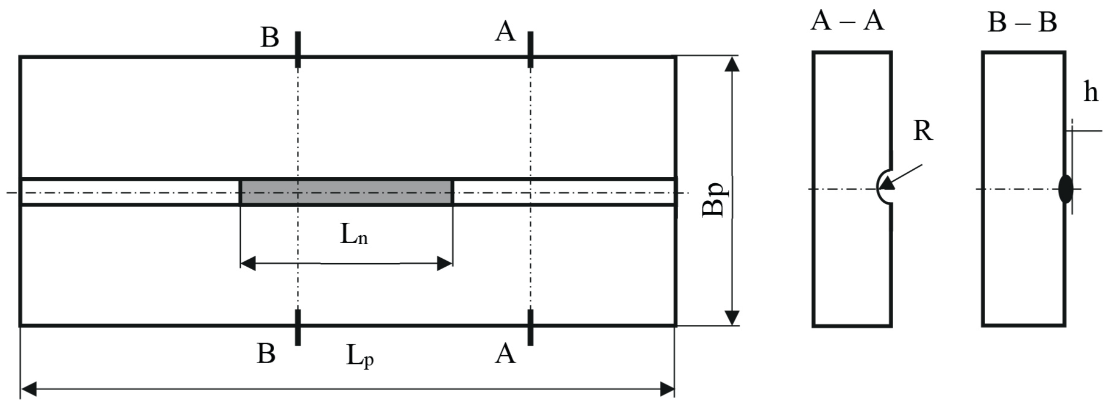

Fig. 1. Schematic diagram of a specimen used in weldability test SEP 1390 [12]

Table 1. Dimensions of specimens in relation to the thickness of a material subjected to tests [11]

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 ≤ g ≤ 35	410	200	175	4
35 < g ≤ 40	440	200	190	4
40 < g ≤ 45	470	200	220	4
45 < g ≤ 50	500	200	220	4
g > 50	500	200	220	4

bend test involving an appropriately prepared specimen is presented in Figure 2, whereas the dimensions of the bending mandrel, support spacing and support diameters are presented in Table 2.

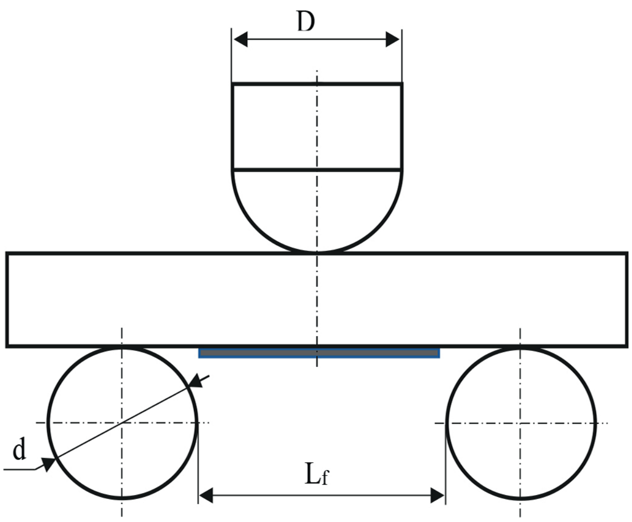

Fig. 2. Schematic diagram presenting the weldability test including the bend test [12]

Table 2. Dimensions in the bend test-related schematic diagram for a range of specimens [12]

Thickness g, mm	Mandrel diameter D, mm	Support spacing L_f, mm	Support diameter D, mm
30 ≤ g ≤ 35	105	190	
35 < g ≤ 40	120	220	
40 < g ≤ 45	135	250	≥ 50
45 < g ≤ 50	150	280	
g > 50	150	280	

The bend test should be performed using a testing machine featuring an appropriately wide load range (preferably 1000 kN) and related fixtures, consistent with the schematic diagram presented in Figure 2 [11–13].

Pre-test preparation of specimens

Specimens should be sampled from test materials in accordance with the scope specified in the guidelines of SEP 1390, concerning the type of a given material and its thickness. Afterwards, the specimen should be processed mechanically to obtain required dimensions and rounded external edges. Specimens used in tests concerning thicker materials should be processed on one side; it is necessary to remove the excess material to a thickness of 50 mm, leaving one surface unprocessed after rolling. The groove (having radius R = 4 mm) for an overlay weld should be made mechanically on an unprocessed surface, in accordance with the schematic diagram presented in Figure 1.

An overlay weld should be made in the groove (in accordance with the schematic diagram presented in Figure 1) using the manual metal arc welding method as well as a heavy coated rutile electrode having a diameter of 5 mm and length (L_n) specified in Table 1. The length of the overlay weld should be appropriately adjusted depending on the thickness of the material. The height of excess weld metal (h) should amount to approximately 1 mm. The higher the overlay weld, the later the crack initiation, which could lead to the obtainment of an invalid test result. The overlay weld should be made in one continuous run, without intermission [12–14].

The specimens subjected to bend test SEP 1390 (performed within the confines of weldability tests) were made of 30 mm, 40 mm and 60 mm thick plates, which, in turn, were made of steel S355J2+N (in accordance with the aforementioned recommendations). The test material satisfied related requirements concerning both the yield point and thicknesses. The most important steel-related data (in terms of the experiment) are presented in Table 3.

The test specimens designated as 1/40 and 2/40 were sampled from plates obtained from various heats, which was indicated by differences in primary properties and carbon contents as well as by the same value of carbon equivalent.

As regards the above-named steel, the value of carbon equivalent (in accordance with related

Table 3. Specifications of steel S3553J2N [15, 16]

Specimen designation	Material thickness t, mm	Yield point R_e, MPa	Tensile strength R_m, MPa	Carbon content C, %	Carbon equivalent Ce, %
1/30	30	356	558	0.16	0.41
1/40	40	355	556	0.16	0.42
2/40	40	363	545	0.17	0.42
1/60	60	358	512	0.18	0.44

recommendations specified by the International Institute of Welding (IIW)) was identified using the dependence presented below:

$$Ce = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

and should reach a maximum of up to 0.47% in relation to materials having thicknesses restricted within the range of 40 mm to 150 mm. In addition, if the following conditions concerning limit values of carbon content and those of carbon equivalent related to material thickness, i.e.

$C \leq 0.20\%$ and $Ce \leq 0.45\%$ and $g \leq 25$ mm

or

$C \leq 0.20\%$ and $Ce \leq 0.41\%$ and $g \leq 37$ mm

were satisfied, it could be assumed that additional precautions (e.g. preheating) were not needed. However, it was also necessary to satisfy the IIW recommendations concerning steel characterised by strength R_m = 490–690 MPa in terms of the low-hydrogen welding process. In terms of greater material thicknesses, i.e. above 40 mm, the above-named conditions are satisfied if Ce ≤ 0.40%. Failure to satisfy the above-named conditions combined with the existence of factors related to the significant thickness of the material (e.g. joint restraint degree) might trigger the formation of hard structures and, consequently, cold cracks [17].

The test specimens having a thickness of 30 mm satisfied the above-presented criteria, the specimens having a thickness of 40 mm were on the border of satisfying the criteria, whereas the specimen having a thickness of 60 mm failed to satisfy the criteria. The performance of technological test SEP 1390 involving all the materials should enable the verification of assessment concerning weldability determined using the analytical method.

All the specimens were subjected to cladding performed using the manual metal arc welding method (MMA) and OK FEMAX 33.80 heavy coated filler metal wires having a core diameter of 5 mm (satisfying related requirements of test SEP 1390:1996) [18]. The above-named electrode wires are recommended for the welding of thick elements. In addition, the weld deposit obtained using such electrodes is characterised by a low carbon content and favourable mechanical properties (appropriate for the steel subjected to the tests).

The test specimen (in accordance with SEP 1390-related recommendations) prepared for the cladding process and containing the overlay weld is presented in Figure 3.

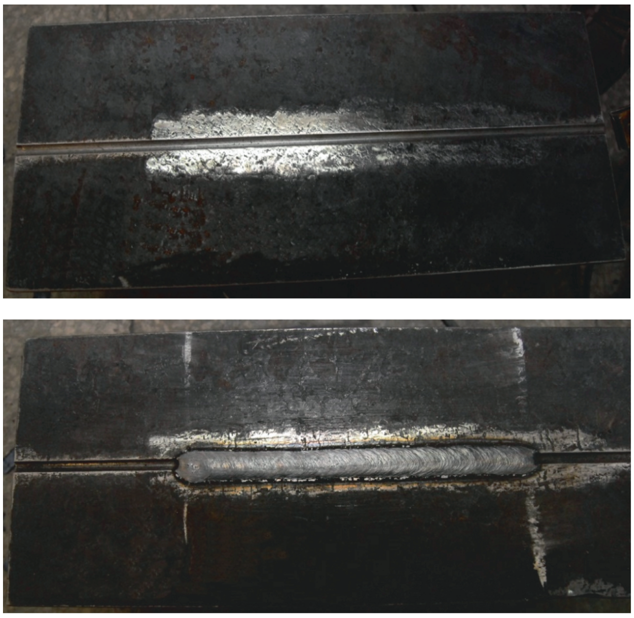

Fig. 3. Test specimen before and after the cladding process

Bend test

The bend test was performed using a testing machine provided with appropriate fixtures (in accordance with the schematic diagram presented in Figure 2). The specimens were placed on support rollers, with the overlay weld facing downwards and located in the tension zone. The bending mandrel and support spacing were adjusted in relation to the thickness of the test material (in accordance with the schematic diagram presented in Figure 2 and the data presented in Table 2). The bend tests were performed as static bend tests under conditions of a uniformly increasing load. The tests involved the observation of the tension zone and the control of the specimen bend angle. The test was continued until the obtainment of a minimum bend angle of 60°.

The observation of the tension zone enabled the initial assessment of the bend test, which consisted in the identification of crack formation and propagation (see Fig. 4). The crack area was observed using a mirror located underneath the specimen.

Fig. 4. Cracks in the overlay weld at the initial stage of bending

Assessment of bend tests and test results

After the bend tests, the specimens were subjected to assessment which consisted in the visual inspection of the specimen surface with the overlay weld and measurements of crack lengths in relation to the overlay weld axis. To obtain better resolution when assessing the size of the crack on the surface it was necessary to perform penetrant tests.

The test results were regarded as positive in relation to specimens 1/30, 1/40 and 2/40 as each of the specimens contained at least one crack in the overlay weld which crossed the heat affected zone (HAZ) and was blocked in the test material (base material). The length of the crack did not exceed 80 mm (measured from the overlay weld axis to the specimen edge). The above-named conditions were not satisfied as regards specimen 1/60 as it ruptured before reaching a bend angle of 60°. For this reason, the above-named test result was classified as negative.

Specimens nos. 1/30, 1/40 and 2/40 after the bend test are presented in Figures 5, 6 and 7.

The 30 mm thick specimen (Fig. 5) subjected to bending until the obtainment of a bend angle of 60° contained four cracks. The length of the longest crack (measured from the overlay weld axis) amounted to 17 mm. The test result was classified as positive, making the material approvable as regards the fabrication of welded structures.

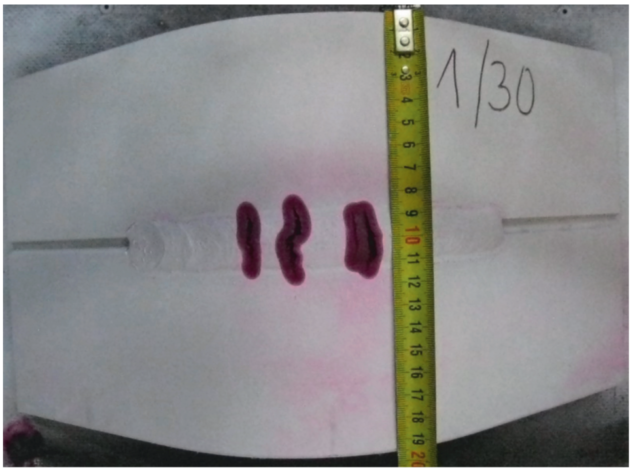

Fig. 5. Crack-triggered penetrant test indications in the 30 mm thick specimen subjected to the bend test

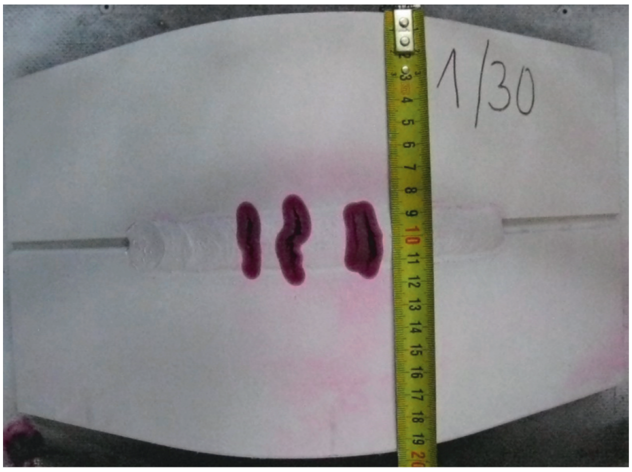

Fig. 6. Crack-triggered penetrant test indications in the 40 mm thick specimen subjected to the bend test

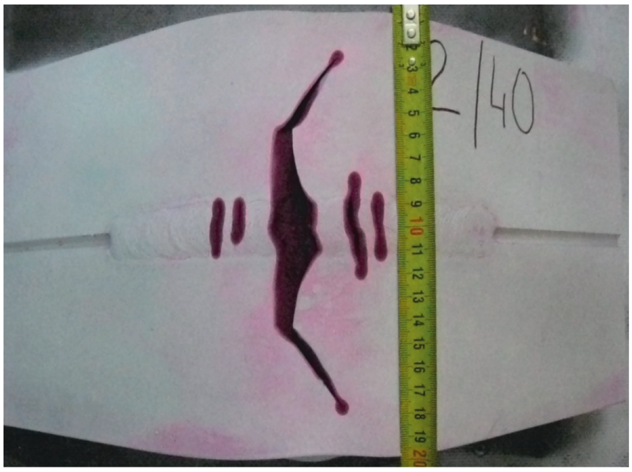

Fig. 7. Crack-triggered penetrant test indications in the 40 mm thick specimen subjected to the bend test

The first 40 mm thick specimen (Fig. 6) subjected to bending until the obtainment of a bend angle of 60° contained five cracks. The length of the longest crack (measured from the overlay weld axis) amounted to 63 mm. The test result was classified

Fig. 8. Cross-section of specimen no. 1/60 containing the bend-triggered fracture

as positive, making the material acceptable in the fabrication of welded structures.

The second 40 mm thick specimen (Fig. 7) subjected to bending until the obtainment of a bend angle of 60° contained five cracks. The length of the longest crack (measured from the overlay weld axis) amounted to 76 mm. The test result was classified as positive, making the material acceptable as regards the fabrication of welded structures.

The last bend test, involving specimen no. 1/60, also sampled from steel S355J2+N (having a thickness of 60 mm), revealed that the specimen ruptured in relation to a bend angle of approximately 50°. The post-rupture cross-section of the specimen is presented in Figure 8.

During bending up to an angle of 50°, the course of the test was similar to the previous trials (with gradually increasing cracks) until the critical moment, i.e. the entire rupture of the specimen. Because of the negative test result, the required criterion of weldability was not satisfied in relation to the material subjected to the test.

Summary

The above-presented test along with their results revealed that technological test SEP 1390 could be applied to verify the weldability of thick-walled materials from group S355J2+N, used in the fabrication of welded structures. The positive bend test results obtained for the 30 mm and 40 mm thick materials confirmed their favourable welding properties and, at the same time, the satisfaction of related criteria of weldability and usability as regards the fabrication of welded structures. In turn, the negative test result obtained in relation to the 60 mm thick material excluded the applicability of latter from welded structure-related applications (in accordance with the ZTV-ING recommendations). The length of the maximum crack in the specimen sampled from the 30 mm thick material amounted to 17 mm, which indicated the very fast and effective blocking of crack propagation in the material and confirmed very favourable welding properties of the material itself. In terms of specimen no. 1/40, sampled from the 40 mm thick material, the length of the crack amounted to 63 mm, which could be regarded as a relatively safe value. In turn, the length of the crack obtained in specimen no. 2/40 amounted to 76 mm, which was close to the limit value (amounting to 80 mm). In view of the foregoing, the material could be approved, yet such an approval was at the verge of safety. In turn, the specimen sampled from the 60 mm thick material ruptured before reaching a boundary angle of 60°. The negative test result concerning the 60 mm thick material disqualified the latter as inappropriate in terms of the fabrication of welded structures. In relation to all material thicknesses (i.e. 30 mm, 40 mm and 60 mm), the results obtained in the technological tests were fully consistent with analytically identified weldability. The foregoing justified the conclusion that the verification of welding properties was successful within the entire range subjected to the tests and that test SEP 1390 proved usable as regards the weldability assessment concerning thick-walled materials used in crucial structural elements exposed to dynamic loads.

In addition, during the tests it was possible to observe significant differences as regards the frequency of crack formation in overlay welds and the propagation of the cracks in the material. In view of the foregoing, it could be presumed that factors responsible for the varied behaviour of cracks included the geometry and properties of the overlay weld made in the groove of the specimen and the properties of the material subjected to bending.

It should be noted that, because of the fact that tests could lead to the obtainment of negative results, it is advisable that such trials should be performed by the manufacturer of steel products (steelworks) and that information concerning the performance and results of such tests should be contained in related inspection certificates (conformity certificates). The performance of the tests by the buyer (following the purchase of steel) could entail (in cases of negative test results) significant losses, particularly in terms of thick and heavy materials. When ordering a given material, the purchasing party should, in advance, specify all necessary quality-related requirements and verify their satisfaction upon the delivery of the material.

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