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Calculation of welding trusses overlap joints made of channels and RHS sections

Obliczanie połączeń spawanych kratownic wykonanych z ceowników i kształtowników zamkniętych RHS

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Abstract. The aim of the article is to propose a new method for assessing the flexible joints of welded trusses with chords made of C-sections and braces made of rectangular hollow sections. In this method, the capacity of the welds is determined depending on the value of the axial force, taking into account the effective lengths of the fillet welds. As shown in the article, in such connections, the use of thin fillet welds with a thickness matched to the member's load is twice cheaper than the use of solid butt welds. Additionally, the life cycle analysis performed showed that the use of thinner fillet welds could reduce the overall environmental impact of the welded joint by 73% in terms of greenhouse gas emissions and 70% in terms of non-renewable primary energy consumption.

Keywords: steel structures; hollow sections; welded joints; effective lengths; calculation methods; economic analysis; environmental analysis.

Streszczenie. Celem artykułu jest zaproponowanie metody oceny podatnych połączeń spawanych kratownic o pasach wykonanych z ceowników i krzyżulców z rur prostokątnych. W metodzie tej nośność spoin określa się w zależności od wielkości siły osiowej, uwzględniając długości współpracujące spoin pachwinowych. Jak wykazano w artykule, zastosowanie w takich połączeniach cienkich spoin pachwinowych, o grubości dobranej do wytężenia pręta, jest dwukrotnie tańsze niż pełnościennych spoin czołowych. Ponadto przeprowadzona analiza cyklu życia wykazała, że zastosowanie cienkich spoin pachwinowych może zmniejszyć wpływ złącza spawanego na środowisko – o 73% pod względem emisji gazów cieplarnianych i o 70% pod względem zużycia nieodnawialnej energii pierwotnej.

Słowa kluczowe: konstrukcje stalowe; kształtowniki zamknięte; połączenia spawane; metoda obliczeniowa; analiza kosztów; LCA.

Industrial buildings with medium to light loads typically use roof trusses with braces made of rectangular hollow sections and chords made of channel sections located axially in the plane of the truss (Figure 1). Such design scenarios are typically found in halls, pavilions, auxiliary structures, industrial enterprises, and buildings meant to provide social and commercial services [1].

The European standard EN 1993-1-8 [2] contains very general recommendations regarding the calculation of the load capacity of welded joints in such trusses. The standard recommends designing full butt welds or fillet welds of such thickness that their load-bearing capacity per unit length of the perimeter is not lower than the design capacity of the cross-section of the joining member, regardless of the degree of its effort. This causes a significant overestimation of the cross-sections of the chosen welds in the case of unified joints, where the braces are united for technological reasons, and their cross-sections are determined based on the maximum axial forces. This significantly raises the structure's cost. The standard [2] does not offer specific guidelines on how to design such welded joints, but it does allow for waiving the requirement of accepting full-wall welds in situations where a smaller weld size is justified due to the required load-bearing capacity.

Roof trusses with chords made of channels [1]
Dźwigary stalowe o pasach wykonanych z ceowników [1]

The cost of construction is significantly increased by designing thick welds with a load capacity equal to the load capacity of the member. It also promotes the development of high stresses and welding deformations, results in thin walls of tubular sections burning through, necessitates pre-heating before welding, and slow cooling of the joined parts after welding to prevent welding cracks. When using butt welds, the edges of the joined elements must be prepared in order to

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achieve the necessary penetration and to make welding easier, both of which are necessary in order to get a weld that is correct in terms of shape and quality. Slag buildup, porosity, and cracking are flaws that weaken thick butt and fillet welds.The aim of the article is to propose a method for calculating thewelded connections in the joints of trusses made of hollow sections with chords made of rolled C-sections. This is the effective length of weld technique designed for these kinds of joints. Our earlier research focused on lattice systems composed of hollow sections with T, N, and K type joints that overlap or have gaps, bracing composed of CHS and RHS sections, and chords composed of hollow sections and I-sections [3, 4].

Calculation of the resistance of fillet welds taking into account the effective length

The joints in lattice systems made of hollow sections are flexible. The forces from the braces are transferred to the chord members through the thin wall of the chord, which deforms under load. As the tests have shown, only the outer areas of the walls located at the corners of the element are effective when transferring forces, while the central part does not cooperate in transferring the load. The welds located on the circumference of the joined members are similarly strained. Depending on the angle of inclination of the bracing bar to the chord, the entire weld or only part of it is effective in transferring the force.

Fillet welds in K-joints made of RHS sections in Warren trusses are loaded in proportion to the effort of the member walls, according to studies done at the University of Toronto [5, 6]. This means that not the entire length of the welds used is used to transfer the load. It was discovered that longitudinal and transverse welds on all four sides of the RHS bar are fully effective when the angle between the chord and the bracing is 50° or less, but the acute transverse weld is completely ineffective when the brace is inclined to the chord at an angle of 60° or more. It is advised to use linear interpolation for diagonal angles between 50° and 60°.

The latest third edition of the IIW recommendations [7] requires that the design resistance of hollow section joints be determined only by assessing the failure of elements in the joints, not welds. To achieve this, one of the following recommendations must be followed: (i) welds should be suitable for "fit-to-purpose" member strength, taking into account the deformation/rotation capacity of the joint and taking into account the effective length of the weld, or (ii) the load capacity of the welds should correspond to the load capacity of the walls of the joined element. The IIW document [7] unequivocally supports the use of "effective weld lengths" in the design of welded joints between hollow sections.

A truss with Warren-type bracing is depicted in Figure 1 in diagram form. The chords are made of rolled channel sections, and the bracings are made of RHS sections. To compare the costs of creating welded joints, weld cross-sections were computed for joints 1, 2, 3, 4, 5, 6, 7 and 8. The assumed thickness of fillet welds was 3 mm. The diagram of the analyzed joint 1 is shown in Figure 2. The weld layers are shown (Figure 3) to make it easier to record the effective section lengths of welds and the cross-sectional areas of these sections as required by the IIW guidelines [7]. The method of determining the effective length of welds is as follows.

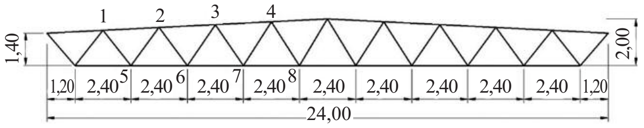

Fig. 1. View of the analysed truss geometry
Rys. 1. Widok geometrii analizowanej kratownicy

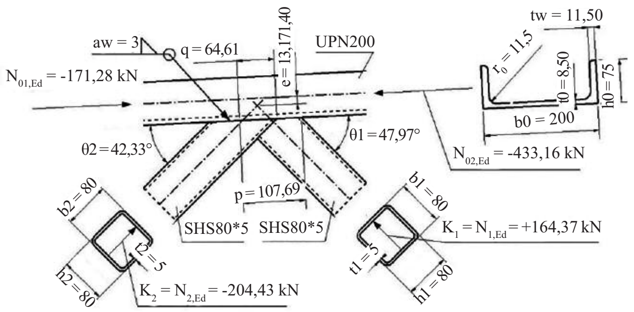

Fig. 2. Scheme of joint number 1
Rys. 2. Schemat węzła nr 1

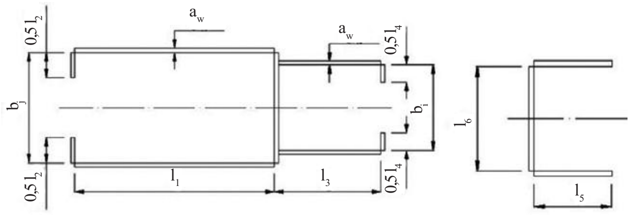

Fig. 3. Weld shape in the analysed joint
Rys. 3. Układ spoin w analizowanym węźle

$$l_1 = \frac{h_2}{\sin\theta_2} = 118.8 \text{ mm} \tag{1}$$

$$l_2 = b_{2,eff} = 75.06 \text{ mm} \tag{2}$$

$$l_3 = \frac{(1-\alpha)h_1}{\sin\theta_1} = 43.07 \text{ mm} \tag{3}$$

$$l_4 = b_{1,eff} = 75.06 \text{ mm} \tag{4}$$

$$l_5 = \frac{q}{(1 + \tan\theta_2/\tan\theta_1)\cos\theta_2} = 48 \text{ mm} \tag{5}$$

$$l_6 = b_{e,ov} = 50 \text{ mm} \tag{6}$$

$$\sum l = 2 \cdot l_1 + l_2 + 2l_3 + l_4 = 473.88 \text{ mm} \tag{7}$$

where: α – overlap;

$$\alpha = q/p = 0{,}6 \tag{8}$$

q – length of overlap, measured at the face of the chord, between one brace member toe and the position of the other projected brace member toe, in a K or N joint,

$$q = \left(e_0 + \frac{h_0}{2}\right)\frac{\sin(\theta_1 + \theta_2)}{\sin\theta_1 \sin\theta_2} - \frac{h_1}{2\sin\theta_1} - \frac{h_2}{2\sin\theta_2} = -64.61 \text{ mm} \tag{9}$$

where:

h_0 = 75 mm – chord height; $q < 0$ – negative value corresponds to the case of overlapping braces, a positive value was adopted for further calculations; e_0 = -13,17 mm – eccentricity value; p – length of the projected contact area of the overlapping brace member onto the face of the chord, in the absence of the overlapped brace member, in a K or N joint;

$$p = \frac{h_1}{\sin\theta_1} = 107.69 \text{ mm} \tag{10}$$

h_1 = 80 mm – height of the overlapping brace;
h_2 = 80 mm – height of the overlapped brace;
b_1 = 80 mm – width of the overlapping brace;

b_2 = 80 mm – width of the overlapped brace;
θ_1 = 47.98° – angle between overlapping brace and the chord;
θ_2 = 42.33° – angle between overlapped brace and the chord;
$b_{1,eff}$ – effective width of the brace 1 in connection with the chord;

$$b_{1,eff} = \frac{10}{b_0^*/t_0} \frac{f_{y0}t_0}{f_{y1}t_1} b_1 = 75.06\ \mathrm{mm} < b_1 = 80\ \mathrm{mm} \tag{11}$$

b_0^* – effective width of the chord,

$$b_0^* = b_0 - 2(t_w - r_0) = 154\ \mathrm{mm} \tag{12}$$

b_0 = 200 mm – chord width;
t_w = 11.5 mm – thickness of flange of the chord;
r_0 = 11.5 mm – corner fillet radius of the chord;
t_0 = 8.5 mm – chord web thickness;
f_{y0} = 355 N/mm² – yield strength of the chord;
f_{y1} = 355 N/mm² – yield strength of the overlapping brace;
t_1 = 5 mm – wall thickness of the overlapping brace;
b_1 = 80 mm – width of the overlapping brace;
$b_{2,eff}$ – effective width of the brace 2 in connection with the chord:

$$b_{2,eff} = \frac{10}{b_0^*/t_0} \frac{f_{y0}t_0}{f_{y2}t_2} b_2 = 75{,}06\ \mathrm{mm} < b_2 = 80\ \mathrm{mm} \tag{13}$$

f_{y2} = 355 N/mm² – yield strength of the overlapped brace;
t_2 = 5 mm – wall thickness of the overlapped brace;
$b_{e,ov}$ – effective width of the overlapping brace in combination with the overlapped brace:

$$b_{e,ov} = \frac{10}{b_2/t_2} \frac{f_{y2}t_2}{f_{y1}t_1} b_1 = 50\ \mathrm{mm} < b_1 = 80\ \mathrm{mm} \tag{14}$$

Determination of bracings overlap:

$$\lambda_{ov} = \left(\frac{q}{p}\right) \cdot 100\% = 60\% \tag{15}$$

Determination of the joint load capacity $N_{i,Rd}$ according to Table 7.24 [2].
At the overlap value $25\% < \lambda_{ov} = 60\% < 100\%$ the brace member fails:

$$N_{1,Rd} = \frac{f_{y1}t_1(b_{1,eff} + b_{e,ov} + 2h_1 - 4t_1)}{\lambda_{M5}} = 470.49\ \mathrm{kN} > N_{1,Ed} = 204.43\ \mathrm{kN} \tag{16}$$

γ_{M5} = 1,0 – partial coefficient for the load-bearing capacity of truss joints made of hollow sections according to Table 2.1 of the standard [2].

Determination of parallel and perpendicular component forces in individual welds:

$$\Delta K_1 = \alpha K_1 \sin\theta_1 = 73.27\ \mathrm{kN} \tag{17}$$

$$\mathrm{red}\Delta K_2 = K_2 \sin\theta_2 - \alpha K_1 \sin\theta_1 = 64.4\ \mathrm{kN} \tag{18}$$

$$P'_1 = \frac{(K_2\cos\theta_2 + K_1\cos\theta_1)l_1}{\sum l} = 65.47\ \mathrm{kN} \tag{19}$$

$$P''_1 = \mathrm{red}\Delta K_2 \cdot \frac{l_1}{(2l_1 + l_2)} = 24.47\ \mathrm{kN} \tag{20}$$

$$P'_2 = \frac{(K_2\cos\theta_2 + K_1\cos\theta_1)l_2}{\sum l} = 41.37\ \mathrm{kN} \tag{21}$$

$$P''_2 = \frac{\mathrm{red}\Delta K_2 l_2}{(2l_1 + l_2)} = 15.46\ \mathrm{kN} \tag{22}$$

$$P'_3 = \frac{(K_2\cos\theta_2 + K_1\cos\theta_1)l_3}{\sum l} = 23.47\ \mathrm{kN} \tag{23}$$

$$P''_3 = \frac{\Delta K_1 l_3}{(2l_3 + l_4)} = 19.58\ \mathrm{kN} \tag{24}$$

$$P'_4 = \frac{(K_2\cos\theta_2 + K_1\cos\theta_1)l_4}{\sum l} = 41.37\ \mathrm{kN} \tag{25}$$

$$P''_4 = \frac{\Delta K_1 l_4}{(2l_3 + l_4)} = 34.11\ \mathrm{kN} \tag{26}$$

$$P'_5 = \frac{\Delta K_1 \sin\theta_2 l_5}{(2l_5 + l_6)} = 16.22\ \mathrm{kN} \tag{27}$$

$$P''_5 = \frac{\Delta K_1 \cos\theta_2 l_5}{(2l_5 + l_6)} = 17.81\ \mathrm{kN} \tag{28}$$

$K_1 = N_{1,Ed}$ = 164.37 kN – force in the overlapping brace, $K_2 = N_{2,Ed}$ = 204.43 kN – force in the overlapped brace.

The determination of stresses in the welds in joint 1, taking into account the effective lengths of welds due to loads parallel to the chord. The thickness of the welds α_w = 3 mm was assumed:

$$\sigma'_1 = 0 \tag{29}$$

$$\sigma'_2 = \frac{P'_2}{a_w l_2} = 183.7\ \mathrm{MPa} \tag{30}$$

$$\sigma'_{1,\perp} = 0 \tag{31}$$

$$\sigma'_{2,\perp} = \sigma'_2 \sin(\theta_2/2) = 66.33\ \mathrm{MPa} \tag{32}$$

$$\tau'_{1,\perp} = 0 \tag{33}$$

$$\tau'_{2,\perp} = \sigma'_2 \cos(\theta_2/2) = 171.31\ \mathrm{MPa} \tag{34}$$

$$\tau'_{1,II} = \frac{P'_1}{a_w l_1} = 183.7\ \mathrm{MPa} \tag{35}$$

$$\tau'_{2,II} = 0 \tag{36}$$

$$\sigma'_3 = 0 \tag{37}$$

$$\sigma'_4 = \frac{P'_4}{a_w l_4} = 183.7\ \mathrm{MPa} \tag{38}$$

$$\sigma'_{3,\perp} = 0 \tag{39}$$

$$\sigma'_{4,\perp} = \sigma'_4 \sin(\theta_1/2) = 74.69\ \mathrm{MPa} \tag{40}$$

$$\tau'_{3,\perp} = 0 \tag{41}$$

$$\tau'_{4,\perp} = \sigma'_4 \cos(\theta_1/2) = 167.83\ \mathrm{MPa} \tag{42}$$

$$\tau'_{3,II} = \frac{P'_3}{a_w l_3} = 183.7\ \mathrm{MPa} \tag{43}$$

$$\tau'_{4,II} = 0 \tag{44}$$

$$\sigma'_5 = 0 \tag{45}$$

$$\sigma'_6 = \frac{P'_6}{a_w l_6} = 112.64\ \mathrm{MPa} \tag{46}$$

$$\sigma'_{5,\perp} = 0 \tag{47}$$

$$\sigma'_{6,\perp} = -\sigma'_6 \cos(\theta_1 + \theta_2)/2 = -74.43\ \mathrm{MPa} \tag{48}$$

$$\tau'_{5,\perp} = 0 \tag{49}$$

$$\tau'_{6,\perp} = \sigma'_6 \sin(\theta_1 + \theta_2)/2 = 79.78\ \mathrm{MPa} \tag{50}$$

$$\tau'_{5,II} = \frac{P'_5}{a_w l_5} = 112.64\ \mathrm{MPa} \tag{51}$$

$$\tau'_{6,II} = 0 \tag{52}$$

Determination of stresses in welds due to loads perpendicular to the chord:

$$\sigma''_1 = \frac{P''_1}{a_w l_1} = 68.65\ \mathrm{MPa} \tag{53}$$

$$\sigma''_2 = \frac{P''_2}{a_w l_2} = 68.65\ \mathrm{MPa} \tag{54}$$

$$\sigma''_{1,\perp} = \frac{\sigma''_1}{\sqrt{2}} = 48.55\ \text{MPa} \qquad (55)$$

$$\sigma''_{2,\perp} = -\sigma''_2 \cos(\theta_2/2) = -64.02\ \text{MPa} \qquad (56)$$

$$\tau''_{1,\perp} = -\frac{\sigma''_1}{\sqrt{2}} = -48.55\ \text{MPa} \qquad (57)$$

$$\tau''_{2,\perp} = \sigma''_2 \sin(\theta_2/2) = 24.79\ \text{MPa} \qquad (58)$$

$$\tau''_{1,II} = 0 \qquad (59)$$

$$\tau''_{2,II} = 0 \qquad (60)$$

$$\sigma''_3 = \frac{P''_3}{a_w l_3} = 151.49\ \text{MPa} \qquad (61)$$

$$\sigma''_4 = \frac{P''_4}{a_w l_4} = 151.49\ \text{MPa} \qquad (62)$$

$$\sigma''_{3,\perp} = -\frac{\sigma''_3}{\sqrt{2}} = -107.12\ \text{MPa} \qquad (63)$$

$$\sigma''_{4,\perp} = -\sigma''_4 \cos(\theta_1/2) = -138.4\ \text{MPa} \qquad (64)$$

$$\tau''_{3,\perp} = \frac{\sigma''_3}{\sqrt{2}} = 107.12\ \text{MPa} \qquad (65)$$

$$\tau''_{4,\perp} = \sigma''_4 \sin(\theta_1/2) = 61.59\ \text{MPa} \qquad (66)$$

$$\tau''_{3,II} = 0 \qquad (67)$$

$$\tau''_{2,II} = 0 \qquad (68)$$

$$\sigma''_5 = \frac{P''_5}{a_w l_5} = 123.66\ \text{MPa} \qquad (69)$$

$$\sigma''_6 = \frac{P''_6}{a_w l_6} = 123.66\ \text{MPa} \qquad (70)$$

$$\sigma''_{5,\perp} = -\frac{\sigma''_5}{\sqrt{2}} = -87.44\ \text{MPa} \qquad (71)$$

$$\sigma'_{6,\perp} = \sigma'_6 \cos(\theta_1 + \theta_2)/2 = 87.21\ \text{MPa} \qquad (72)$$

$$\tau''_{5,\perp} = \frac{\sigma''_5}{\sqrt{2}} = 87.44\ \text{MPa} \qquad (73)$$

$$\tau'_{6,\perp} = -\sigma'_6 \sin(\theta_1 + \theta_2)/2 = -87.68\ \text{MPa} \qquad (74)$$

$$\tau''_{5,II} = 0 \qquad (75)$$

$$\tau''_{6,II} = 0 \qquad (76)$$

Checking the design resistance of fillet welds according to the formula (4.1) of the standard [2] is presented in tabular form (Table 1).

Table 1. Checking the design resistance of fillet welds of joint 1
Tabela 1. Sprawdzenie nośności spoin pachwinowych w węźle nr 1

Stresses [MPa]	Weld number					
	1	2	3	4	5	6
$\tau_{II} = \tau'_{II} + \tau''_{II}$	183.7	0	183.7	0	112.6	0
$\sigma_\perp = \sigma'_\perp + \sigma''_\perp$	48.55	2.3	-107.1	-63.7	-87.4	7.8
$\tau_\perp = \tau'_\perp + \tau''_\perp$	-48.55	196.1	107.1	229.4	87.4	-7.8
$\sigma = [\sigma_\perp^2 + 3(\tau_\perp^2 + \tau_{II}^2)]^{0,5}$	332.7	339.7	383.6	402.5	262.0	15.6
$\sigma \leq f_u/\beta_w\gamma_{M2}$	$\sigma = 402.45 < 435.6$					
$\sigma_\perp \leq 0{,}9\ f_u/\gamma_{M2}$	$\sigma_\perp = 107.12 < 352.8$					
Safety margin [%]	(435.6 – 402.45)/435.6 • 100% = 7.61%					

Comparative analysis of the costs of making welds

The cost of fabricating full butt welds with a thickness of 5 mm, designed in accordance with the recommendations of the PN-EN 1993-1-8 standard [2], was compared to the cost of fabricating fillet welds with a thickness of 3 mm, calculated taking into account effective lengths procedure presented in this article, with a resistance adjusted to the axial force in a given member (Table 2). According to the comparison, creating smaller fillet welds that are tailored to the forces present in the truss members costs half as much as creating full butt welds.

Table 2. Comparison of the costs of welds in the truss according to proposed procedure in accordance with the EN 1993-1-8 [2]
Tabela 2. Porównanie kosztu wykonania spoin pachwinowych z pełnymi spoinami czołowymi wg normy EN-1993-1-8 [2]

Joint number	Lengty of welds [mm]	Fillet welds 3 mm		Butt welds 5 mm	
		welding time [min]	welding costs [EUR]	welding time [min]	welding costs [EUR]
1	619.9	12.40	7.4	24.80	14.8
2	604.7	12.09	7.2	24.19	14.4
3	593.7	11.87	7.1	23.75	14.2
4	585.8	11.72	7.0	23.43	14.0
5	604.5	12.09	7.2	24.18	14.4
6	595.6	11.91	7.1	23.82	14.2
7	586.2	11.72	7.0	23.45	14.0
8	580.9	11.62	6.9	23.24	13.8
Sum[1)]	**9542.6**	**190.9**	**113.7**	**381.7**	**227.5**

[1)] The sums in the last row of the table take into account the symmetry of the truss. Welding performance of 3 mm fillet weld is 1 m – 20 min. Welding performance of 5 mm butt weld is 1 m – 40 min (welding + element preparation). Labor cost 1 hr – EUR 32.5 (+10% profit). The time of transport ng and rotating the element during welding was omitted during the cost analysis.

According to the American Institute of Steel Construction guidelines [8], effective welds for overlapped K-connections under branch axial loads should be calculated from the following formulas. If $50\% < \lambda_{ov}(O_v) = 60\% < 80\%$ the effective length of the welds for the overlapping member is:

$$l_{e,i} = 2[(1 - (\lambda_{ov}/100)\ (h_1/\sin\theta_1) + \lambda_{ov}/100(h_1/\sin\theta_1 + \theta_2))] + \\ + b_{1,eff} + b_{2,eff} = 332.3\ \text{mm} \qquad (77)$$

If $\beta = 0.4 < 0.85$ and $\theta_1 = 47.98° < 50°$ the effective length of the welds for the overlapped member should be calculated from the formula [8]:

$$l_{e,j} = 2h_2/\sin\theta_2 + 2b_{2,eff} = 387.7\ \text{mm} \qquad (78)$$

All data used in the formulas above have been described previously.

Table 3 compares the cost of fabricating fillet welds with a thickness of 3 mm while accounting for the effective lengths of welds made in accordance with AISC procedure with full butt welds. Comparing the calculation method presented in the AISC guidelines to the method proposed in this article based on European standards reveals significant differences in the evaluation of the effective length of welds.

Table 3. Comparison of the costs of welds in the truss according to ASCI procedure [8]
Tabela 3. Porównanie kosztów spoin kratownicy wg procedury ASCI [8]

Joint number	Length of welds [mm]	Fillet welds 3 mm		Butt welds 5 mm	
		welding time [min]	welding costs [EUR]	welding time [min]	welding costs [EUR]
1	720.01	14.40	8.6	28.80	17.2
2	704.86	14.10	8.4	28.19	16.8
3	693.83	13.88	8.3	27.75	16.5
4	685.89	13.72	8.2	27.44	16.4
5	704.60	14.09	8.4	28.18	16.8
6	695.75	13.92	8.3	27.83	16.6
7	686.34	13.73	8.2	27.45	16.4
8	681.04	13.62	8.1	27.24	16.2
SUM	**11144.7**	**222.9**	**132.8**	**445.8**	**265.7**

Life Cycle Analysis

Industrial products have an overall environmental impact, thus manufacturing processes must be examined in light of their ecological footprint. In the global context, welding as a significant element of industrial processes accounts for the overall environmental impact of several industry sectors. Energy and resources are consumed in substantial quantities throughout the welding procedures. As a result, the need for a welding process-related life cycle assessment is broadly addressed, with applications comprising from the building industry. Therefore, using the life cycle analysis method, the environmental impacts associated with the implementation of solid-wall butt welds with a thickness of 5 mm (Figure 4) and fillet welds with a thickness of 3 mm (Figu-re 5) were compared in the case of the analysed truss.

LCA for Experts (v. 10.7.0.183) [9] was used for the analysis. The study's objective was to measure the differences between fillet welds made in accordance with the suggested method of effective lengths and full butt welds. Without considering the impact of intermediary transport, the environmental impact of the material production phase and the construction phase (A1-A5) were evaluated. The greenhouse effect potential GWP [kg CO_2eq] and the consumption of non-renewable primary energy EP [kWh] were used as indicators for the LCA results, which were calculated using the CML 2001.

The welding process itself, specifically the electricity consumption required to generate voltage and form the welding arc, is the primary cause of the welded joint's environmental impact. This process contributed 72% of the greenhouse potential and 55% of the non-renewable primary energy consumption of the examined welded joints, respectively, for the fillet welds and 83% and 71%, respectively, for the butt weld. In both of the investigated categories, it was responsible for more than half of the values of the welded joint.

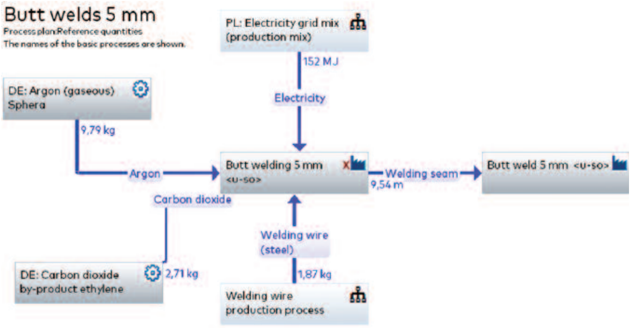

Fig. 4. LCA analysis for full butt welds 5 mm
Rys. 4. Analiza LCA spoin czołowych o grubości 5 mm

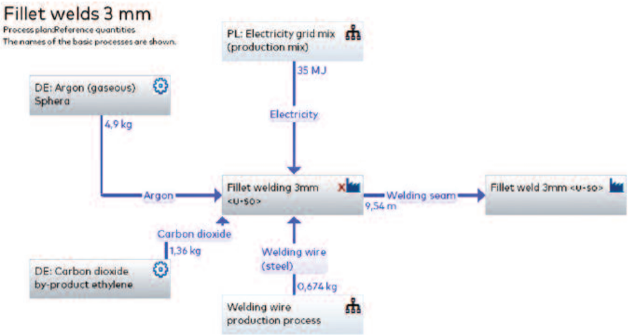

Fig. 5. LCA analysis for fillet welds 3 mm
Rys. 5. Analiza LCA spoin pachwinowych o grubości 3 mm

Fillet welds are capable of reducing the overall environmental effect of the welded joint from 157.72 kWh to 46.71 kWh and from 45.13 kg CO_2eq to 12.00 kg CO_2eq, a 73% and 70% reduction, respectively (Figure 6). Due to the high energy consumption of the processes necessary to create this form of weld and the required high power, the butt weld has a high environmental effect. The impacts from the use of shielding gas and welding wire in the case of a fillet weld accounted for 28% of greenhouse gas emissions and 45% of non-renewable primary energy consumption, while for a butt weld they accounted for only 18% and 29%.

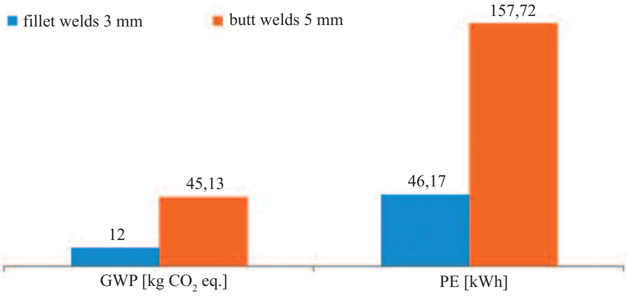

Fig. 6. Environmental impact of both types of welds
Rys. 6. Oddziaływania środowiskowe obu rodzajów spoin

Conclusions

The article's goal was to suggest a method for evaluating welded joints of trusses built of RHS sections and chords made of channel sections with mutually overlapping braces while accounting for the length of effective welds. It is a complicated issue to evaluate the resistance of welds in flexible hollow section joints, as it requires determining the effective lengths of the welds, their arrangement in the system of walls with different flexibility and the division of component forces from loads acting in the joint on individual sections of welds.

According to the PN-EN 1993-1-8 [2] standard, a smaller weld size may be acceptable if it can be computationally justified in terms of load capacity, deformation, and rotation ability while taking into account the length of the cooperating weld. Typically, cross-sections of bracing members are selected not because of their capacity but because of the need to unify the members to several elements in the case of designing tension and compression members with small longitudinal forces. In such cases, the design load capacity of such members is usually greater than the forces in them, and thus the welds selected for the full cross-section are usually oversized. The use of welds with smaller thicknesses that are adapted to the forces acting on the members is permitted by EU standards, offers substantial financial advantages, and improves the safety of the welded structure.

As shown in Tables 2 and 3, using full butt welds in accordance with the recommendations of the PN-EN 1993-1-8 standard [2] is twice as expensive as making fillet welds with a thinner thickness than that recommended by the standard [2], which is tailored to the actual forces occurring in the members.

Furthermore, both welding techniques underwent an LCA analysis. Research shows that employing fillet welds with a thickness less than that recommended by the [2] standard led to a 73% decrease in the usage of non-renewable primary energy and a 70% decrease in greenhouse gas emissions.

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