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Analysis of dimensions of test joints in the process of technology qualification according to PN-EN ISO 15614-1 in the aspect of ultrasonic testing according to PN-EN ISO 17640

Abstract: Quality assurance systems in welding engineering demand that the manufacturers of welded structures and welding equipment should apply qualified welding technologies. The most commonly used mode of welding technology qualification is testing a given welding technology by making test joints and carrying out their examination. This article presents the analysis of test joint dimensions recommended in PN-EN ISO 15614-1 in relation to the possibility of testing the quality of such joints using ultrasonic testing according to recommendations of currently valid related standards. The article contains a proposal how to determine the width of a test joint on the basis of the nomogram developed. The target readers of the article include welding engineers and technologists, other welding coordination personnel involved in the preparation of test joints as well as NDT personnel, due to the extensive analysis concerning the selection of testing methods and ultrasonic examination of test joints.

Keywords: test joints dimensions, ultrasonic testing, PN-EN ISO 15614-1, PN-EN ISO 17640

Introduction

The concept of quality assurance according to PN-EN ISO 3834 assumes that in production processes, non-destructive testing (NDT) plays an important role not only at the phase of finished product quality control but also at the stage of production preparation. NDT is used for controlling the quality of test joints in the most common welding technology qualification mode, i.e. one based on testing a given technology in accordance with PN-EN ISO 15614-1 [1]. The type and range of tests used is presented in Table 1 of the standard referred to above [4]. Both butt joints and T-joints as well as pipe branches with butt welds should undergo radiographic or ultrasonic testing in the test range covering 100% of the weld length. In order to select an NDT method, as well as due to the correlation between the required quality level B and acceptance levels for individual NDT methods standard PN-EN ISO 15614-1 refers to EN 12062 replaced in 2010 by PN-EN ISO 17635. Table 3 of this standard [7] contains recommendations concerning the selection of a volumetric testing method depending on the material thickness t; for joints having thicknesses t>40mm it is also recommended to carry out ultrasonic examination, whereas conducting

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radiographic examination is not recommended. At the same time, PN-EN ISO 15614-1 requires that in the case of the ultrasonic method, related tests should be carried out in accordance with PN-EN 1714 (the standard replaced by PN-EN ISO 17640). For this reason it is important that test joints, particularly those of great thicknesses, have a sufficient width enabling the performance of UT in accordance with PN-EN ISO 17640.

Test joint dimensions

In the case of butt joints of plates and pipes as well as for T-joints PN-EN ISO 15614-1 specifies only the minimum values of individual test joint dimensions. These dimensions for butt joints being the basis for further analysis are presented in Figure 1. The minimum value a = 150 mm is constant and does not depend on thickness. At the same time the standard contains an instruction that test joint dimensions should be sufficient for carrying out all required tests. A person preparing a test joint is obliged, among others, to ensure that the joint width (dimension a) is sufficient for carrying out ultrasonic examination. In most cases it is difficult or impossible due to the lack of necessary information related to UT resulting from the specific character of this testing method and requirements of related standards, in particular PN-EN ISO 17640. For this reason, in practice it is often necessary to use recommendations contained in appropriate reference publications such as those, among others, which can be found in "Poradnik inżyniera Spawalnictwo" (Engineer's Guide; Welding Engineering) [2], based on withdrawn standard PN-EN 288-3. In 2005 standard PN-EN 288-3 [6] was replaced by PN-EN ISO 15614-1. In addition to providing information about the minimum dimensions of test joints identical with the recommendations of the current standard [4], standard PN-EN 288-3 also contained formulas for joint dimensions in relation to material thicknesses. In the case of test plates the dependence defining the half-width of plates has the form a = 3t; minimum 150 mm. The analysis conducted has revealed that in the case of very thick joints, this width also is not sufficient for ensuring the minimum head travel zone during ultrasonic examination according to normative regulations concerning UT and, as a result, fails to satisfy the requirements of PN-EN ISO 15614-1. These circumstances lie at the heart of the attempt to determine the range of material thicknesses for which it would be possible to carry out UT in accordance with PN-EN ISO 17640 using available heads having various angles of beam insertion.

UT standard requirements

As it was mentioned above, standard PN-EN ISO 15614-1 assumes that test joints should meet the requirements specified for quality level B (with some minor exceptions negligible for UT). In turn, PN-EN ISO 17635 in Table A.7.1 assigns for the quality level B the following levels in UT involving the echo technique:

- acceptance level 2 according to PN-EN ISO 11666,
- test level at least B according to PN-EN ISO 17640.

In UT from test level A to test level C increased detectability is obtained by the increased coverage of the test area by, e.g. the number of searches (using several types of heads, carrying out additional searches for transverse indications) or by surface treatments (grinding of weld faces and roots) [5]. Standard PN-EN ISO 17640 in Table A.1 contains recommendations concerning the number of angles for inserting a beam and head travel zone width along with head positions depending on the test level and joint thickness. In the case of a butt joint, required quality level B and a thickness exceeding 15 mm it is necessary to use two angles for inserting a beam. If the frequency of a head used is below 3 MHz, it is possible to carry out the test using only one angle for inserting a beam, yet only for a joint thickness lower or amounting to 25 mm. This justifies the conclusion that for test joint thicknesses above 25 mm the width of such joints must enable carrying out ultrasonic examination with two angles for inserting a beam, between which – in accordance with PN-EN ISO 17640 recommendations – it is necessary to maintain at least 10° difference. The standard also assumes that tests should allow the use of heads having angles for beam insertion between 35° and 70°. Therefore, for available ultrasonic heads it is possible to use the following beam insertion angles: $\alpha = 35°, 45°$, 60° and 70°. The standard also requires that the width of head travel zone should be not less than $b_{min} = 1.25\ p$, where p – head pitch. Such a width along with the angle of a head used determines the minimum test joint dimension a which must amount to at least bmin increased by the half-length of the housing of an ultrasonic head used, i.e. usually approximately 13 mm (it was taken into account that the insertion of an ultrasonic beam takes place at the half-length of the head housing).

Analysis of test joint dimensions in relation to UT requirements

The analysis took into consideration the dimensions of test joints specified in PN-EN ISO 15614-1. Due to the previously mentioned fact that the determination of test joint widths for great thicknesses very often requires the use of reference publication recommendations [8], the analysis of test joint widths incorporated the use of instructions contained in the previous standard, i.e. PN-EN 288-3.

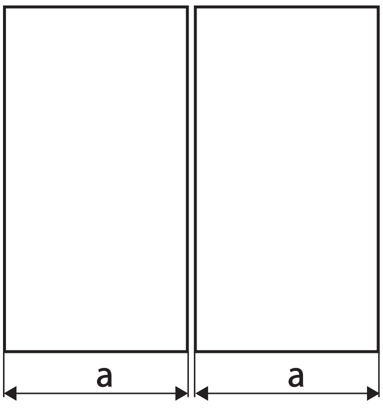

Fig. 1. Test plate dimension a according to PN-EN ISO 15614-1 [4]; a – minimum value 150 mm

Standard PN-EN ISO 15614-1 imposes only the minimum test joint dimension a amounting to 150 mm. In turn, following PN-EN 288-3 the width of one test plate part a is the triple material thickness, yet it cannot be less than 150 mm (Fig. 1). This means that for a material thickness $t = 50$ mm the width of a test plate is always 150 mm, and that above 50 mm the width is the function of material thickness and amounts to $a = 3t$.

In turn, standard PN-EN ISO 17640 specifies that the minimum test area width b for the UT method should amount to $b_{min} = 1.25\ p$, where p – head pitch. The head pitch p (Fig. 2) is the function of beam insertion angle α and test material thickness t and amounts to: $p=2t{\cdot}tg\ \alpha$

Bearing in mind the assumptions mentioned above it was necessary to carry out calculations aimed at verifying whether for test plate dimensions required by PN-EN ISO 15614-1 and PN-EN 288-3 there is a sufficient test area width which would enable conducting ultrasonic examination in accordance with the requirements of PN-EN ISO 17640. The calculations were carried out for all conventional ultrasonic heads available on the market, i.e. those having beam insertion angles $\alpha = 35°, 45°, 60°$ and 70°. The head $\alpha = 80°$ was not included on purpose as it is used solely for testing very thin elements rarely examined using UT methods. The calculations also took into consideration the test area width recommended from the practical point of view, i.e.:

$$b = 1.5 \cdot p,$$

where p – head pitch, at which, during a search, an ultrasonic wave strikes the root of a weld two times. Such an approach is justified due to very dangerous imperfections often present in this part of a weld and being of critical importance to the strength of a joint.

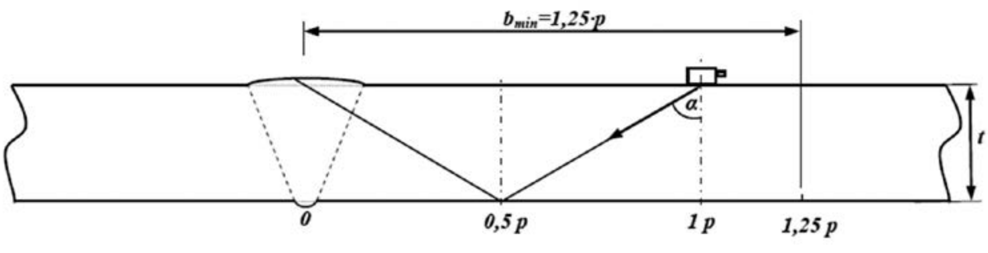

Fig. 2. Search zone width b according to PN-EN ISO 17640 [5]

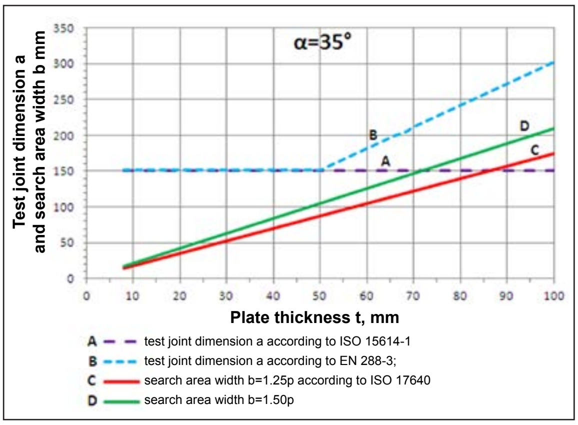

Fig. 3. Test plate width and search area width for the head having the beam insertion angle α=35°[3]

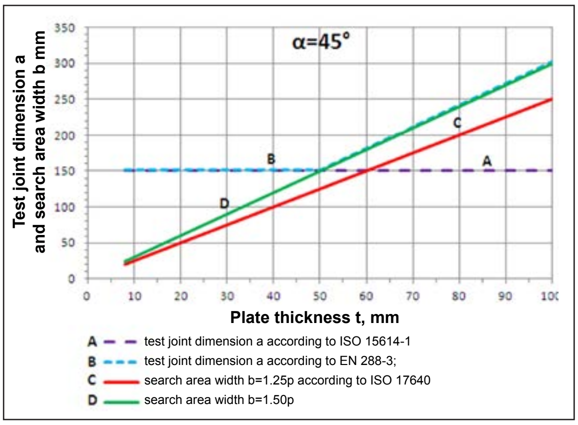

Fig. 4. Test plate width and search area width for the head having the beam insertion angle α=45°[3]

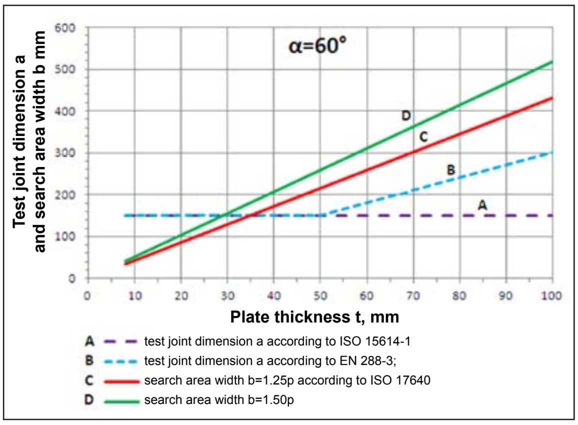

Fig. 5. Test plate width and search area width for the head having the beam insertion angle α=60°[3]

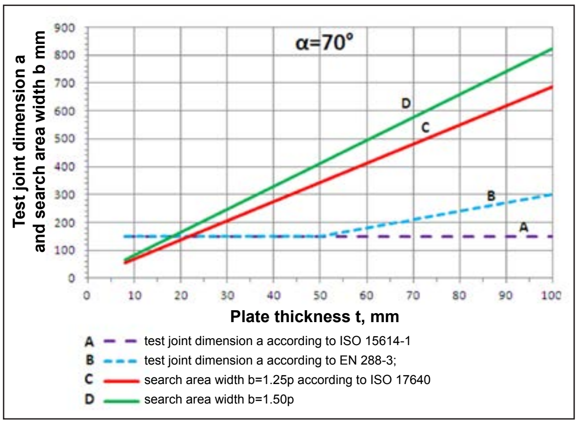

Fig. 6. Test plate width and search area width for the head having the beam insertion angle α=70°[3]

The calculation results are presented in the form of four diagrams (Fig. 3÷6), at which the axis of abscissae represents the parent metal thickness *t* and the axis of ordinates represents the test plate width a (corresponding to the above-mentioned thickness) in accordance with PN-EN ISO 15614-1 and PN-EN 288-3 as well as the search area width b_{min}=1.25·*p* (recommended by PN-EN ISO 17640) and *b* = 1.5·*p*. The diagrams contain four curves:

- curve A (violet, dashed) – test plate width according to PN-EN ISO 15614-1 (*a* = 150mm),
- curve B (blue, dashed) - test plate width according to PN-EN 288-3 (a = 3·t, min. 150 mm),
- curve C (red, full) – test area width *b* depending on the full head pitch p according to PN-EN ISO 17640, bmin = 1.25·*p*,
- curve D (green, full) – recommended test area width enabling the double passage of a beam through the root of a weld, *b* = 1.5·*p*.

Tables 1 and 2 contain the ranges of test plate thicknesses for which it is possible to carry out UT in accordance with the recommendations of PN-EN ISO 17640 using the heads referred to above. On this basis it is easily possible to observe which of the heads ensure conducting UT in accordance with guidelines for a given test plate thickness *t*.

The ranges were determined for the widths (dimension a) of test joints according to PN-EN ISO 15614-1 (Table 1) and PN-EN 288-3

Table 1. Ranges of test joint thicknesses which enable conducting UT in accordance with the requirements of PN-EN ISO 17640. The test joint dimension a adopted for all plate thicknesses is the minimum dimension required by PN-EN ISO 15640-1, i.e. a = 150 mm [3]

Criterion of search area width *b* in relation to full head pitch *p*	Range of plate thicknesses possible to test in accordance with adopted criterion (mm)			
	35°	45°	60°	70°
b = 1.25·p according to PN-EN ISO 17640	8-84	8-60	8-34	8-20
b = 1.5·p	8-70	8-50	8-28	8-18

Table 2. Ranges of test joint thicknesses which enable conducting UT in accordance with the requirements of PN-EN ISO 17640. The adopted test joint dimension is the minimum dimension required by PN-EN ISO 288-3, i.e. a = 3t, min. 150 mm [3]

Criterion of search area width *b* in relation to full head pitch *p*	Range of plate thicknesses possible to test in accordance with adopted criterion (mm)			
	35°	45°	60°	70°
b = 1.25·p according to PN-EN ISO 17640	8-without limits	8-without limits	8-34	8-20
b = 1.5·p	8-without limits	8-without limits	8-28	8-18

(Table 2). The bottom range limit always amounts to 8 mm as standard PN-EN ISO 17640 is concerned with UT of joints having thicknesses equal to or exceeding 8 mm.

Results of test joint width analysis - discussion

The analysis of the diagrams (Fig. 3÷6) and Tables (1 and 2) leads to the conclusion that for the minimum test plate thickness according to ISO 15614-1 (*a* = 150 mm) none of the available ultrasonic heads ensures testing the complete range of thicknesses (Table 1). The 35°, 45° and 60° heads provide the proper head travel width *b* only for the thickness values of 84 mm, 60 mm and 34 mm respectively. This means that in the case of thick elements $t > 40$ mm, for which the standards [7] recommend carrying out UT and do not recommend conducting alternative RT, a test joint should have the dimension a greater than the minimum value of 150 mm recommended in PN-EN ISO 15614-1. Such a situation is assumed in the standard itself, containing the instruction that the dimensions of test joints should be sufficient for carrying out all required tests.

The case when the test joint was prepared on the basis of reference publication recommendations [2] contained in withdrawn standard PN-EN 288-3 is presented in Table 2. As can be seen, the width of test joints in this case enables testing the whole range of thicknesses using the 35° and 45° heads. The 60° head enables carrying out tests for thicknesses not exceeding 34 mm. However, as it was mentioned before, quite often for joints of thicknesses from the 15-25 mm range (i.e. for the frequency of a head amounting to 4MHz) and always for thicknesses exceeding 25 mm (irrespective of frequency) it is necessary to use two beam insertion angles [5]. Tables 1 and 2 reveal that for thicknesses above 34 mm and test joint dimensions as specified in PN-EN ISO 15614-1 and PN-EN 288-3 it is possible to use 60° and 45° heads. In turn, above this thickness, in order to ensure the search area width required by ISO 17640 it would be necessary to use the angle of 35° as the second angle of the head. However, such a head configuration (45° and 35°) for thicknesses above 34 mm entirely fails to meet another requirement of the standard stating that the beam insertion angle of at least one head used should make it possible for the ultrasonic beam to strike the fusion line at an angle close to 90°. Such an approach aims to increase the detectability of edge incomplete fusions oriented in relation to the ultrasonic beam as the groove wall. For the most commonly used bevelling angles restricted within a range between 22.5° and 30° [2] such an assumption is best fulfilled by the 60° head. If the assumption mentioned above is not fulfilled, in the echo method the beam emitted at an inconvenient angle may strike even a significant incomplete fusion and be reflected in another direction failing to return to the head and signal such a discontinuity on a defectoscope [8]. As a result, it is possible to omit even the whole series of edge incomplete fusions as each of them tends to be oriented in the same way. Such an error could dramatically affect the whole WPS-based production approved on the basis of improperly conducted tests having lower detectability. Although while qualifying a welding technology NDT is accompanied by destructive tests which can detect incomplete fusions, yet they are carried out on test pieces sampled from small weld fragments, whereas NDT, in this case UT, covers 100% of the joint length.

For this reason, in order to increase detectability it is necessary to ensure a test joint width which enables carrying out UT using a 60° head. Although such a solution entails greater test-related labour due to significantly greater search area than in the case of a 35° head, yet, in return, it ensures the detection of incomplete fusions and satisfaction of related standard requirements.

The foregoing justifies the conclusion that also the width of the test plate made assuming $a = 3t$, min. 150 mm (according to PN-EN 288-3) is not sufficient for the proper performance of test joint ultrasonic examination; the reason being the overly low dimension a for joint thicknesses exceeding 34 mm. In order to properly carry out examination following all the requirements of related standards as regards large thicknesses t of test joints their dimension should be adequate for carrying out tests using 60° and 45° heads within the whole thickness range.

In order to facilitate the determination of the proper dimension a in relation to the angle α of the head used and the joint thickness t, Figure 7 presents the nomogram developed on the basis of the analysis conducted. The nomogram shows the minimum test joint dimension a for ultrasonic examination. In addition to the minimum width of the head travel the nomogram takes into consideration the half-length of the head housing (13 mm) valid for commonly used miniature heads (e.g. AM2R-8X9-60, MWB60-2). If tests involve the use of heads with 20x22mm transducers (e.g. AM2R-20X22-60, WB60-2), it is necessary to add 14 mm to the value read out of the nomogram; this is due to the greater housing length of such heads.

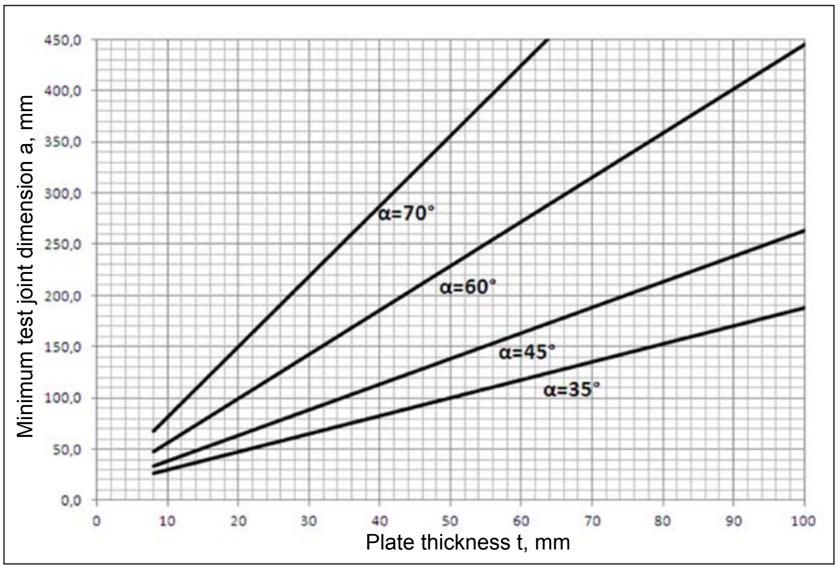

Fig. 7. Nomogram for determining the minimum dimension a of test joints in relation to the angle α of an ultrasonic head used for testing the thickness t of plates

Summary

In order to properly carry out the qualification of welding technologies for great thicknesses it is necessary to take into consideration the minimum dimensions of test joints necessary for conducting all required destructive and non-destructive tests. The minimum dimension a provided in PN-EN ISO 15614-1 for the thickness $t > 34$ mm is not sufficient for carrying out ultrasonic examination recommended in this thickness range. For this reason it is recommended that test joint widths a should be selected on the basis of the nomogram (Fig. 7) using the assumption that examination with the 60° head must be possible to carry out within the whole thickness range. Such an assumption will make it possible to satisfy all the requirements set for ultrasonic examination in PN-EN ISO 17640 as well as will ensure the proper detectability and assessment accuracy of potential indications.

Using greater widths of test joints for great thicknesses is necessary not only due to ultrasonic examination requirements. It is known that a test joint having a thickness of 100 mm and a minimum width of 150 mm has different key welding process conditions (heating, heat distribution, cooling rate, stresses etc.) than a structural element having the same thickness, but – usually – significantly greater width. Such a test joint fails to fulfil its primary task, i.e. the simulation of conditions possibly the closest to those present during making joints in a given structure. Adopting such an approach is necessary in order to initially eliminate the possibility of using a welding technology which will lead to the production of faulty joints failing to provide proper load capacity.

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