CZASOPISMO INŻYNIERII LĄDOWEJ, ŚRODOWISKA I ARCHITEKTURY
JOURNAL OF CIVIL ENGINEERING, ENVIRONMENT AND ARCHITECTURE
JCEEA, t. XXXV, z. 65 (2/18), kwiecień-czerwiec 2018, s. 35-42, DOI:10.7862/rb.2018.22

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TECHNOLOGICAL ASPECTS OF EXECUTION OF WELDED JOINTS IN HOLLOW SECTIONS

Steel structures designed according to Eurocode 3 are executed in accordance with the provisions of the standard PN-EN 1090-2, which is referred to in Eurocode 3. In addition, the standard PN-EN 1090-2 refers to in its content a number of welding standards, e.g. PN-EN ISO 9692-1. These standards provide guidelines for welded connections, which should be applied in the case of joints connecting steel hollow sections. Analysis of above-mentioned provisions revealed that for fillet welds they are simultaneously fulfilled only if the inclination angles of the elements are in the range of 70°–100°. According to recommendations of PN-EN 1993-1-8 and EN 1090-2, the same weld type around the perimeter of the element connected to the chord of lattice structure is possible to execute only for inclination angle lower than 60°. Discrepancies between these standards also exist with regard to the interpretation of the dimension of the flare groove welds in connections of rectangular hollow sections with the same width. In addition, analyses of the recommendations for welding in cold-formed zones indicate that, for steel grades currently used for the production of cold-formed rectangular hollow sections, welding in these zones is not permitted only for profiles with wall thickness equal to 12.5 and 16 mm. The above-mentioned issues point out the need for mutual unification of standards for the design and execution of steel joints in hollow sections.

Keywords: steel structures, lattice structures, welded joints, hollow sections

1. Introduction

Exactly 30 years ago, in Europe came into force the Construction Product Directive (CPD) 89/106/EEC [2]. The purpose of the CPD was to harmonise the production process of construction products and to ensure the free movement of construction products and unlimited use of these products in the European Union. Additionally, on 1st of July 2013 came into force the Regulation (EU)

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No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC [13]. The regulation applies to all construction products covered by harmonised European standards or European Technical Assessments. It includes both products, which are manufactured in series and placed on the market for sale to the general public, as well as products produced on individual order to be built in the specified structure. In accordance with article 5 of the Regulation [13] the manufacturer may refrain from drawing up a declaration of performance when placing a product covered by a harmonised standard on the market, where the construction product is individually manufactured or custom-made in a non-series process in response to a specific order, and installed in a single identified construction work – as usually in the case of steel building structures. In this situation, the manufacturer shall provide for executed structure a statement of conformity with project documentation and PN-EN 1090-2 [7] for steel structures or PN-EN 1090-3 [8] for aluminium structures. Building metal structures designed according to the Eurocodes have to be manufactured by the producers having a certified system of factory production control according to PN-EN 1090-1 [6]. These issues were further described in [3]. The authors of this publication had the opportunity to participate in the process of steel workshop adaptation to the requirements of the current regulations, and as a result had a chance to confront assumptions and provisions included in European design standards for welded connections in steel hollow sections with the provisions of the standards relating to steel structure execution, including welding technology. In this paper technological and metallurgical aspects of welded joints execution in steel hollow sections are discussed.

2. Welding in cold-formed zones

In the case of cold-formed sections, the standard PN-EN 1993-1-8 [11] allows for welding in the cold-formed zone provided that the cold-formed zones are normalized after cold-forming but before welding or the ratio of corner inner radius r_i to profile wall thickness t fulfils appropriate condition. The standard defines above-mentioned parameters for general case, distinguishing between predominantly static loading and situations where fatigue predominates, it also specifies the case of fully killed steel (see Table 1). As can be seen from Table 1, in the case of fully killed steels welding in cold-formed zones is permitted in the wider range than in the general case. Seemed cold-formed steel hollow made of non-alloy and fine grain steels are manufactured in accordance with PN-EN 10219 [4, 5]. This standard was officially referred to in the design standard of joints in steel structures [11]. The first part of PN-EN 10219 [4] specifies the technical delivery conditions. According to its provisions sections are made of following non-alloy quality steels: S275J0H, S275J2H, S355J0H, S235JRH, S355J2H, S355K2H and fine grain steel grades: S275NH, S275NLH,

Table 1. Conditions for welding cold-formed zones and adjacent material [11] and corner geometry for steel cold-formed sections manufactured according to [5]

Conditions for welding cold-formed zones and adjacent material [11]				**Cross-section parameters according to PN-EN 10219-2 [5]**			
ri/t	Generally		Fully killed steel				
	Predominantly static loading	Where fatigue predominates					
	max t [mm]	max t [mm]	max t [mm]				
≥ 25	any	any	any				
≥ 10	any	16	any	t [mm]	assumed		tolerance
≥ 3,0	24	12	24		ri/t	re/t	re/t
≥ 2,0	12	10	12	> 10	2.0	3.0	2.4–3.6
≥ 1,5	8	8	10	6< t ≤ 10	1.5	2.5	2–3
≥ 1,0	4	4	6	≤ 6	1.0	2.0	1.6–2.4

S355NH, S355LNH, S460NH, S460NLH. Both in the case of non-alloy and fine grain steels fully killed steels are used. For non-alloyed steels deoxidation method is designated as FF, it means that steel contains nitrogen binding elements in amount sufficient to bind available nitrogen (e.g. min. 0.020% total Al, or 0.015% soluble Al). For fine grain steels deoxidation method is designated as GF – steel contains nitrogen binding elements in amount sufficient to bind available nitrogen and have fine grain structure.

The second part of PN-EN 10219 [5] specifies tolerances, dimensions and sectional properties. The depth, width, and wall thickness of the profiles are specified in Tables C.2 and C.3 of PN-EN 10219-2 [5], but the values of the corner inner and outer radii can be found only as assumed values in the calculation of geometrical characteristics. It can be noticed that for cold-formed sections with wall thickness not exceeding 12 mm made of fully killed steel, welding in cold-formed zone is permitted. In the case of square and rectangular hollow sections with wall thickness t equal to 12.5 mm and 16 mm listed in Tables C.2 and C.3 of PN-EN 10219-2 [5], welds should located at a distance of $5t$ from the cold-formed zone. In engineering practice, the designers often use a very popular in Poland publication [1] where for both square and rectangular hollow sections – manufactured according to [4, 5] – instead of the values of corner inner radius, as marked on the figure, corner external radius is given – Fig. 1. The error described above may affect invalid geometry shaping in the joints between hollow section members committed at the design stage.

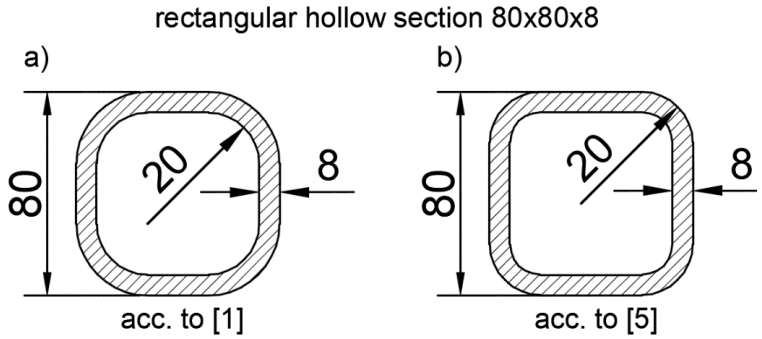


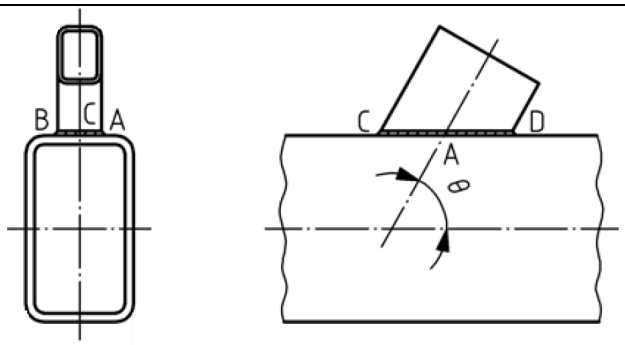
Fig. 1. Comparison of square hollow section geometry according to a) publication [1] and b) standard PN-EN 10219-2 [5]

3. Welded joints in hollow sections

Welded joints in steel hollow sections are contemporary designed in accordance with [11]. This standard restricts possibility to use fillet welds to the case of connected parts where the fusion faces form an angle of between 60° and 120°. In the case of inclination angles lower than 60°, the welds should be treated as partial penetration butt welds. For angles greater than 120°, fillet welds resistance should be determined by testing according to provisions of Annex D of PN-EN 1990 [9]. With regard to the fillet welds all round, the standard [11] additionally states that they may only be used to transmit shear. In respect of butt welds the standard [11] does not introduce restrictions about the connected parts inclination angle. It should be noted that, in accordance with the provisions of [10], Eurocode 3 is intended to be used together with [7] concerning the execution of steel structures. This standard introduces geometrical limitations, in the form of the inclination angle between axes of connected members, concerning the possibility of using fillet and butt welds. Conditions for the use of butt and fillet welds in joints connecting rectangular or circular hollow sections according to [7], depending on the location of the weld, are presented in Table 2 and 3.

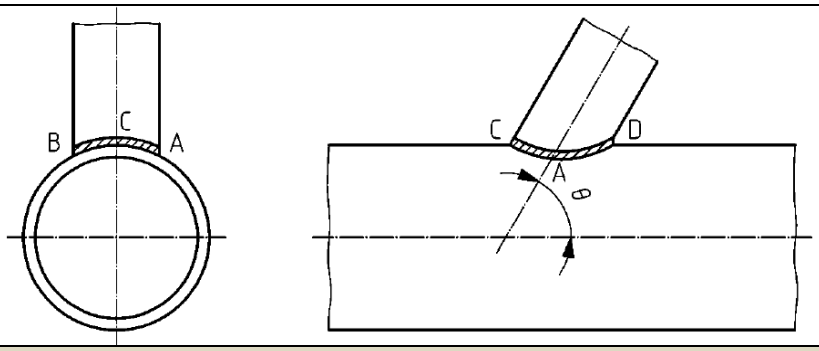
In addition, standard [7] refers to [12] that specifies how to prepare steel joints for welding. In the case of fillet welds, this last standard limits the inclination angle between walls of connected elements to the range from 70° to 100°. Figure 2 shows the conditions of applicability of fillet and butt welds in steel hollow sections joints, depending on the shape of the profile cross section and the location of the weld. Well known limitation of the minimum slope of the brace to the value of 30° is also taken into account on presented drawings. If one wants to meet all restrictions, given in above-mentioned standards, the possibility of using fillet welds on whole perimeter of the section is limited to the members with the inclination angle not less than 80°. In the case of fillet welds all round, the minimum value of the inclination angle for which the standard provision about the joint geometry are met is 60°.

Table 2. Geometrical limitations according to [7] on using butt and fillet welds in welded joints between rectangular hollow sections



Option I					
	Weld location				
	A, B	C		D	
Weld type	butt	butt		θ<60º	60º ≤θ<90º
				fillet	fillet
Option II					
	Weld location				
	A, B	C		D	
Weld type	fillet	θ<60º	60º ≤θ<90º	fillet	
		butt	fillet		

Table 3. Geometrical limitations according to [7] on using butt and fillet welds in welded joints between circular hollow sections



Option I					
	Weld location				
	A, B	C		D	
Weld type	butt	60º ≤θ<90º		θ<60º	60º ≤θ<90º
		butt		fillet	butt
Option II					
	Weld location				
	A, B	C		D	
Weld type	fillet	θ<60º	60º ≤θ<90º	fillet	
		butt	fillet		

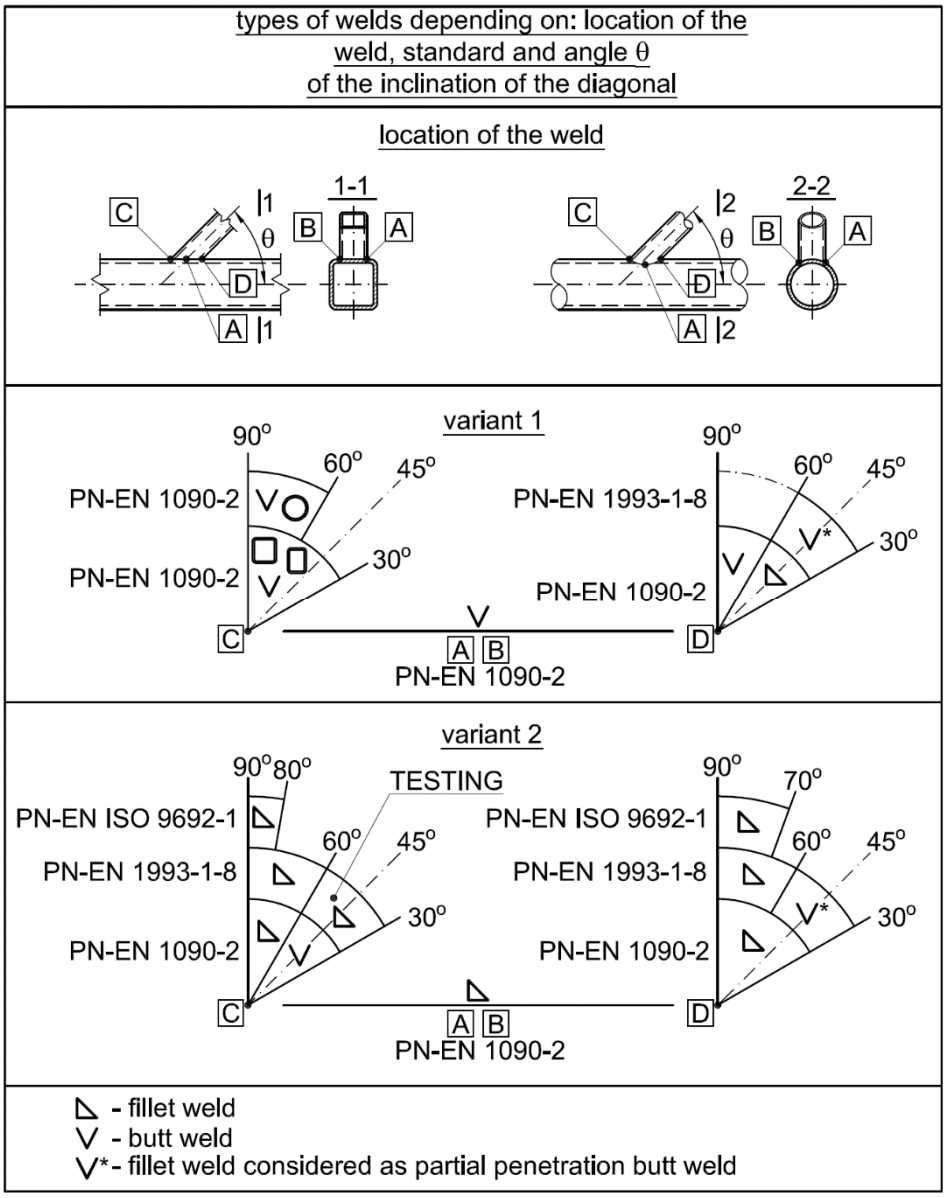


Fig. 2. The conditions of applicability of fillet and butt welds in steel hollow sections joints

4. Welds in cold-formed zone of hollow sections

In the joints between rectangular hollow sections flare groove welds are used. The standard [11] specifies the thickness of this weld type as shown on Fig. 3a. Whereas according to [7], the thickness of the weld shall be determined

on the basis of the interfacial angle inscribed in the groove weld, and its value should not be smaller than 60°. In addition, the standard [11] refers to the design thickness, while the standard [7] to effective thickness.

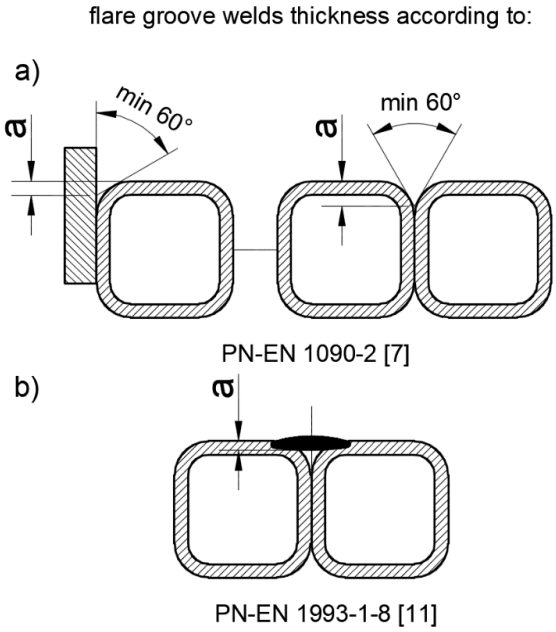


Fig. 3. Interpretation of flare groove welds thickness according to: a) standard PN-EN 1090-2 [7] and b) standard PN-EN 1993-1-8 [11]

5. Conclusions

Welded joints in steel hollow sections designed according to PN-EN 1993-1-8 [11] should be executed in accordance with PN-EN 1090-2. [7]. This last standard refers to PN-EN ISO 9692-1 [12] which includes recommendations for the preparation of welded joints. The first two of the above mentioned standards, apart from general provisions for welded joints, also provide detailed requirements for joints in hollow sections. It may seem that the provisions of mentioned standards should be consistent with each other. However, it appears that in many areas are mutually contradictory, and it is not possible to simultaneously meet the provisions of all above-mentioned standards. This may mean that welded joint designed in accordance with the provisions of PN-EN 1993-1-8 [11] is not possible to execute.

Analysis of aforementioned provisions revealed that for fillet welds they are simultaneously fulfilled only if the inclination angles of the elements are in the range of 70°–100°. According to recommendations of PN-EN 1993-1-8 and EN 1090-2, the same weld type around the perimeter of the element connected

to the chord of lattice structure is possible to execute only for inclination angle not lower than 60°. Discrepancies between these standards also exist with regard to the interpretation of the dimension of the flare groove welds in connections of rectangular hollow sections with the same width. In addition, analyses of the recommendations for welding in cold-formed zones of indicate that, for steel grades currently used for the production of cold-formed rectangular hollow sections, welding in these zones is not permitted only for profiles with wall thickness equal to 12.5 and 16 mm. The above-mentioned issues point out the need for mutual unification of Standards for the design and execution of steel joints in hollow sections.

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[11] PN-EN 1993-1-8 Eurocode 3. Design of steel structures. Design of joints.

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Przesłano do redakcji: 01.05.2018 r.
Przyjęto do druku: 15.06.2018 r.