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Experimental tests of bonded steel-OSB composite beam

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ABSTRACT:
Rapidly rising metal prices force scientists to develop innovative materials. Therefore, composite structures, including sandwich structures, are gaining more and more popularity. The paper presents an assessment of a composite beam which is an alternative to a steel beam. The aim of the work was to determine the bending resistance of the steel-OSB composite beam. The subject of the three-point bending tests was a sandwich beam made of three 25 mm thick oriented strand boards and two 2 mm thick steel sheets. The components of the beam were joined with a polymer glue. The beam had a rectangular section 80 mm wide and 50 mm high. Its length was 800 mm. The tested bending capacity of the beam was 1 kNm. The work also included tests of the mechanical properties of the steel sheets used for the construction of the beam. As a result, the weight and consumption of steel in the steel-OSB composite beam and the analytically designed steel beam were compared.

KEYWORDS:
composite beam; steel; oriented strand boards; adhesively bonded joints

1. Introduction

Rapidly rising metal prices force scientists to develop new sustainable building materials. One idea is to use thin-walled metal structures. However, such structural members are characterized by buckling [1, 2]. Therefore, research is still being carried out on stiffening thin-walled sections with other materials. The works [3, 4] propose stiffening with polyurethane foam. This solution is very advantageous for reasons of strength. Additionally, PU foam is very light, but it is a plastic material that can be difficult to dispose of.

One of the examples of stiffening thin-walled structures with ecological material is the use of wood [5]. Authors of paper [6] presented the possibility of improving the buckling properties of cold-formed steel members by combining them with wooden layers. The composite member was obtained by attaching wooden laminates to the web portion of cold formed Z, C and double C sections. The test results showed that the increase in compressive load was significant at 1.4 to 6.7 times bigger than for steel members.

Another ecological material which could increase the bearing capacity of thin-walled steel sections is bamboo. Bamboo is characterised by excellent mechanical properties, including high

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tensile strength, toughness, and low weight. A few studies have been conducted on the bamboo–steel composite beams with I-section [7-9] or box section [10-12]. They overcome the shortcomings of instability in thin-walled steel allowing the strength of both materials to be fully utilized.

Oriented strand board (OSB) is a wood-based panel product, designed as a structural replacement for plywood. OSB is characterised by its constituent strand elements which vary in size and aspect ratio. OSB is mainly used during the construction of roofs, walls of houses with a frame structure and creating formwork and roof soffits [13-15]. The results of test of the CFS channel with OSB was presented in [16]. The OSB filled the channel in such a way to obtain a solid symmetrical section. Designed cross-section minimises the buckling problem during the compression loads.

The lack of research on the use of OSB in the design of thin-walled bending structures contributed to the development of new sustainable building member presented in this paper.

2. Goal and scope of work

The aim of the study was to determine the bending capacity of an innovative composite steel-OSB beam. The scope of the work includes a manufacturing of the beam and an experimental three-point bending test of the beam.

The subject of the research was the beam consisting of five components: three oriented strand boards (OSB) with the thickness of 25 mm and two sheets of S235 steel [17, 18] with the thickness of 2 mm. The metal sheets were placed between the boards in such a way that the sandwich beam was created. The components were connected by an adhesive polymer glue with a density of 0.95 kg/l.

The beam was made by hand (Fig. 1a). Before applying the glue, the sheets were degreased with acetone. Then glue was evenly applied to the metal sheets and OSB boards, and the components were pressed together with clamps. The beam was allowed to dry at room temperature. The glue setting time specified by the manufacturer is 24 hours. The bending test was performed 48 hours after the application of the adhesive. After the glue set, the beam thickness increased from 79 mm to 80 mm.

The beam's section height was 50 mm, and its length was 800 mm (Fig. 1c). The spacing of the supports during the test was 700 mm (Fig. 1b, c). The test was conducted in the elastic range.

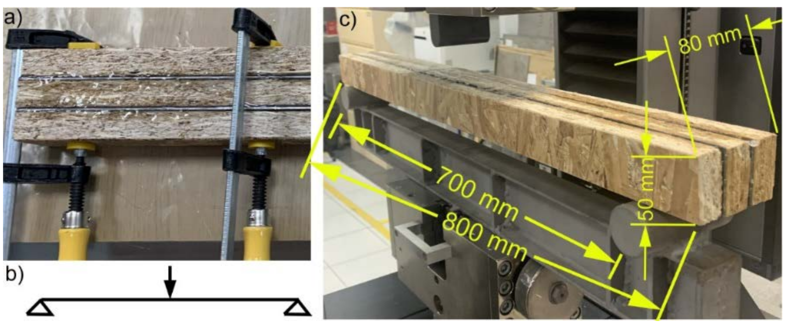

Fig. 1. Composite beam: a) during manufacturing, b) static schema, c) during bending test

The beam tests were preceded by steel tensile tests. The determination of the real mechanical properties of steel allowed the analytical design of an all-steel beam with identical material properties like metal sheets and the bending resistance like the composite beam. Ultimately, the innovative composite beam was compared to the steel beam in terms of total weight and in terms of steel consumption.

Tensile tests were carried out in accordance with the standard [19]. The geometry of the samples is presented in Figure 2. The statistics were compiled based on the results from 10 samples.

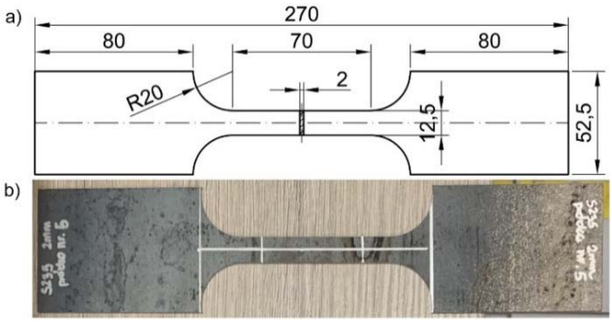

Fig. 2. Steel sample for tensile test: a) geometry, b) real photo

The mechanical properties of oriented strand board were not experimentally verified. Material data specified by the manufacturer was presented in Table 1.

Table 1
Properties of oriented strand board based on manufacturer data

	Value
Tensile strength R_m [MPa]	9
Modulus of elasticity E [GPa]	3
Poisson ratio	0.23
Density [kg/m^3]	630

Both the beam test and the steel tests were carried out on the Zwick Z050 testing machine.

3. Results

Graphs of engineering strain – engineering stress from tensile tests of steels sheets are presented in Figure 3. It is easy to see that the curves are similar which proves the repeatability of the results.

Details of the mechanical properties of the analysed samples are summarized in Table 2. The average yield strength R_e is equal to 370 MPa with the standard deviation of 7 MPa. The average tensile strength R_m is equal to 444 MPa with the standard deviation of 2.47 MPa. The average elongation after fracture A is 28.8% with the standard deviation of 1.4 MPa. Modulus of elasticity E of each sample is equal 210 GPa. All samples were damaged in the measuring area.

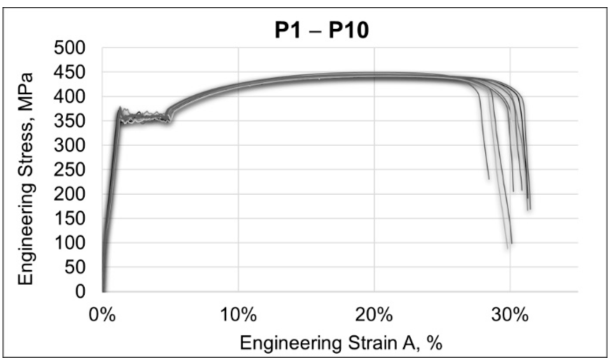

Fig. 3. Engineering strain – engineering stress graph from tensile tests of steel sheets

Table 2
Results from tensile tests of steel sheets

Sample	Yield strength R_e [MPa]	Tensile strength R_m [MPa]	Elongation after fracture A [%]	Modulus of elasticity E [GPa]
P1	360	442	28.7	210
P2	363	449	27.3	210
P3	372	441	30.1	210
P4	362	442	25.6	210
P5	364	442	28.5	210
P6	379	445	30.0	210
P7	376	445	28.9	210
P8	369	445	29.0	210
P9	374	445	29.6	210
P10	377	445	30.1	210
Average	**370**	**444**	**28.8**	**210**
Standard deviation	**7.0**	**2.47**	**1.4**	**0**

Results from the three-point bending test of the composite steel-OSB beam are presented in Figure 4. The deflection – force graph was obtained on the testing machine. The deflection – bending moment graph was created based on the calculation of bending moment from the static schema of the beam. Into the deflection – force graph the trend line was added. The intersection of the curves marked the elastic range point. This means that the beam carried the load in its elastic range of 5.76 kN which corresponds to the 1.0 kNm bending moment. The deflection in the elastic range was about 5.1 mm.

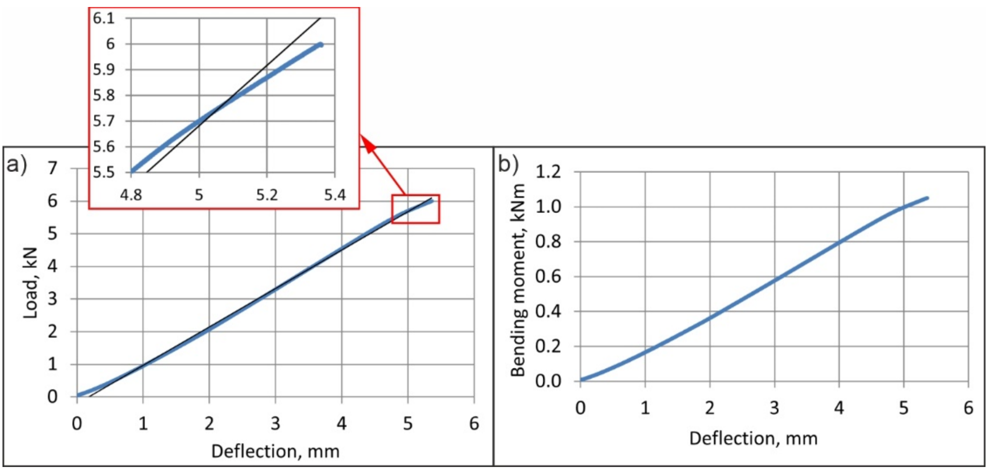

Fig. 4. Graphs from three-point bending test of composite beam: a) deflection – force, b) deflection – bending moment

The measured mass of the steel-OSB composite beam is 3160 g, where the measured mass of steel sheets in the manufactured beam is 1250 g.

The beam made of steel with the same mechanical properties as the steel in the composite beam was designed. It allows a comparison of the analysed composite beam with the all-steel beam. The calculations presented below shown that the rectangular cross-section of the designed steel beam has the dimensions 16 mm x 32 mm.

Assumptions for calculations:

- Designed section width: b = 16 mm
- Designed section height: h = 32 mm
- Length of beam: L = 800 mm
- Yield strength (from experimental test): 370 MPa
- Density of steel: ρ = 7850 kg/m^3

Elastic modulus:

$$W = \frac{b \cdot h^2}{6} = \frac{1.6\ \text{cm} \cdot (3.2\ \text{cm})^2}{6} = 2.731\ \text{cm}^3 \tag{1}$$

Bending moment:

$$M = W \cdot f_y = 2.731\ \text{cm}^3 \cdot 370\ \text{MPa} = 1\ \text{kNm} \tag{2}$$

Mass:

$$b \cdot h \cdot L \cdot \rho = 1.6\ \text{cm} \cdot 3.2\ \text{cm} \cdot 800\ \text{cm} \cdot 7.85 \frac{\text{g}}{\text{cm}^3} = 3215\ \text{g} \tag{3}$$

4. Discussion

The mechanical properties of the steel sheets meet the requirements for the S235 grade in accordance with the standard PN-EN 10025-2 [17]. The determined yield strength is 370 MPa and is 58% higher than the required minimum 235 MPa, while the determined tensile strength is equal to 444 and is 23% higher than the required minimum 360 MPa. The required minimum elongation after fracture is equal to 20%. However, the determined average value is 28.8%.

The total mass of the tested composite steel-OSB beam is similar to the mass of the designed steel beam. However, the share of steel in the composite beam is only 40% of the weight of the steel beam. This translates into a significant reduction in material costs, because currently OSB is much cheaper than steel. It is true that the composite beam requires additional production operations, i.e. surface degreasing and gluing, but it is relatively easy to automate.

5. Conclusions

- The steel-OSB composite beam tests were shown that it is an alternative to the 16 x 32 mm rectangular steel beam.
- The analysed beam carried the load of 5.76 kN, which corresponds to a bending resistance of 1 kNm.
- The determined mechanical properties of the steel sheets meet the standard requirements for sheets made of structural steel S235.
- The determined mechanical properties of the steel sheets and the composite beam allow the development of a numerical model of beam bending and, consequently, optimization of the beam geometry.

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Badania eksperymentalne klejonej belki kompozytowej stalowo-OSB

STRESZCZENIE:
Bardzo szybko rosnące ceny metali zmuszają naukowców do opracowywania innowacyjnych materiałów, dlatego coraz większą popularność zyskują konstrukcje kompozytowe, w tym konstrukcje typu sandwich. W pracy dokonano oceny belki kompozytowej stanowiącej alternatywę dla belki stalowej. Celem pracy było wyznaczenie nośności na zginanie belki kompozytowej stalowo-OSB. Przedmiotem badań trójpunktowego zginania była belka typu sandwich zbudowana z trzech płyt OSB o grubości 25 mm oraz dwóch blach stalowych o grubości 2 mm. Komponenty belki połączono za pomocą kleju polimerowego. Belka posiadała prostokątny przekrój o szerokości 80 mm oraz wysokości 50 mm. Jej długość wynosiła 800 mm. Nośność belki na zginanie wyniosła 1 kNm. Wykonano również badania właściwości mechanicznych blach stalowych wykorzystanych do budowy belki. Dzięki temu porównano masę i zużycie stali w belce kompozytowej oraz analitycznie zaprojektowanej belce stalowej.

SŁOWA KLUCZOWE:
belka kompozytowa; stal; OSB; połączenia klejone