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Possibilities of Using Production Tests of the Arc Welding of Pins in the Qualifying of Operators

Abstract: The study discussed in the article involved the analysis of standard-related conditions concerning the qualification testing of stud welding operators. Special attention was paid to the licensing of personnel making welds of shear connectors using drawn arc and ceramic ferrules. The authors emphasized the risk of technical standards misinterpretation and its financial consequences. The study also focused on frequent approaches to examinations by examining bodies. The final part of the article indicates the existence of legally effective methods enabling the production test-based qualification of production personnel.

Keywords: arc stud welding, shear connectors, ceramic ferrule, drawn arc, qualifying of arc stud welding operators, tests of arc stud welding technologies, production tests of arc stud welding; composite structures

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Introduction

The drawn-arc welding of shear connectors performed using ceramic ferrules is one of many joining methods commonly applied when making building structures [1–7]. The unpredictability of results, potential current instability and significant dependence on the technical condition of individual elements of the workstation speak for recognising the above-named technique as a special process. Following the interpretation of the aforesaid notion presented in a series of standards concerning quality management systems [8] and documents related to welding engineering-related quality requirements [9], the outcome of the drawn arc welding process can also, to a significant extent, be affected by the human factor [10]. To minimise negative results of the aforementioned influence, personnel participating in the welding process should possess skills confirmed by an examining body approved in the EU. The EN ISO 14555 standard, concerning the above-named welding method, contains regulations necessitating the qualification examination of individual workers [11]. The foregoing becomes particularly important as regards the making of joints referred to in quality requirements [12–14].

Standards governing the qualifying of operators

The authors of the last of the aforesaid normative recommendations are certain that stud welding operators should be qualified in

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accordance with regulations specifying requirements for personnel dealing with mechanised and automated joining processes (see EN ISO 14732). The recent version of the aforesaid document contains information on as many as four acceptable qualifying methods [15]:

a) through the testing of a given fusion welding/pressure welding technology in accordance with a related fragment of ISO 15614;
b) on the basis of pre-production tests of fusion welding/pressure welding in accordance with ISO 15613;
c) on the basis of tests of a test joint in accordance with a related sheet of ISO 9606;
d) on the basis of production tests or random tests.

The analysis of the scope of the above-named standards as well as the analysis of the nature of arc stud welding revealed that the situation under discussion only requires the application of the last variant. Such reasoning is confirmed by the content of the fifth sub-paragraph of EN ISO 14732, where, when applying a qualification method c) or d), it should be performed in accordance with a standard concerning the use of a product and the application of a process. Detailed guidance can be found in EN ISO 14555, i.e. the document provided with priority. An additional restriction is the necessity of supplementing the procedure with an examination in expertise on the operation of production equipment used in a given welding station [15].

Because of the high degree of process automation, the performance of arc stud welding does not require particularly good manual skills, as is the case with, e.g. manual welding. However, operators should possess knowledge sufficient for the proper operation of equipment (e.g. settings of technological parameters in accordance with a written specification). In addition, regulations necessitate the adequate configuration of a workstation (e.g. the proper contact of a stud in a clamp and the proper positioning of a welding gun, the elimination of unnecessary backlash in moving systems etc.). It is also necessary that production personnel should be fluent in detecting welding imperfections and deviations from a previously assumed quality level on the basis of a visual inspection and bend tests [6, 11]. Another important aspect is the operator's own initiative in undertaking corrective and preventive actions and, in more complicated situations, in reporting a need for intervention by a welding supervision personnel.

The internal coordinator's scope of duties involves the continuous welding process quality surveillance and management. On the coordinator's authority, operators who have not participated in the process of welding procedure qualification, i.e. operators not listed in related WPQRs (Welding Procedure Qualification Records), can be allowed to make welded joints of steel bolts. The aforesaid approval requires that a given operator has to have previously passed a related examination [6, 11]. Coordinator's identification data are contained in a manufacturer's welding certificate executed in accordance with EN 1090-1 [16].

Standard-imposed requirement of production tests

Arc stud welding results depend not only on personal skills and experience of individual operators and their observance of welding procedure specifications but also on the technical condition of welding equipment (welding gun, current and control conduits, earth clamps etc.) [6]. Because of this, at least once a year it is necessary to perform a production test in accordance with sub-paragraph 14.2 of EN ISO 14555 [11]. In the above-named case, classical testing procedures related to mechanical and technological properties of welded joints only apply to a limited extent. The foregoing results from unique features of stud welds, where the line of the action of the highest load force runs along from the stud axis directly to the substrate. The primary mechanical properties such as, for instance, tensile strength or toughness, must be controlled effectively, particularly in crucial joints. For instance, the drawn-arc welding of shear connectors having a diameter in excess of 12 mm, performed using ceramic ferrules, requires the making of a minimum of ten welds. Welds, located one by one on a single steel sheet having a thickness of at least 0.25 of the weld diameter, must be subjected to visual tests. The acceptance criterion is the presence of the full weld collar characterised by a regular height around the entire perimeter, blue-grey colour and metallic gloss (Fig. 1). A joint satisfying the above-presented conditions has been made using proper energy without unnecessary stud immersion resistance. It is also required that the shank of the connector be entirely welded to the substrate surface without the presence of undercuts. Following the process, the length of the connector shank should be restricted within an appropriate tolerance range [6, 11, 17].

Fig. 1. Proper joints of arc welded studs (SD 22×175)

Five of the welded connectors should be subjected to bend tests where the bend angle amounts to 60° (Fig. 2) so that controlled weld zones could be subjected to tensile stresses. The substrate material located in the direct vicinity of the joint is characterised by the presence of the two-dimensional residual stresses, the value of which is similar to that of a yield point. The aforesaid situation results from the thermal contraction accompanying the crystallisation of the weld. The bending load not only triggers the deformation of the stud but is also responsible for the generation of significant tensile stress directed vertically towards the sheet surface. During the bend test, the weld area is exposed to three-dimensional stresses affecting the manner of joint deformation. In addition, the area between the stud and its flash constitutes a mechanical notch. The bend tests of arc welds aim to simulate conditions of impact strength tests of structural materials and welded joints. Because the weld collar constitutes the support for the loaded side of the stud and absorbs some of the existing stresses, the results of such tests are not as reliable as the assessment of the impact energy test results. Nonetheless, weld toughness-related conclusions can be drawn from a bend angle value obtained in the test. Rupture taking place at a bend angle below 20° indicates significant brittleness and high likelihood that a joint subjected to the test is defective. If the bend angle amounts to at least 60° and the weld zone subjected to tension is free from cracks, the joint is characterised by sufficient ductility.

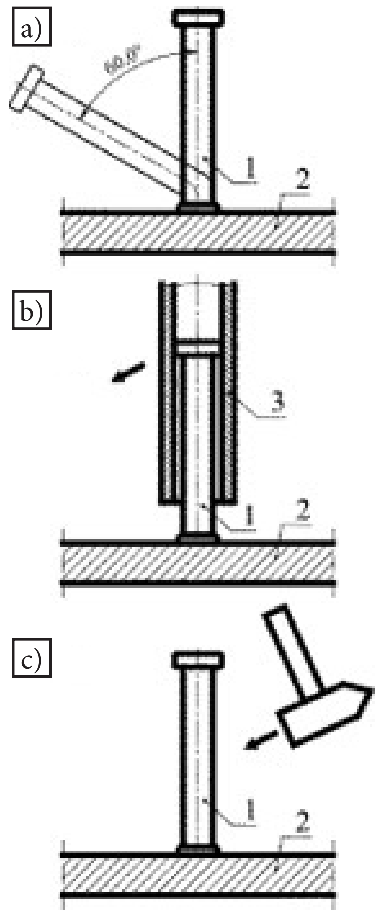

Fig. 2. Schematic diagram of a bend test of shear connectors: a) performed using a dynamic load (hammering); b) performed using a tubular device; c) final result; where: 1 – shear connector subjected to bending; 2 – base (steel sheet); 3 – tubular device; individual study based on publications [6, 11]

A production test result can be regarded as satisfactory if none of the five joints contains cracks after the obtainment of a previously assumed angle strain [6, 11].

The final stage involves macroscopic tests of two joints. It is necessary to make two macroscopic metallographic specimens, where one specimen is shifted by an angle of 90° in relation to the other (Fig. 3). Metallographic specimens are subjected to grinding (performed using abrasive paper having a granularity of 320) followed by etching in Nital for approximately 60 seconds. A result can only be regarded as positive if the entire length of a given welding imperfection does not exceed 20% of the visible width of the welded zone (tantamount to the stud diameter). It is possible to accept a weld containing an undercut, yet only if the undercut is present on one side, its size amounts to a maximum of 5% of the welded zone width and the bend test involving the stud produced a positive result. At the same time, all imperfections being below 0.5 mm in size are ignored provided the distance between neighbouring indications amounts to a minimum of 0.5 mm [6, 11].

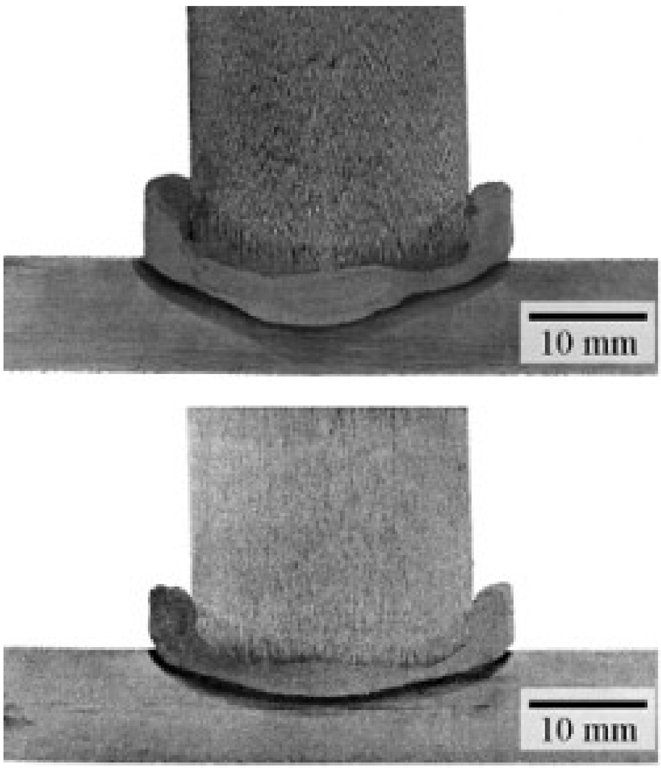

Fig. 3. Exemplary macroscopic photographs of arc welds of studs (SD 25×200) free from imperfections failing to meet acceptance criteria

In the aforesaid manner, the standard imposes regular checks verifying the applicability of a given welding process under specific production conditions [11]. As a result, once every twelve months it is possible to perform the qualification of new operators on the basis of test results. Positive results of the above-named tests confirm the satisfactory technical condition of equipment and personnel's skills. Acceptable results cannot be achieved without ensuring the proper course of the welding process. Welding operators are licensed appropriately, i.e. in relation to material grades and joining techniques.

Controversial practice of examination bodies

According to the authors' experience, most of the examination bodies operating in the Polish market share an opinion stating that it is possible to qualify stud welding operators solely on the basis of welding technology tests in accordance with item 10.2 of publication [11]. In terms of producers of crucial building structures, who usually have to comply with complete welding engineering-related quality requirements [12], the performance of the above-named procedure requires the making of twelve welds. Studs having diameters of between ten and twenty millimetres as well as studs having diameters of tens of millimetres are located in the direct vicinity (lack of precise identification) on a single steel sheet/plate, the thickness of which amounts to a minimum of 0.25 of the stud diameter. Each subsequent listing of four technological factors, i.e.: operator, stud, welding gun and a welding power source requires separate qualification. All joints must be assessed visually, where five studs are subjected to bend tests (60° bend angle) and two other welds are sampled for macroscopic metallographic specimens, positioned perpendicularly in relation to each other (Table 1). The acceptance criteria related to results obtained in the above-named tests are the same as those concerning welds in terms of production tests. The five remaining studs are subjected to tensile tests performed using specialist equipment.

Table 1. Types of tests and numbers of test specimens required in tests of drawn arc stud welding and welding involving the use of ceramic ferrule; individual study based on publications [6, 11]

Type of test	Number of test studs/welds, pieces			
	Low-temperature applications (T ≤ 100°C).			High-temperature applications (T > 100°C).
	Full quality requirements (see EN ISO 3834-2).		Standard quality requirements (see EN ISO 3834-3).	All quality requirements – full, standard and basic (see EN ISO 3834-2,-3,-4).
	d ≤ 12 mm	d > 12 mm	all diameters	
visual test	all			
bend test	10 angle: 60°	5 angle: 60°	10 angle: 60°	5 angle: 30°
tensile tests	–	5	–	–
radiographic tests	–	5[(a)]	–	–
macroscopic metallographic specimen	–	2	–	2[(b)]

(a) optionally instead of tension;

(b) only in relation to welds in pressure equipment and systems;

Tensile tests (Fig. 4) include axial component and other stresses both in the base material and in the stud material. In the base material there are bending forces resulting from the distance between the point of support and the weld area as well as forces acting perpendicularly to the surface potentially capable of initiating delamination. In the material there are bending loads responsible for transverse strains. Because of the fact that the stud is gripped by the clamps of a testing machine, a test joint may be exposed to torque of unspecified intensity. In addition, because of the presence of unidentified fraction, the value of actual tensile stress can only be identified through estimation.

The tensile test is performed to simulate (with the highest possible accuracy) the mechanical resistance of the arc weld of a stud to axial stresses. It is required that, in a joint subjected to a breaking load, both the weld and the heat affected zone should remain intact. Only the rupture in a stud with a previously reduced area is acceptable. However, if a fracture is formed in the weld area, the area of the fracture should be subjected to visual inspection for the presence of welding imperfections (primarily triggered by the excessive amount of gas pores inside the joint). For instance, in relation to studs having a diameter of 22 mm there is an empirically proven principle, according to which as long as the proportion of the total area of all observed gas pores to the entire cross-sectional area of the fracture does not exceed 15%, the rupture is likely to take place outside the weld accompanied by the highest possible tensile strength (in such conditions). Higher values of the aforesaid ratio indicate the possibility of cracks appearing directly in the joint characterised by a significant decrease in Rm. A limit indicating a significant decrease in mechanical strength is a 25% ratio [18].

It is possible that a stud subjected to tension will be torn out along with a fragment of the base material without compromising the integrity of the weld. The above-presented situation takes place during tests of joints connecting studs with metal elements characterised by small cross-sectional areas (stud diameter-plate thickness ratio exceeds 2). The aforesaid situation is acceptable if it is preceded by the appropriate deformation of the stud and the obtainment of required Re [6, 11].

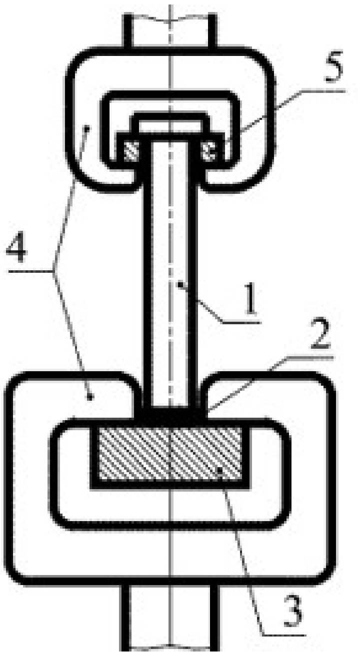

Fig. 4. Exemplary design of the test rig for tensile stresses of shear connectors,
where: 1 – shear connector subjected to bending; 2 – weld collar; 3 – base (steel sheet); 4 – testing machine clamps; 5 – strip/clamping ring 40 ≤ HRC ≤ 55 [6, 11]

Tensile tests results concerning five welds tested within the test of a given technology are regarded as positive if fractures did not take place in the welding area and the base material was sufficiently thick to prevent the formation of shear fracture. Alternatively, where the rupture took place in the weld, the acceptance of such a joint is only allowed if the total area of all welding imperfections observed on the surface of the fracture does not exceed 5% of the entire cross-sectional area after the failure of the specimen [11].

The aforesaid examiners' position is responsible for the fact that producers incur additional and relatively high costs which, based on the above-presented analysis, seem to be legally groundless. When comparing the aforementioned expenses with costs related to the qualification examination of personnel performing manual welding-related operations (in accordance with EN ISO 9606-1 [19]), it is possible to observe a two, if not three-fold, increase in prices. In addition, expenses multiply along with each set subjected to examination: stud diameter, welding gun and a welding power source. Technical aspects do not constitute a convincing argument either as, pursuant to the standard concerned with the application of the product [11], the manufacturer of the steel structure is already obliged to perform annual production tests of each such combination. The duplication of the test of a previously tested technology successfully applied on a continuous basis for the sole examination of operators seems unjustified. Such a situation is particularly difficult for small and medium manufacturers of steel structures as such enterprises, having relatively low financial resources, may ignore certain standard-related requirements.

Summary

The contents of the stud arc welding-related standard almost clearly indicates the necessity of qualifying arc stud welding operators solely on the basis of production tests. The misinterpretation of technical regulations results in the unnecessary duplication/multiplication of expensive technological procedures. The contents of the document concerning the practical application of the above-named welding process explicitly indicates that the multiple qualification of the same technology based on the test of the welding technology for the purpose of examining production personnel is not required.

Before the performance of method 783-based joining it is first worth overviewing all qualified technologies of the manufacturer as well as licences of all workers who could perform the arc welding of studs. The aforesaid analysis will indicate needs (if any) for the extension of manufacturer's scope of qualifications and enable rational decision-making related to the examination of other operators or the re-examination of workers with expiring licences.

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