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Evaluation of the connection between sandwich panels and cold-formed beams using acrylic tapes

Ocena połączenia płyt warstwowych z belkami zimnogiętymi na taśmy akrylowe

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Abstract. The article presents the results on cold-formed beams connected to sandwich panels using acrylic tapes. Two variants of connection were evaluated – continuous and sectional. Research was aimed at determining the behavior of such a connection and determining its load bearing capacity in laboratory conditions. The failure mechanisms of the beam-tape-panel system are described and the equilibrium paths of selected control points defined on the beam and the sandwich panel are recorded.
Keywords: sandwich panels; cold-formed beams; acrylic tapes, glued connection; laboratory tests.

Streszczenie. W artykule przedstawiono wyniki badań belek zimnogiętych połączonych z płytami warstwowymi za pomocą taśm akrylowych. Ocenie poddane zostały dwa warianty połączenia – ciągłe i odcinkowe. Badania ukierunkowane zostały na określenie zachowania się połączenia i wyznaczenia jego nośności w warunkach laboratoryjnych. Opisano mechanizmy zniszczenia układu belka – taśma – płyta oraz zarejestrowano ścieżki równowagi wybranych punktów kontrolnych określonych na belce i płycie.
Słowa kluczowe: płyty warstwowe; belki zimnogięte; taśmy akrylowe; połączenie klejone; badania doświadczalne.

In the construction industry, sandwich panels are used as elements of cladding for walls and roofs of buildings. They consist of two thin steel facings and a thick core made of thermal insulation material. The exception is when they are used in livestock facilities. Due to the unfavourable environmental conditions in such facilities, the inner facing is made of laminate. The role of sandwich panels in the functioning of a building structure is very wide. The basic tasks of sandwich panels include: providing protection from the weather, maintaining the desired level of thermal insulation of partitions, and transferring external load (mechanical and thermal) to the supporting structure (main systems or secondary structures). Climate change and the resulting warming of the climate are prompting representatives of the construction sector to implement solutions that result in reducing the energy consumption of building solutions. This is realised within the framework of the idea of sustainable building [1, 2]. An original look at the production of sustainable building products is presented in [3]. In the context of sustainable building, accounting for the stiffening effect of the cold-formed beam by the sandwich panel presented in this article offers the possibility of reducing its cross-sectional area. This results in less steel consumption and, thus, a smaller carbon footprint for the structure. In this case, in addition to the utility and technical functions mentioned above of sandwich panels, the function of lateral stiffening of the element supporting the panel is added. Through lateral stiffening, we observe an increase in the load-bearing capacity of the element due to lateral torsion and flexural buckling around the weaker axis.

Investigations on the effectiveness of sandwich panel bracing bar members have been carried out in many research centres [4, 5, 6]. The state of the art is so well established that in 2014 the ECCS TWG7.9 *Sandwich panels and related structures* working group published recommendations that describe how to evaluate the stabilisationof structural steel members by sandwich panels [7]. The studies described in the literature as well as the study guidelines issued by ECCS refer to the situation in which the connection between the sandwich panel and the steel beam is provided by mechanical fasteners (self-tapping screws). The tests presented in this article show the load-bearing capacity of a beam-panel connection realised with double-sided acrylic tapes; so it is a different class of connection, an adhesive connection. The results presented in the article are related to the studies described in an earlier work of the authors [8] in which an experiment was carried out on the same test stand and with the same elements (from the same production batch) using mechanical fasteners to connect sandwich panels with cold-formed beams. The investigated connection, with regard to the connection of sandwich panels with thin-walled elements, is not included in PN-EN 14509:2013-12 [9] and in the technical conditions for the execution and acceptance of construction works [10]. In addition, due to the temperature range of the tapes' operation (-40°C to +230°C), they would require additional evaluation under elevated temperature or fire conditions.

Problem formulation

Figure 1 shows a scheme of the test stand used during the experiments. The structural system under investigation consisted of two sandwich panels of 1.1 m x 0.6 m each, stacked on two cold-formed beams of zeta cross-section. The zeta beams were arranged so that

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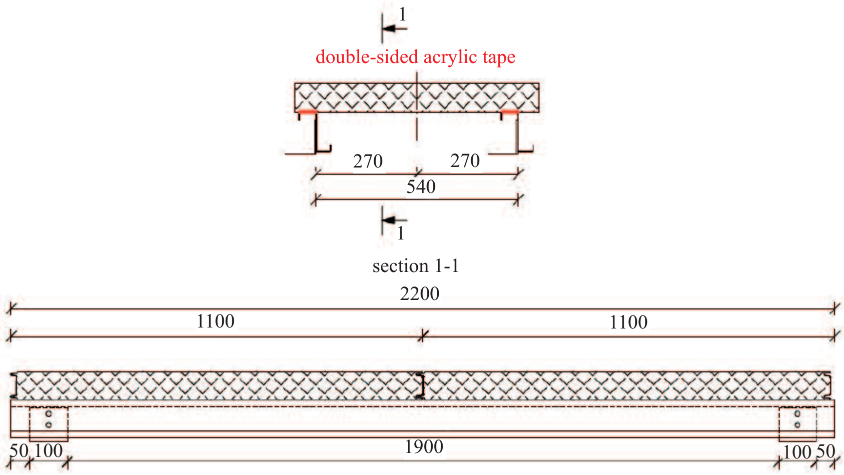


Fig. 1. Scheme of the testbed
Rys. 1. Schemat stanowiska badawczego

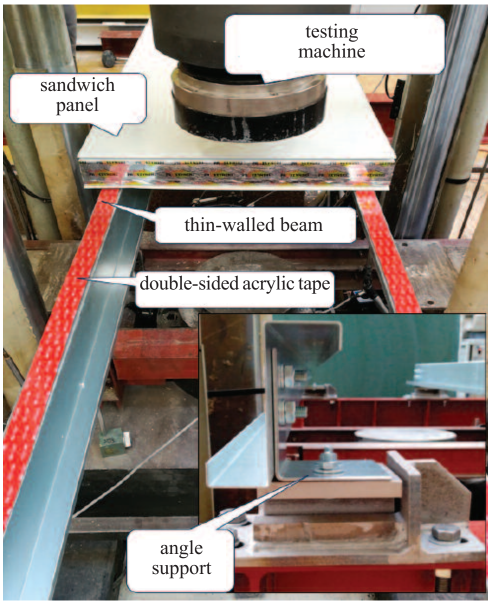


Photo 1. Testbed and beam support view
Fot. 1. Stanowisko badawcze i widok podparcia belki

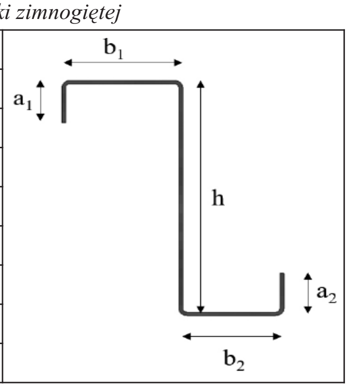
their flanges faced the same direction, resulting in the asymmetry of the tested system. To achieve symmetric loading of these two beams, the entire system was moved with respect to the machine axis so that the centre of gravity of the system coincided with the axis of load application. The thick 80 mm core of the sandwich panels was made of polyisocyanurate (PIR) foam, and the thin outer facings were made of S280GD steel. The nominal thicknesses measured for the facings were 0.545 mm and 0.491 mm for the top and bottom facings, respectively.

The cross section of the beam was formed by cold bending of the DX51D + Z275 steel sheet with a nominal thickness of 1.5 mm. The section has edge bends on the flanges. The wall dimensions of the section in development, measured from the edge bend of the top shelf, can be written as follows: 18 mm – 45 mm – 100 mm – 39 mm – 18 mm. Table 1 provides information on the basic geometric characteristics of the beam section. The material properties of the members of the analysed structural system are described in the earlier work of the authors [11].

In the structural system under consideration, cold-formed beams were attached to a support structure via angle supports made of 3 mm thick sheet metal. The angle supports were attached to a support bearing allowing the beam to rotate in the main plane of bending (y-y axis taking the designation as in EC). The beam was connected to the purlin with two M12 cl. 5.6 bolts in vertical arrangement, cf. Figure 2. The bolt connection introduces a 10 mm distance between the lower flange of the beam and the bearing plate – this eliminates the possibility of local failure of the beam due to the vertical reaction at the support. This is a common system solution used by cold-formed purlin manufacturers. The original element of the structural system studied is the use of double-sided acrylic tapes to connect the cold-formed beam to the sandwich panel. The tapes used in the study, 3M VHB 5952 [12], are designed to connect steel elements and also plastics. The tape consists of flexible acrylic foam with a thickness of 1.1 mm, which is coated on both sides with acrylic adhesive. The tapes used are 38 mm wide. According to the product card [10], the declared resistance to tensile load perpendicular to the plane of contact and tangential load is 480.0 kPa and 550.0 kPa, respectively. The tapes retain their mechanical properties in the temperature range from -40°C to +230°C.

Table 1. Geometric properties of a cold-formed beam cross-section
Tabela 1. Charakterystyka geometryczna przekroju belki zimnogiętej

Dimensions	a_1	b_1	h	b_2	a_2
	[mm]				
	18,0	45,0	100,0	39,0	18,0
Geometrical properties	A	I_y	I_z	I_x	I_{yz}
	[cm²]	[cm⁴]	[cm⁴]	[cm⁴]	[cm⁴]
	3,2	18,6	14,7	0,024	-20,0
	I_I	I_{II}	I_w	α	t
	[cm⁴]	[cm⁴]	[cm⁶]	[-]	[mm]
	57,9	5,4	259,0	24,9	1,5



The study examined the load-bearing capacity of the cold-formed beam/sandwich panel connection for two variants of taping. The first variant assumed continuous application of the tape along the entire length of the beam element, cf. Figure 3a. The second variant assumed a sectional application of the tape where the mechanical fasteners would be; cf. Figure 3b. In the case of sectional strip application, rectangular strip strips of 135 mm x 38 mm were used. Rectangular strips were used to facilitate connection of the sandwich panel to the top flange of the thin-walled beam. The band was arranged perpendicular to the longitudinal axis of the beam, resulting in the acrylic tape contacting the upper flange in an area of 38 mm x 45 mm. Before applying the tape, the surfaces of the bonded parts were cleaned and wiped with a 50 : 50 solution of isopropyl alcohol and water. After the surfaces dried, the tape was applied.

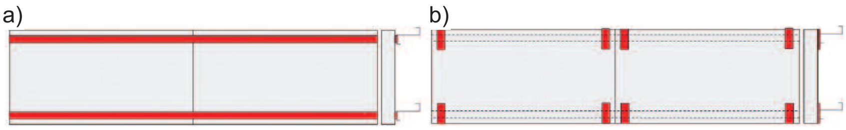


Fig. 2. Layout schemes for acrylic tape: a) continuous variant, b) sectional variant
Rys. 2. Schematy ułożenia taśmy akrylowej: a) wariant ciągły; b) wariant odcinkowy

In the structural system studied, the load was applied in the centre of the system as linear (via the traverse) along the width of the slab and at the same time perpendicular to the beam axis. In such a loading system, the cold-formed beam functions in a three-point bending scheme.

Analysis of experimental results

The tests reported in an earlier chapter were carried out for the static and quasi-cyclic loading scenario. In the case of static load, the piston travel of the testing machine was assumed to be at a constant speed of 10 mm/min. For quasi-cyclic forcing, 5 load cycles were programmed at the following intervals: 0.1 kN → 1.0 kN; 0.1 kN → 1.5 kN; 0.1 kN → 2.0 kN; 0.1 kN → 3.0 kN; 0.1 kN → 4.0 kN; 0.1kN → to failure. During the test, the vertical displacement of the lower flange of the cross section located at the centre of the beam span and the deflection of the sandwich panel after the load line were recorded. The vertical displacement diagrams of the sandwich panel will be discussed in detail as representative of the tests carried out, cf. Figure 3.

Figures 3a and 3b show the graphs for the test with tapes in the segmented and continuous variants, respectively. The tests showed that the quasicyclic load (continuous thin line) does not reduce the stiffness of the connection and its load-bearing level compared to the static load (thin dashed line) for both variants of tape application. To evaluate the effectiveness of the proposed type of connection (double-sided acrylic tapes), the results were compared with the equilibrium path while mechanical fasteners were used (Figure 3b). In Figures 3a and Photo 2b, the thick continuous line represents the results of a previous study [8], in which a mechanical fastener solution was used to connect a sandwich panel to a thin-walled beam. A quantitative comparison of the results is shown in Table 2, using the following test denotations: F8 – mechanical fasteners, T8 – sectional straps, TL – continuous straps, S – static load, C – cyclic load, 0 – refers to the angle of inclination of the tested system with respect to the plane of the machine, P – assumed load.

The following physical quantities are listed in Table 2: F_{max} – failure force, u(panel) – panel deflection at F_{max}, u (beam) – beam deflection at F_{max}, k_s (panel) – panel secant stiffness at failure, k_s (beam) – beam secant stiffness at failure. Photo 2 shows the recorded failure mechanisms of the systems analysed. In both variants of the strip arrangement, the failure occurred primarily due to the interactional loss of stability of the cold-formed beam. The interactional loss of stability consists of the global form of instability (the flexural-torsional form of buckling visible in the photos) and the local loss of stability of the compression walls of the section (top flange and web) in the middle of the beam span. This mechanism corresponds to a three-point bending beam. Additionally, in the beam support zone in the post-failure condition, the connection between the beam and the panel was discontinued on the tapes.

Concluding remarks

The article presents original experimental research analysing the load-bearing capacity of the connection between a sandwich panel and a cold-formed beam using double-sidedacrylic tapes. The results obtained by the tape connec-

Table 2. Test results; the result of mechanical fasteners [8] was added for reference
Tabela 2. Wyniki badań; porównawczo dodano wynik dotyczący łączników mechanicznych [8]

Name	F_{max} [kN]	avg. F_{max} [kN]	u(panel) [mm]	avg. u(panel) [mm]	u(beam) [mm]	avg. u(beam) [mm]	k_s(panel) [kN/mm]	k_s(beam) [kN/mm]
F8-0-P-S-1	12,29		34,2		15,1			
F8-0-P-C-1	12,27	12,35	36,3	35,56	15,2	15,33	0,35	0,81
F8-0-P-S-2	12,48		36,2		15,7			
T8-0-P-C-1	7,93	7,89	29,2	29,23	11,0	11,02	0,27	0,72
T8-0-P-S-1	7,85		29,3		11,0			
TL-0-P-C-1	8,87	9,22	38,4	38,87	14,7	12,74	0,24	0,72
TL-0-P-S-1	9,58		39,3		10,8			

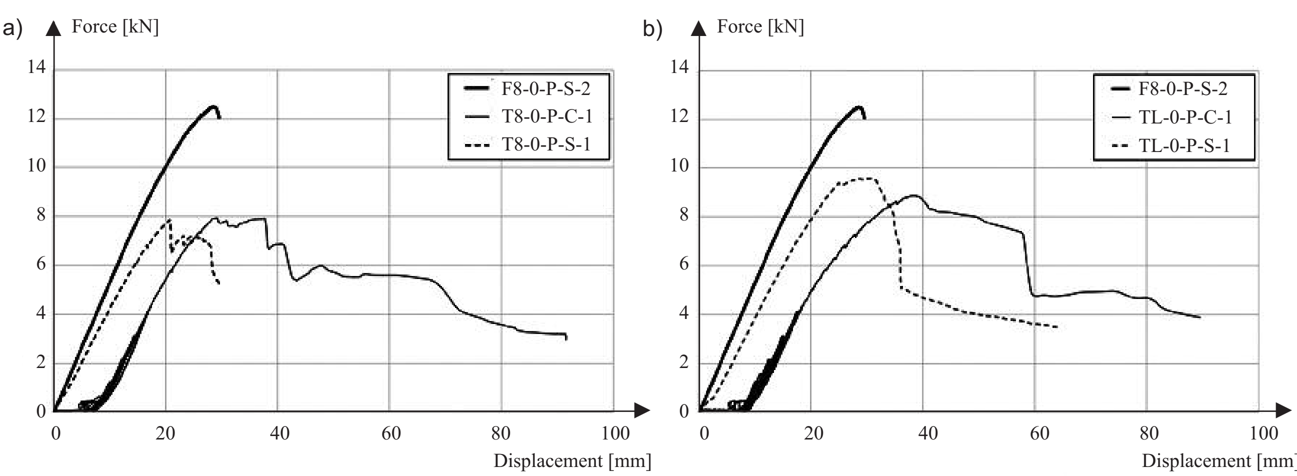


Fig. 3. The force-vertical displacement relations of the sandwich panel: a) tapes applied sectionally; b) tapes applied continuously
Rys. 3. Zależność siła-przemieszczenie pionowe płyty warstwowej: a) taśmy nałożone odcinkowo; b) taśmy nałożone liniowo

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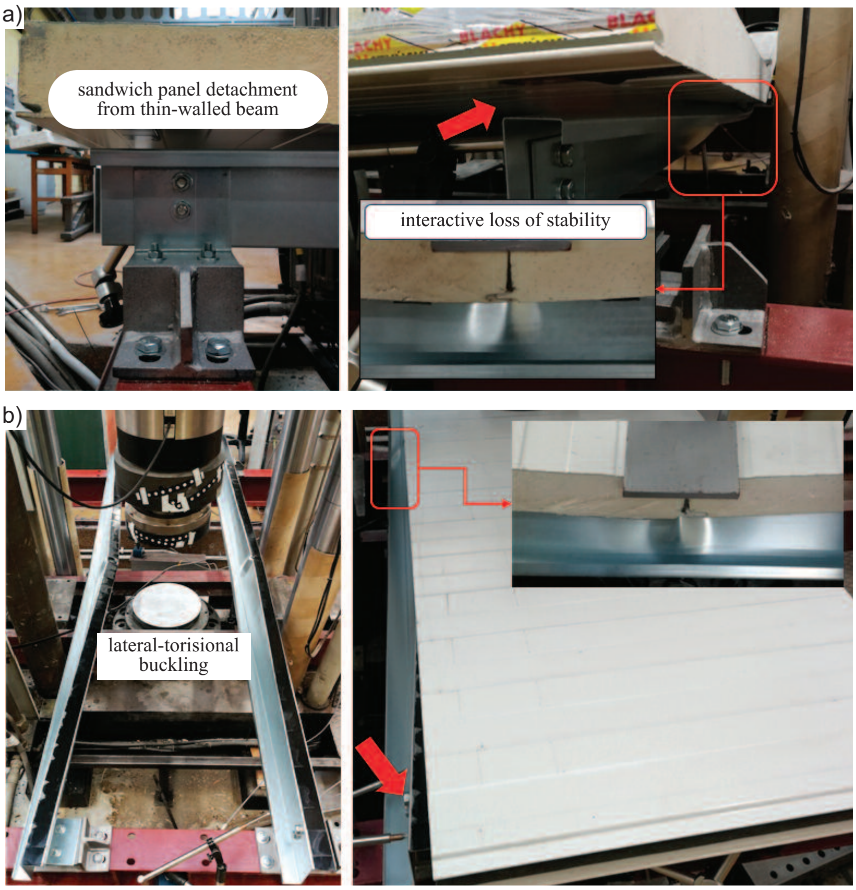

Photo 2. Failure mechanisms of sandwich panels connected to thin-wall beams with acrylic tapes: a) sectional variant; b) continuous variant
Fot. 2. Mechanizmy zniszczenia płyt warstwowych łączonych z belkami cienkościennymi taśmami akrylowymi: a) wariant odcinkowy; b) wariant ciągły

tion were related to the results of the mechanical fastener connection (self-drilling fasteners). Such a comparison is reliable because both the tape tests and the mechanical fastener tests were performed on the same test bench and using materials from the same production batch. Material compatibility applies to the cold-formed beams and sandwich panels used. This is particularly important in the case of sandwich panels with polyisocyanurate foam core, whose properties (adhesion, shear strength, and compressive strength) strongly depend on the preparation of two components, isocyanine, and polyols. In the process of applying these two components, an addition polymerisation reaction occurs, accompanied by the release of carbon dioxide, which creates a foaming process in the foam.

It was noted that the connection to acrylic double-sided tapes has a lower load capacity than the connection to fasteners. For sectionally and linearly applied tapes, the load carrying capacity of the joint is 64% and 75% of that of the fastener connection, respectively. The secant stiffness, measured as the ratio of failure force to displacement at failure, also compares more favourably with the connection to mechanical fasteners. The secant stiffness of a cold-formed beam with a sectional and linear tape connection is 90% of that of a cold-formed beam with a fastener connection. This means that the bracing levels of the beam element with the sandwich panel were very similar in both variants. The results obtained are very promising for double-side dacrylic tapes as an alternative way of joining sandwich panels and cold-formed beams.

However, they require further research before they can be applied in practice. Due to the limited range of applicability of the tapes (-40°C to +230°C), special attention should be paid in this case on the aspect of working of the connection on acrylic tapes in conditions of increased temperature or fire. In case of the possibility of such working conditions, an appropriate form of passive fire protection should be provided. Nevertheless, it will be reasonable to test the acrylic tape connection under elevated temperature conditions. In addition, it will be reasonable to supplement the tests with an evaluation of the load-bearing capacity of the connection to acrylic double-sided tapes for wind suction loading (the case of detaching a sandwich panel from a cold-formed beam).

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