Qualification of welding procedures for aluminium, steel and iron castings

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Abstract
The article presents the qualification process concerned with the following procedures: finishing welding of aluminium castings pursuant to PN-EN ISO 15614-4, production welding of steel castings pursuant to PN-EN ISO 11970 and production- and finishing welding of cast irons pursuant to PN-EN ISO 15614-3. The work enumerates the cases of qualification of welding procedures for aluminium, steel and iron castings and presents details related to test joint designs as well as the manner of their preparation taking into account welding conditions and other technological aspects. The text also contains precise characteristics of test joint examinations and their range of application while qualifying a given welding procedure. In addition, the article informs about test results which justify the qualification of a finishing welding procedure for aluminium castings and test plate butt joints in case of cast irons and cast steels. In all cases particular attention was paid to the range of qualification of procedures for characteristic conditions of the welding process and its basic variables.

Key words: production welding, qualification of procedure; welding of castings; aluminium, cast steel, cast iron

1. Introduction

Domestic producers increasingly often encounter the necessity of possessing documents qualifying applied welding procedures and documents certifying qualifications of personnel performing specific welding operations. Such requirements arise mostly from a quality management system applied at a given enterprise but also are voiced by customers interested in products or technological services representing the highest possible quality and repeatability. The qualification of welding procedures and examination of welding personnel are carried out by examining bodies, which often constitute the so-called approved third party. Such centres, as notified bodies, possess approved qualifications, accredited laboratories and are independent both of the manufacturer and their customer [1].

As regards welding, the issues of qualification through testing of procedures are regulated by 12-section (as of today) international standard PN-EN ISO 15614 ("Specification and qualification of welding technologies for metallic materials. Welding procedure test") which has replaced another multi-section European standard EN 288 ("Specification and Approval of Welding Procedures for Metallic Materials"). Test-related details concerned with finishing welding of aluminium castings are presented in Part 4, whereas the issues connected with the qualification of welding procedures for cast iron are described in Part 3 of the aforementioned international standard. Apart from the series of PN-EN ISO 15614 standard in the past two years another standard related to welding of castings has appeared i.e. PN-EN ISO 11970 (Specification and Approval of Production Welding Procedures for Steel Castings) [1-6].

The text below presents the principles for qualification through testing of the finishing welding procedure for aluminium castings and production welding procedure for cast irons and steel castings; special attention being paid to the most important information from the procedure user’s point of view i.e. joint-related requirements and range of qualifications for specific variables of the welding process.

Welding of castings is becoming increasingly popular as this welding process offers faster and cheaper elimination of casting imperfections such as faulty shape, misrun casting, porosity, and fractures accompanying more complicated castings. This procedure also allows the user to join smaller and easy-to-cast elements into one more complicated product [1-3].
2. Qualification of finishing welding procedure for aluminium castings

According to standard PN-EN ISO 15614-4 [4] finishing welding is production-accompanying welding aimed at the elimination of casting imperfections and core holes in order to obtain intended quality of castings. The standard specifies how a finishing welding technological specification for aluminium castings is qualified through a welding procedure test. It does not, however, concern repair welding [1,4].

Similarly to the qualification of other welding procedures, also in case of finishing welding of aluminium castings it was necessary to specify test joints representative of cast elements. The shape and minimum dimensions of the test joint are presented in Figure 1 [4].

Fig. 1. Combined test joint with gap, hole and groove [4] where: t - material thickness, mm

The test joint should be cast as a whole or as three separate test joints. Test joints may also be sampled from a production casting, characterised by the same features as shown in Figure 1 (gaps, holes and grooves). The mechanical working of test joints is allowed.

The preparation and welding of test joints should be carried out pursuant to a prequalified Welding Procedure Specification (pWPS) and general welding conditions applied in the production of related joints. The manner of material preparation is presented in Figure 2. In each case it is necessary to discontinue and resume the welding process. The welding and testing of test joints should be performed in presence of an examiner or a representative of an examining body [1,7].

Furthermore, the standard contains instructions related to welding and assessment of test joints. According to the denotations of Figure 2, the said recommendations are as follows:

Detail A1 - should present the filling of a half-round recess. Welding should be conducted in the vertical up position (PF) or flat position (PA). Critical imperfections include undercuts in corners and lack of fusion.

Detail A2 - should present the filling of a gap. Welding should be conducted in the flat position. Critical imperfections include cracks, cavings in craters, cracks in craters, undercuts and lack of fusion.

Detail B1 - should present the filling of a hole. Welding should be conducted in the flat position so that it is possible to show the closure of the hole in the casting. It is typical to use a backing bar. Critical imperfections include inclusions and lack of fusion.

Detail C1 - should present the production welding of a recess. Welding should be performed in PF or PA positions. Critical imperfections include undercuts in corners and lack of fusion.

Detail C2 - (groove) should be welded in the direction as shown in the figure, in the flat position. It is necessary to discontinue and resume the welding process. Critical imperfections include undercuts, cracks in craters and lack of fusion.

Afterwards, representative test joints produced in accordance with the aforesaid requirements should undergo non-destructive and destructive tests. Standard PN-EN ISO 15614-4 requires the following tests to be carried out: visual inspection, liquid-penetrant inspection, radiographic and break tests as well as microscopic metallographic examination. The break test should be performed with test joints provided with a notch. Notch-preparation manner in individual areas of the test joint is presented in standard PN-EN ISO 15614-4. In contrast to other required tests, the break test is qualitative and thus makes it possible to obtain important information concerning imperfections, if any, inside the weld e.g. lack of fusion, cracks, blisters, metallic inclusions etc. [1,4].

The criterion of qualification of finishing welding procedure for aluminium castings requires that allowed welding imperfections should be within the limits of quality level C pursuant to PN-EN ISO 10042, whereas in case of pressure elements - within the limits of quality level B of the aforementioned standard [8].

The qualification of a prequalified Welding Procedure Specification based on a welding procedure test pursuant to PN-EN ISO 15614-4 is valid for welding in production or on-site conditions, upon maintaining the same technical and quality-related surveillance of the manufacturer. The qualification range is concerned with the type and thickness of the parent metal as well as to essential variables of the welding process. The ranges...
of qualification are the same as in case of standard PN-EN ISO 15614-2 concerned with the welding procedure for aluminium and its alloys. In this case, material types include those from groups 24, 25 and 26 (casting aluminium alloys) [9,10].

3. Qualification of welding procedure for steel castings

The first stage of approval of a welding procedure for steel castings requires the development of a prequalified Welding Procedure Specification and collection of necessary documentation (material certificates, welder examination certificates). Next, in accordance with the pWSP, it is necessary to produce a test joint of dimensions as specified in PN-EN ISO 11970 (Fig. 3). The dimensions provided in the aforesaid standard represent the minimum values; one may produce a joint of greater dimensions (width, length) e.g. while conducting additional tests [2,6,7].

Standard PN-EN ISO 11970 requires the following tests to be performed in 100% range: visual inspection, radiographic or ultrasonic test, liquid-penetrant or magnetic particle inspection. If non-destructive tests were successful, it is necessary to conduct obligatory destructive tests, which include a transverse tensile test (one test piece) and an impact test (two sets with three test pieces each). Macro- and microscopic tests, hardness test, bend test, corrosion test and other additional tests are performed if so required by the ordering party or an appropriate related standard (e.g. product-related standard) [6,11].

In order to meet the NDT approval requirements, the weld should represent quality level C pursuant to standard PN-EN ISO 5817:2009, except for excess weld metal and excess face concavity which may represent quality level D [6,11].

The manufacturer-related range of qualification is the same as in case of the whole series of standards concerning the qualification of welding procedures [4-6]. There are, however, differences connected with the qualification range for the parent metal. Standard PN-EN ISO 11970 stands out as it does not concern the guidelines on material grouping system pursuant to ISO TR 15608, but contains its own division of steel casting materials (Table 2) [6,9].

In order to reduce the number of welding procedure tests, cast steels are grouped as in Table 2. The approval of one material applies to the whole material group or sub-group containing a material used during a welding procedure test.

In addition, within each group A, B, C or F, each sub-group admits a sub-group with a lower index. For instance, a test joint made of cast steel from sub-group C3 admits welding of cast steels also from sub-groups C2 and C1 [2,6].

If qualification is conducted for a cast steel not contained in a cast steel division system (acc. to PN-EN ISO 11970), it is necessary to carry out separate qualification of a welding procedure. In such case, an approval applies only to a specific material used in a welding procedure test.

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**Fig. 3. Test joints a) butt joints of plates (cast steel or cast iron), b) butt joints of pipes (cast steel) [2,3,5,6]**
The range of parent metal thickness obtained on the basis of a qualified test joint is presented in Table 1.

Table 1. Parent metal thickness range [2,6]

<table>
<thead>
<tr>
<th>Test joint thickness, ( t ) mm</th>
<th>Range of approval</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 15 &lt; t \leq 30 )</td>
<td>3 mm do 2t</td>
</tr>
<tr>
<td>( t &gt; 30 )</td>
<td>0.5t do 2t or 200 mm*</td>
</tr>
</tbody>
</table>

* whichever value is higher

The range of filler metal approval should meet the requirements of materials referred to in Table 2. Other filler metals may be applied if they meet the criteria presented below:
- they are in the same group of mechanical properties (Rm) – if no impact test is required or,
- the chemical composition of the filler metal corresponds to the chemical composition of the parent metal or,
- it contains a greater content of alloying components in order to maintain the level of ferrite in group F parent metal unchanged or,
- it contains a greater content of alloying components in order to maintain the level of operational properties of parent metals from groups D, E, F, G, H, I, J and K unchanged.

The range of qualification also concerns the amount of supplied heat, where, in case of hardness-related requirements, the lower qualification range is by 15% lower and, in case of impact-related requirements, the upper qualification limit is by 15% higher [6].

Table 2. Cast steel division system according to PN-EN ISO 11970 [2,6,12-20]

<table>
<thead>
<tr>
<th>Group</th>
<th>Sub-group</th>
<th>Name</th>
<th>Designation</th>
<th>Division criterion</th>
<th>Cast steel examples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cast steel examples</td>
</tr>
<tr>
<td>A</td>
<td>A1</td>
<td>Cast carbon steels (Si 0.8 % max, Mn 1.7 % max)</td>
<td>C(\leq0.25%); Rp(\leq275)MPa</td>
<td>200-400</td>
<td>PN-ISO 3755</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td></td>
<td>C(\leq0.25%); 275 &lt; Rp (\leq 360) MPa</td>
<td>GS240</td>
<td>PN-EN 10340, PN-EN 10293</td>
</tr>
<tr>
<td></td>
<td>A3</td>
<td></td>
<td>0.25 &lt; C (\leq 0.35) %</td>
<td>L500</td>
<td>PN-88/H83152</td>
</tr>
<tr>
<td></td>
<td>A4</td>
<td></td>
<td>C (&gt; 0.35) %</td>
<td>L600</td>
<td>PN-88/H83152</td>
</tr>
<tr>
<td>B</td>
<td>B1</td>
<td>Low-alloy cast steels: annealed, standardised, standardised and tempered</td>
<td>Rp (\leq 360) MPa</td>
<td>G20Mn5; GP240GR</td>
<td>PN-EN 10293</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td></td>
<td>Rp (&gt; 360) MPa</td>
<td>GX3CrNi13-4</td>
<td>PN-EN 10293</td>
</tr>
<tr>
<td>C</td>
<td>C1</td>
<td>Low-alloy cast steels: hardened and tempered</td>
<td>Re (\leq 500) MPa</td>
<td>G24Mn6</td>
<td>PN-EN 10293, PN-EN 10340</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td></td>
<td>500 &lt; Re (\leq 700) MPa</td>
<td>G30CrMoV6-4</td>
<td>PN-EN 10293</td>
</tr>
<tr>
<td></td>
<td>C3</td>
<td></td>
<td>Re (&gt; 700) MPa</td>
<td>GX4CrNi16-4</td>
<td>PN-EN 10293</td>
</tr>
<tr>
<td>D</td>
<td>D1</td>
<td>Ferritic stainless cast steels</td>
<td></td>
<td>GX1Cr12</td>
<td>PN-EN 10283</td>
</tr>
<tr>
<td>E</td>
<td>E1</td>
<td>Martensitic stainless cast steels</td>
<td></td>
<td>GX15Cr13</td>
<td>PN-EN 10283</td>
</tr>
<tr>
<td>F</td>
<td>F1</td>
<td>Austenitic stainless cast steels</td>
<td>Austenitic cast steels with ferrite content (\leq 35) %</td>
<td>GXCrNiMo19-11-2</td>
<td>PN-EN 10283</td>
</tr>
<tr>
<td></td>
<td>F2</td>
<td></td>
<td>Fully austenitic cast steels</td>
<td>GXNiCrMoCu25-20-5</td>
<td>PN-EN 10283</td>
</tr>
<tr>
<td>G</td>
<td>G1</td>
<td>Duplex stainless cast steels</td>
<td>Duplex stainless cast steels with ferrite content (\geq 35) %</td>
<td>GX6CrNiN26-7</td>
<td>PN-EN 10283</td>
</tr>
<tr>
<td>H</td>
<td>H1</td>
<td>Heat-resisting austenitic cast steels</td>
<td></td>
<td>GX40CrNiSi22-10</td>
<td>PN-EN 10295</td>
</tr>
<tr>
<td>I</td>
<td>I1</td>
<td>Precipitation-hardened stainless cast steels</td>
<td>PH stainless cast steels (PH - precipitation hardening)</td>
<td>GX5CrNiCuNb16-4</td>
<td>PN-EN 4216</td>
</tr>
<tr>
<td>J</td>
<td>J1</td>
<td>Nickel-based alloys</td>
<td>Nickel alloys</td>
<td>G-NiCr28W</td>
<td>PN-EN 10295</td>
</tr>
<tr>
<td>K</td>
<td>K1</td>
<td>Austenitic cast steels</td>
<td>Mn austenitic cast steels</td>
<td>L120G13</td>
<td>PN-88/H83160</td>
</tr>
</tbody>
</table>
4. Qualification of welding procedures for unalloyed and low-alloy cast irons

The qualification of welding procedure for cast irons is based on a prequalified Welding Procedure Specification prepared by the manufacturer or their authorised representative. In case of arc welding, the said pWPS must meet the requirements of standard PN-EN ISO 15609-1:2007, whilst in case of oxy-acetylene welding – those of standard PN-EN ISO 15609-2:2005 [7,22-27].

A test joint may be cast separately or sampled from a casting or its part and be prepared using machine cutting as presented in Figure 3a. When the geometry of a given test joint does not match the joints produced within a manufacturing process, the preparation of the joint and the qualification of the welding procedure is subject to standard PN-EN ISO 15611:2006 - Specification and Qualification of Welding Procedures for Metallic Materials – Qualification Based on Previous Welding Experience or PN-EN ISO 15613:2006 Specification and Qualification of Welding Procedures for Metallic Materials – Qualification Based on Pre-production Welding Test [3,5]

A test joint should be welded in accordance with a previously developed pWPS and the general welding conditions applied in related production. The production of the joint should be conducted in presence of an examiner or examining body, unless provided otherwise in the order or upon the revision of the agreement [3,5,9].

The standard concerned with the qualification of welding procedure for cast irons does not require such an extensive testing range as in case of the qualification of welding procedure for steels and nickel and its alloys. The standard no longer requires hardness distribution tests for the cross-section of a joint, bend test, impact tests or radiographic examination. As cast irons are characterised by very high vibration damping, they do not undergo ultrasonic tests either [5].

Similarly to the qualification of welding procedure for any other structural material, visual inspection and liquid-penetrant inspection cover 100% of welded joints, irrespective of a group, to which a given cast iron has been qualified. In addition, visual inspection should be conducted at every stage preceding the welding process i.e. pre-welding joint preparation and geometry of a joint during welding. Visual inspection results are considered positive if imperfections present in the test joint are maintained within the limits specified for quality level C pursuant to EN 1011-8 Welding – Recommendations for Welding of Metallic Materials Part 8 – Welding of Cast Irons. The allowed imperfections specified for quality level C of the cited standard are less restrictive with reference to the requirements concerning the same quality level referred to in standard PN-EN ISO 5817:2009 specifying quality levels for arc-welded steel joints [11,21].

Pursuant to standard PN-EN ISO 15614-3:2008, test pieces for welded joint tensile tests should be sampled crosswise in relation to the joint and be circular in shape. For welds of thickness < 50mm a test piece is sampled from one plate, whereas in case of thicker joints, unlike in case of a steel joint test, from two planes i.e. from the plane under the weld surface and from the one in the middle of a run or near the root. Frequent lack of precise information on parent metal mechanical properties implies the necessity of performing additional tensile tests of the parent metal. Such tests enable the determination of the minimum strength of the welded joint, which should be know prior to a tensile test involving this joint. The test piece for examination of parent metal properties is sampled from the test joint [3,5].

If a test joint is made of spheroidal cast iron, the range of qualification covers the welding of all other grades of spheroidal cast iron. In case of grey cast iron and malleable cast iron, a welding procedure test carried out for a selected grade of these iron is valid for all grades, whereas the test of welding procedure for a lower grade is valid for the cast iron grade which was used in the welding procedure test.

In case of the test of welding procedure for cast iron not included in a grouping system, it is necessary to carry out separate tests for each grade of cast iron. Where there are no requirements specified for impact strength or other dynamic tests, welding in any position qualifies welding in all positions. In other cases it is necessary to apply the qualification system as provided in Table 5 [3,5].

| Table 5. Qualification range for cast irons in relation to welding positions [5] |
|----------------|----------------|----------------|----------------|----------------|
| Welding position of test joint (ISO 6947) | Range of qualification |
| PA (flat position) | X | – | – | – |
| PC (transverse position) | X | X | – | – |
| PF (vertical up position) | X | X | X | – |
| PE (horizontal overhead) | X | X | X | X |

Very important, from the manufacturer’s point of view, is information stating that a qualification obtained with the use of the joint presented in Figure 3a is valid for all types of butt joints, both in case of element-joining welding and finishing welding i.e. welding aimed at removing imperfections formed during the casting of cast iron or during operation of a casting or its part [3,5].

5. Summary

In the terminology of standard PN-EN ISO 9001:2009, concerned with a quality management system, welding is regarded as a special process. The aforesaid standard requires that special processes should be carried out according to written technological specifications. The development of technological welding specifications is the basis for a proper and repeatable process, yet it does not ensure that a joint will meet the requirements as the welding process is conditioned by many correlated variables and, more often than not, by welding personnel skills, which significantly affect the quality and properties of welded joints. In order to verify whether a joint
meets necessary requirements, it should be subject to appropriate tests, whose positive outcome makes the basis for the qualification of a welding procedure by a third, independent, party. For this reason, only qualified technological welding specifications constitute a reliable base for planning operations and controlling the quality within a given procedure. Through the qualification of procedures, the cited standards of PN-EN ISO 15614 series and standard PN-EN ISO 11970 make the formal basis for creating the aforesaid base concerned with welding of castings.

As notified body no. 1405, relying on many years’ experience, Instytut Spawalnictwa offers the qualification of welding procedures for castings pursuant to the aforementioned standards [1-3, 27].

References