SANDWICH COMPOSITE PANELS WITH GFRP FACE SHEETS – EXPERIMENTAL ANALYSIS, NUMERICAL SIMULATION AND ANALYTICAL SOLUTION

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Abstract. *This paper deals with the problem of analysis of beams made of SCP (sandwich composite panel) composed of GFRP face sheets and foam core. In the frame of research project, several specimens of different compositions were tested by four-point bending according to the actual standard. Nonlinear behaviour was observed in some specimens and possible reasons are discussed in the paper. SCP beams were also numerically simulated using the finite element method in ANSYS Workbench software. For practical and easy engineering design (prediction of deformations and stresses) the analytical procedure was developed for linear and nonlinear behaviour. Results represented by P-Δ and P-σ diagrams of experimental, numerical, and theoretical analysis are compared together in this paper. Based on the analytical solution the parametric study was performed to find out the optimal composition of SCP members for specific static boundary conditions.*

Keywords

Foam core, Four-point bending, GFRP face sheets, Numerical simulation, Parametric study, Sandwich composite panel.

1. Introduction

SCP members (sandwich composite panel) and structural parts made of them are progressive structural materials combining favourable properties of both partial materials of which the SCP is composed. SCP is composed of two facings and a core between them. Generally, face sheets are made of very stiff and strong material in comparison with the core which may be made of polymeric foam or any substructure (honeycomb or similar shapes) [1]. Many applications may be found in automotive and aerospace, but SCP members may be used in various civil engineering structural applications, such as bridge decks, roofs, building floors, for their lightweight, high strength, thermal insulation, high environmental resistance and ease of assembly [2]. For applicability in civil engineering, SCP members should meet the requirements of acoustic insulations and fire resistance [3], [4].

Within the research presented in this paper, the face sheets are made of GFRP material (glass fiber reinforced polymer), the core is made of polyurethane foam. When SCP member is subject to bending, the bending moment is transferred predominantly by facings. In the case when SCP member is subjected to shear, the shear force is transferred predominantly by core. But the overall deformations depend on material parameters and geometry of both materials. At the same time, the foam core ensures the thermal insulation properties of the SCP member. The goal of the research is to find such a combination of properties ("strength classes") of the core and facings and their thicknesses so that SCP member still meets the criteria given for a specific application.

2. Experimental analysis

Experimental analysis was performed to determine the load-bearing capacity and verify the actual behaviour of beams made of SCP according to the EN 14509 ed. 2 [5]. Experimental testing was performed in the Laboratory of the Institute of Metal and Timber Structures of the Faculty of Civil Engineering at the Brno University of Technology.

2.1. Test set-up and materials

In the frame of experimental analysis overall 20 specimens were tested – there were 4 different combinations of used materials – two types of GFRP facings (GFRP sheets produced by GDP KORAL, s.r.o.) and two types of foam core (PUR – polyurethane). Thicknesses of PUR core were 30 mm or 50 mm, thicknesses of GFRP facings were 3 mm in all cases, and overall thicknesses of SCP were 36 mm or 56 mm. The cross-section width was 150 mm and beam length 1000 mm. Tested specimens are listed in Tab.1.

Tab. 1: List of specimens.

Designation	Facing material	Facing thickness	Core material	Core thickness
1+A-30	GFRP 1	3 mm	PUR A	30 mm
1+B-50	GFRP 1	3 mm	PUR B	50 mm
2+A-30	GFRP 2	3 mm	PUR A	30 mm
2+B-50	GFRP 2	3 mm	PUR B	50 mm

Glass fiber reinforced polymer materials signed “1” and “2” in this study were developed by GDP KORAL, s.r.o. and its composition is the know-how of the producer. Young’s modulus is 36 and 40 GPa respectively, and tension and compression strength are 650 and 795 MPa, respectively (the values are 5% fractiles resulting from tests). Poisson’s coefficient is approximately 0.3. These material properties are valid only in longitudinal direction and result from previous research on GFRP. PUR material designation “A” and “B” also do not correspond to the commercial name of that products. Shear modulus G is from 5.3 to 6.3 MPa and from 36 to 45 MPa, respectively, and shear strength f_v is from 200 to 250 kPa and from 1000 to 1300 kPa, respectively, Poisson’s coefficient is 0.4. These material properties were taken from product technical lists provided by the producer.

Experimental testing was performed according to the code [5] with minor modifications forced by a different facings material than is considered in the code (originally the code is intended for testing sandwich panels with metal facings). Four-point bending test was applied on SCP beams (loading forces were situated exactly in thirds of the theoretical span, which was 810 mm), loading was controlled by displacement of electro-hydraulic cylinder piston of speed 5 mm/min. Loading force (F), vertical deflection in mid-span (u_z), and normal stresses on GFRP facings (T_1 and T_2) were measured during the loading test. The experimental set-up is shown in Fig. 1.

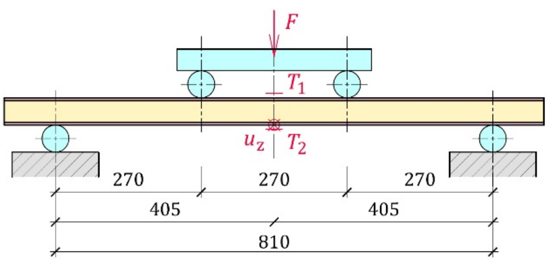

Fig. 1: Experimental set-up.

2.2. Results

The deformed shape of the loaded SCP beam is shown in Fig. 2. The overall shape of SCP beam deformation is given by bending deformation and shear deformation (which is not negligible in this case) together.

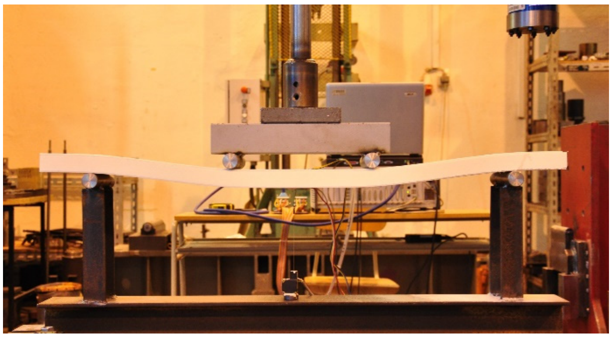

Fig. 2: The deformed shape of specimen 1+A-30_3 during loading test.

The typical failure mode is shown in Fig. 3 – there is the shear failure of the foam polyurethane core in combination with the separation of core and GFRP facings in the area between support and one loading force (where internal shear force arises).

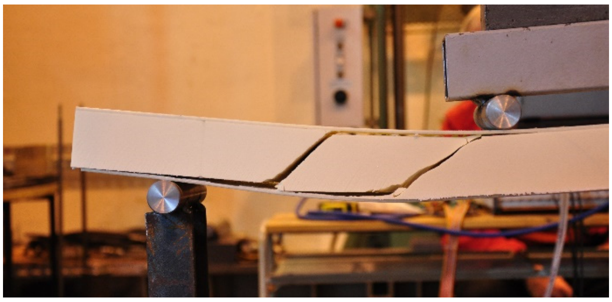

Fig. 3: Typical failure mode (specimen 2+A-50_1).

P-*Δ* diagrams and *P*-*σ* diagrams (which describe relationships between loading forces and deflections and normal stresses) are shown in Fig. 4 and Fig. 5. From the point of view of normal stresses, the behaviour is perfectly linear, but in the case of deformations, there is a significant nonlinearity in specimens made of PUR A (30 mm thick), in specimens made of PUR B (50 mm thick) the nonlinearity is not so significant, but their behaviour is not linear too.

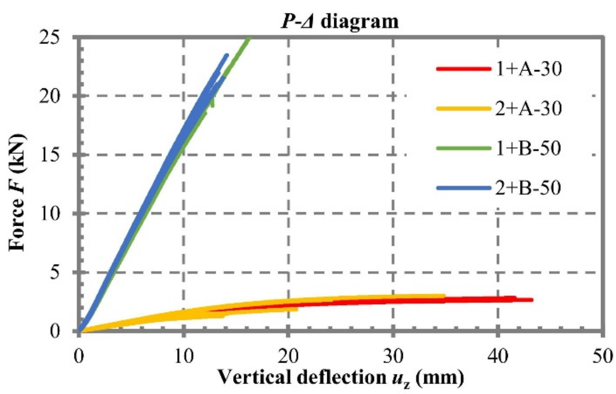

Fig. 4: Experiment results of all specimens - deformations.

The significant difference between results of specimens composed of PUR "A" and "B" is given by (i) significantly different material properties (where "A" material is weaker) and (ii) very different PUR core height (where thickness of "A" core is almost half in comparison with "B" core).

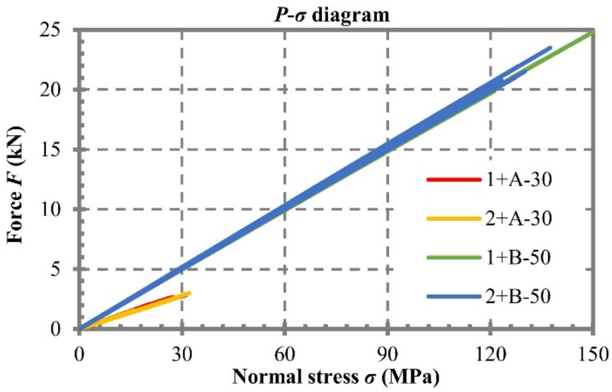

Fig. 5: Experiment results of all specimens – normal stresses.

Shear modulus G and shear strength f_v of foam PUR core was obtained from data measured during tests according to [5] using Eq. (1) and Eq. (2) respectively:

$$G = \frac{\Delta F \cdot L}{6 \cdot A_c \cdot \Delta w_s}, \tag{1}$$

$$f_v = k_v \cdot \frac{F_{max}}{2 \cdot b \cdot h_c}, \tag{2}$$

where ΔF is force increase (N), Δw_s is shear deflection increase (mm), L is theoretical span, A_c is foam core cross-sectional area, F_{max} is maximal force reached during the test, b is cross-section breadth, h_c is foam core height and k_v is reduction factor taking into account the production process of foam core (in our case = 1.00). Force increase and shear deflection increase are measured in the loading interval of vertical deflection from 1.0 mm to 5.0 mm, so it is still in the linear part of the P-Δ diagram.

2.3. Statistical evaluation

Experiment results were statistically evaluated according to annex D of EN 1990 [6]. Mean values and 5% fractiles are listed in Tab. 2.

Tab. 2: Statistical evaluation of experimental results.

Designation	Shear modulus G (MPa)		Shear strength f_v (kPa)	
	Mean value	5% fractile	Mean value	5% fractile
1+A-30	5.78	4.84	289	201
1+B-50	94.6	87.5	1410	930
2+A-30	5.53	3.64	231	39
2+B-50	92.9	84.3	1460	1300
1/2+A-30	5.88	4.98	297	223
1/2+B-50	93.8	81.1	1440	1150

Statistical evaluation was carried out for four different compositions of SCP beams and for two larger groups with the same material of core (PUR A or PUR B), because the material properties of GFRP facings (GFRP 1 or GFRP 2) are not very different, so groups 1+A-30 and 2+A-30 were put together in new group 1/2+A-30 (the same applies for core material B). Coefficients of variation vary from 0.08 to 0.12. Values of shear modulus G and shear strength f_v evaluated from experiments correspond to the properties offered by PUR producer which were mentioned above. It should be mentioned that the difference between resulting values is not influenced by PUR core thickness, it is due to difference in material properties.

3. Theoretical and numerical analysis

As the goal of the research is to develop and evaluate the theoretical solution and numerical solution (FEA) to predict the behaviour of SCP members, the analytical approach and numerical approach were developed on the same set-up as for experimentally tested SCP beams. Material properties used for theoretical and numerical analysis were taken from previous tests (in the case of GFRP facings) and as a result of this research (in the case of PUR core).

3.1. Theoretical analysis

As part of the analytical solution, procedures for determining the load-bearing capacity and deformability of sandwich panels according to the theory of elasticity and plasticity are proposed. The bending stress distribution in the SCP panels (shown in Fig. 6) can be determined based on the transformed-section method when the foam core cross-section is transformed into an equivalent cross-section of GFRP composite material. The transformation is performed using the parameter n, which is defined as the ratio of the modulus of elasticity of the facing material E_{GFRP} to the modulus of elasticity of the foam core E_{PUR}.

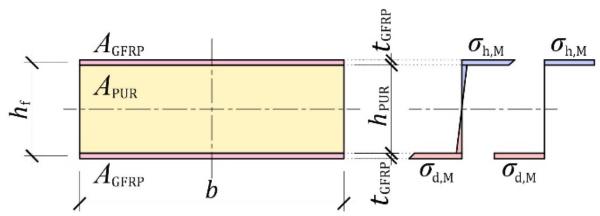

Fig. 6: Bending stress distribution in the composite cross-section.

Since the majority of the bending stress is transmitted by the GFRP facings, for simplicity the contribution of the foam core in bending can be neglected and the stress can be calculated according to Eq. (3).

$$\sigma_M = \pm \frac{M / h_f}{A_{GFRP}} \tag{3}$$

where M is bending moment (Nmm), h_f is the distance between centroids of GFRP facings (mm) and A_{GFRP} is the cross-sectional area of one GFRP facing (mm^2).

When determining the deformation (deflection) of beams, in addition to bending, it is necessary to consider the effect of shear (shear forces). For the case of a simply supported beam loaded by a pair of concentrated loads in thirds of the beam span (experimentally investigated case), the total deflection of the beam w can be determined according to Eq. (4) as the sum of bending deflection w_M (see top scheme in Fig. 7) and shear deflection w_S (bottom scheme in Fig. 7).

$$w = w_M + w_S = \frac{23}{648} \cdot \frac{F/2 \cdot L^3}{E_{GFRP} \cdot I_i} + \frac{1}{6} \cdot \frac{F \cdot L}{G_{PUR} \cdot A_{PUR}} \tag{4}$$

where F is concentrated load (N), L is theoretical span (mm), E_{GFRP} is Young's modulus of facings, G_{PUR} is the shear modulus of core, I_i is a moment of inertia of equivalent (ideal) cross-section (mm^4) and A_{PUR} is the cross-sectional area of core (mm^2).

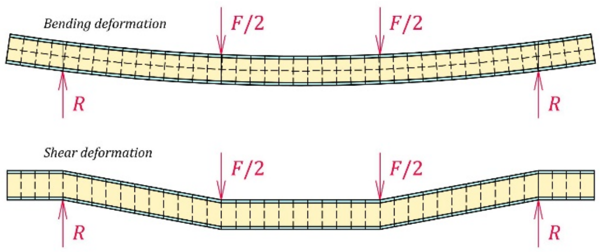

Fig. 7: Vertical deflections of SCP beam due to bending and shear.

This theoretical solution is applicable for nonlinear core behavior too. The dependence of core shear modulus G on shear stress in core τ was evaluated from experimental results. This dependency was taken as input data for a nonlinear theoretical solution. A detailed derivation of the nonlinear G-τ relation was first proposed in [8] and is plotted in Fig. 8 and Fig. 9 for core material PUR "A" and PUR "B". The approximation is bilinear curve according to the tangent shear modulus of the PUR core and shear stress of the PUR core dependency.

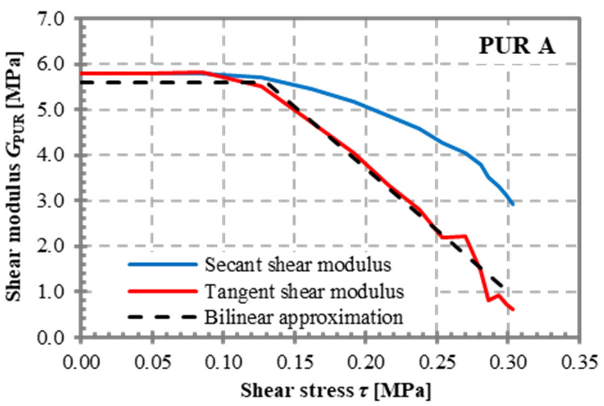

Fig. 8: Determination of G-τ relation – PUR A.

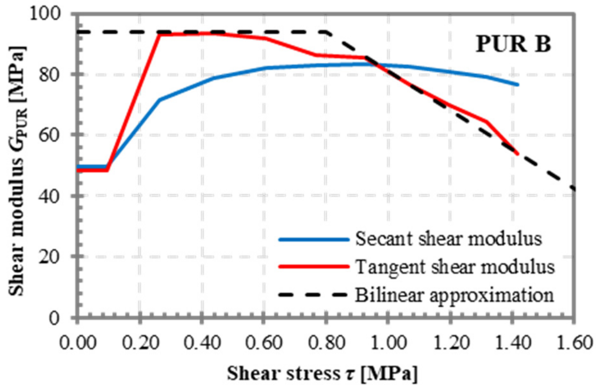

Fig. 9: Determination of G-τ relation – PUR B.

The principle of nonlinear analytical solution is based on increment method – at each load step all values of stresses and deformations are calculated (normal stress in GFRP sheets, shear stress in PUR core, bending and shear deflections and shear stress τ). Once the nonlinear relation G-τ is known, the shear modulus of the PUR core is determined for calculation in the next load step.

3.2. Numerical analysis

Numerical analysis of beams made of SCP was performed in ANSYS Workbench 19.2 software [7], which is based on the finite element method. Material models used in the numerical analysis were linear, because of the difficulty of determining correct input material properties from experimental testing results – PUR foam core material is not isotropic linear material and there is no known relation to calculating shear material properties and bending material properties among themselves.

Solid models were created so that each layer of the SCP beam is represented by one volume. Finite element mesh was composed of 20-node bricks SOLID186 for GFRP and PUR volumes. The number of elements across the thickness was 4 for GFRP facings and 8 for PUR core, in the cross direction there were 10 elements and in the longitudinal direction, the length of the element was set to 20 mm. Supporting and loading members were modelled using tetrahedrons of SOLID186 and material properties correspond to structural steel. The problem is symmetrical, so only half of the beam and one supporting member, and one loading member are modelled with corresponding boundary conditions applied on the plane of symmetry.

Contacts between core and facings were set on "bonded" to ensure full force and stress transfer between these parts, as it is in real behaviour. Contacts between steel members and facings were set on "frictional" with a frictional coefficient of 0.1. Geometrically nonlinear analyses according to the large deformations theory were performed in 20 load substeps. The finite element model is shown in Fig. 10.

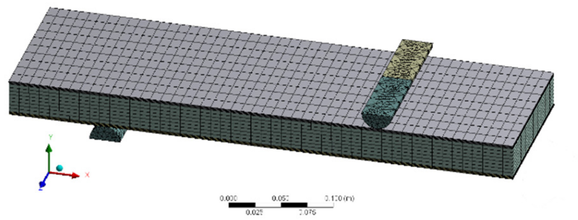

Fig. 10: FEA model with finite element mesh.

Normal stress distribution on GFRP facings is plotted in Fig. 11. In general, the upper facing is compressed and the lower facing is tensioned as it may be imagined using the theory of elasticity. But local bending in regions at supports and where the loading was applied is visible on the stress plot. It is caused by great shear deformations between supporting and loading members and zero shear deformations in the middle part and out of the supports – the shear discontinuity leads to local bending discontinuity.

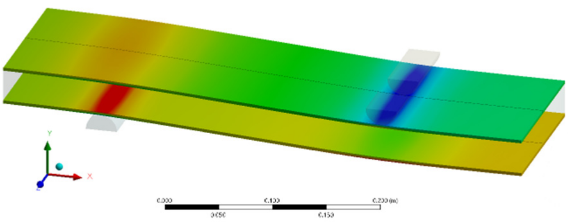

Fig. 11: FEA results – normal stress distribution on GFRP facings.

Shear stress distribution on the PUR core is plotted in Fig. 12. Numerical results confirmed the theoretical assumption that shear occurs only between the supporting member and loading member and in the middle part and out of the supports there is zero shear.

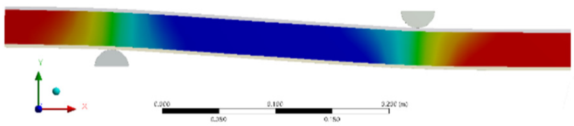

Fig. 12: FEA results – shear stress distribution on PUR core.

The nonlinear material model was not used because of unknown material properties required as input for numerical models – input property is *E*-*σ* dependency and as PUR core is not pure elastic isotropic material, the determination procedure to transfer from *G*-*τ* dependency to *E*-*σ* dependency is not known.

3.3. Comparison of results

To evaluate the accuracy and precision of the theoretical approach and validate the numerical analysis, a comparison of obtained results was performed. Comparison is shown in Fig. 13 for SCP composition 1+A-30 and in Fig. 14 for composition 2+B-50. In the first case, *P*-*Δ* diagram is plotted and in the second case, the *P*-*σ* diagram is plotted. Red curves describe experiments, and blue curves represent theoretical solution when the blue solid line is for the linear material model and the blue dashed line is for the nonlinear material model. The green line characterizes numerical solution in ANSYS.

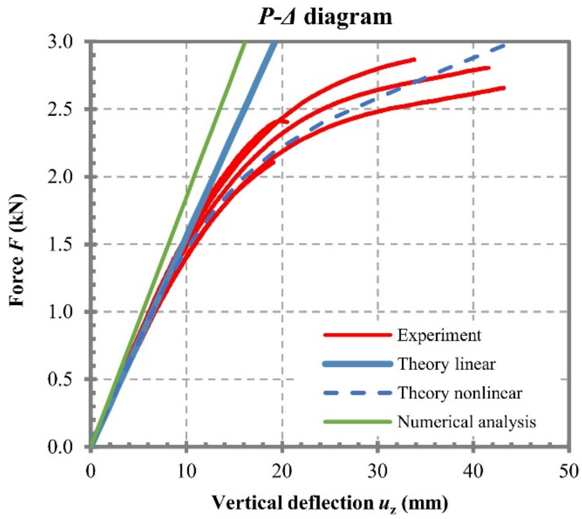

Fig. 13: Comparison of experimental analysis, numerical analysis, and theoretical analysis: 1+A-30 composition.

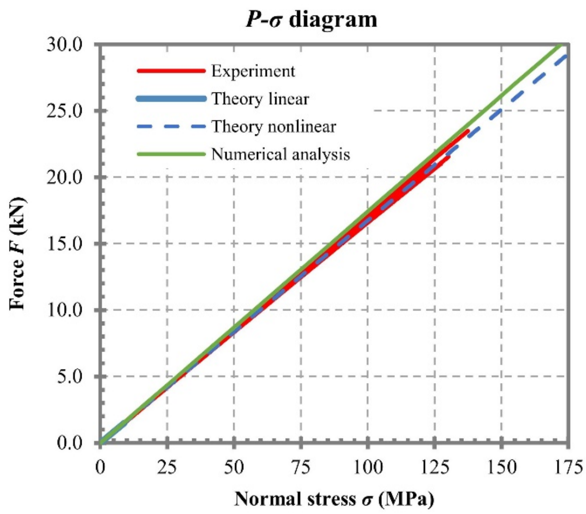

Fig. 14: Comparison of experimental analysis, numerical analysis, and theoretical analysis: 2+B-50 composition.

From the comparison of *P*-*Δ* diagrams it is obvious that both numerical and linear solutions are correct in the linear part of actual diagrams resulting from experiments. In the case of SCP composition with PUR B nonlinear behaviour is not significant so the simplified solution of deflections may be used in the whole spectre of design resistance. But in the case of composition with PUR A, the nonlinearity is not negligible and the solution according to the linear material model is not valid in the whole spectre.

The dependence of normal stresses in GFRP facings on applied load is linear, which means that from this point of view the simplified approach is valid and may be used.

4. Parametric study

In the frame of research on SCP beams, a simple parametric study was performed to get a wider view of actual behaviour of SCP members and to determine the effect of components on overall deflections and stresses. A parametric study was performed using table processor MS Excel and previously determined linear theoretical solution. It should be noted that only the linear behaviour of SCP was taken into account. Selected results of the parametric study are presented in the next charts.

4.1. Influence of components thicknesses

In the first step, a parametric study was carried out on the same SCP beam that was experimentally tested, numerically simulated and the theoretical solution was determined for them. Composition "1+A-30" was chosen for this study

Solution and results of study are valid for next input parameters: Young's modulus of GFRP face sheets E_{GFRP} = 36 GPa; shear modulus of PUR core G = 5.6 MPa; Poisson's coefficient of core ν_{PUR} = 0.4; theoretical beam span L = 0.81 m with concentrated forces in thirds of magnitude F = 1.5 kN each; section breadth b = 0.15 m. PUR core thickness t_{PUR} and GFRP facings thickness t_{GFRP} are variable in this part of the study with the goal to find out the influence of these two parameters. Core thickness varies from 10 mm to 100 mm in steps of 10 mm and face sheets thickness varies from 1 mm to 10 mm in steps of 1 mm, so there are 100 different combinations of parameters.

Figure 15 shows values of overall deflection (including bending deflection and shear deflection). Value of shear deflection is constant for all values of facings thicknesses and deflection due to bending strongly depends on core thickness, because of the moment of inertia is influenced by it, face sheets thickness influencing bending stiffness too, and how strong it depends on core thickness – see Eq. (4)

u (mm)		PUR core thickness t_{PUR} (mm)									
		10	20	30	40	50	60	70	80	90	100
GFRP facings thickness t_{GFPR} (mm)	1	134.5	47.82	26.95	18.27	13.66	10.84	8.96	7.61	6.61	5.84
	2	84.26	34.90	21.18	15.02	11.58	9.40	7.90	6.80	5.97	5.32
	3	68.52	30.67	19.27	13.94	10.88	8.91	7.54	6.53	5.76	5.15
	4	61.23	28.61	18.33	13.40	10.54	8.67	7.37	6.40	5.65	5.06
	5	57.20	27.42	17.77	13.08	10.33	8.53	7.26	6.32	5.59	5.01
	6	54.73	26.65	17.41	12.87	10.20	8.44	7.19	6.26	5.55	4.98
	7	53.12	26.12	17.15	12.73	10.10	8.37	7.14	6.22	5.52	4.95
	8	52.01	25.73	16.97	12.62	10.03	8.32	7.10	6.20	5.49	4.93
	9	51.22	25.45	16.82	12.53	9.97	8.28	7.07	6.17	5.48	4.92
	10	50.63	25.23	16.71	12.47	9.93	8.25	7.05	6.16	5.46	4.91

Fig. 15: Parametric study on 1+A-30: overall vertical deflections.

Figure 16 shows how shear deflections influence overall vertical deflections. The ratio of shear deflection to overall deflection approximately corresponds to the deflections due to bending, which is strongly dependent on input parameters.

w_s/w		PUR core thickness t_{PUR} (mm)									
		10	20	30	40	50	60	70	80	90	100
GFRP facings thickness t_{GFPR} (mm)	1	0.36	0.50	0.60	0.66	0.71	0.74	0.77	0.79	0.81	0.83
	2	0.57	0.69	0.76	0.80	0.83	0.86	0.87	0.89	0.90	0.91
	3	0.70	0.79	0.83	0.86	0.89	0.90	0.91	0.92	0.93	0.94
	4	0.79	0.84	0.88	0.90	0.91	0.93	0.94	0.94	0.95	0.95
	5	0.84	0.88	0.90	0.92	0.93	0.94	0.95	0.95	0.96	0.96
	6	0.88	0.90	0.92	0.94	0.95	0.95	0.96	0.96	0.97	0.97
	7	0.91	0.92	0.94	0.95	0.95	0.96	0.96	0.97	0.97	0.97
	8	0.93	0.94	0.95	0.96	0.96	0.97	0.97	0.97	0.98	0.98
	9	0.94	0.95	0.96	0.96	0.97	0.97	0.97	0.98	0.98	0.98
	10	0.95	0.96	0.96	0.97	0.97	0.97	0.98	0.98	0.98	0.98

Fig. 16: Parametric study on 1+A-30: ratio of shear deflection to overall deflection.

Normal stresses on face sheets are strongly influenced by foam core thickness and also by face sheets thickness. Shear stress in foam core is influenced by only core thickness.

4.2. Influence of core shear modulus

Here the goal of the study is to evaluate the influence of core shear modulus on overall SCP member behavior. In comparison to the previous study only one variable parameter was changed – PUR core shear modulus which varies from 2 MPa to 500 MPa in ten non-constant steps. This range of values was chosen as a real range of material properties of PUR material which could be used in SCP members. GFRP face sheets thickness was set at 3 mm. Other input parameters remained unchanged. Since the nonlinear G-τ relations where known only for the experimentally investigated PUR core materials, the linear analyses were performed in the parametric studies only.

Figure 17 shows vertical deflection due to shear force. It is clear that an increase of shear modulus leads to a decrease of deflection and in the same way it is valid for core thickness. In both cases the dependency is strictly linear – see Eq. (4). Vertical deflection due to bending is almost independent on core shear modulus since bending effects are transmitted almost in full range by facings.

w_S (mm)		PUR core thickness t_{PUR} (mm)									
		10	20	30	40	50	60	70	80	90	100
PUR shear modulus G (MPa)	2	135.0	67.50	45.00	33.75	27.00	22.50	19.29	16.88	15.00	13.50
	5	54.00	27.00	18.00	13.50	10.80	9.00	7.71	6.75	6.00	5.40
	10	27.00	13.50	9.00	6.75	5.40	4.50	3.86	3.38	3.00	2.70
	20	13.50	6.75	4.50	3.38	2.70	2.25	1.93	1.69	1.50	1.35
	30	9.00	4.50	3.00	2.25	1.80	1.50	1.29	1.13	1.00	0.90
	40	6.75	3.38	2.25	1.69	1.35	1.13	0.96	0.84	0.75	0.68
	50	5.40	2.70	1.80	1.35	1.08	0.90	0.77	0.68	0.60	0.54
	100	2.70	1.35	0.90	0.68	0.54	0.45	0.39	0.34	0.30	0.27
	200	1.35	0.68	0.45	0.34	0.27	0.23	0.19	0.17	0.15	0.14
	500	0.54	0.27	0.18	0.14	0.11	0.09	0.08	0.07	0.06	0.05

Fig. 17: Parametric study on the influence of core shear modulus: shear deflection.

The ratio of shear deflections to overall deflections is plotted in Fig. 18. As the relation of shear deflections and shear modulus and core area (core thickness) are linear, the nonlinear variability in the chart is caused by the nonlinear dependency of bending deflection on core thickness in the horizontal direction, and in the vertical direction it is caused by non-constant steps of core shear modulus.

w_s/w		PUR core thickness t_{PUR} (mm)									
		10	20	30	40	50	60	70	80	90	100
PUR shear modulus G (MPa)	2	0.87	0.91	0.93	0.95	0.96	0.96	0.97	0.97	0.97	0.98
	5	0.73	0.80	0.85	0.88	0.90	0.91	0.92	0.93	0.94	0.94
	10	0.57	0.67	0.74	0.78	0.81	0.84	0.86	0.87	0.88	0.89
	20	0.40	0.51	0.59	0.64	0.69	0.72	0.75	0.77	0.79	0.81
	30	0.31	0.41	0.48	0.55	0.59	0.63	0.66	0.69	0.71	0.73
	40	0.25	0.34	0.41	0.47	0.52	0.56	0.60	0.63	0.65	0.68
	50	0.21	0.29	0.36	0.42	0.47	0.51	0.54	0.58	0.60	0.63
	100	0.12	0.17	0.22	0.27	0.31	0.34	0.38	0.41	0.44	0.46
	200	0.06	0.09	0.13	0.16	0.18	0.21	0.24	0.26	0.28	0.31
	500	0.03	0.04	0.06	0.07	0.09	0.10	0.12	0.13	0.15	0.16

Fig. 18: Parametric study on the influence of core shear modulus: ratio of shear deflection to overall deflection.

Normal stress on face sheets is strongly influenced by foam core thickness and only slightly (almost negligibly) by foam core shear modulus. Shear stress in foam core is influenced by only core thickness (same as in the previous study).

5. Discussion

One of the important (and surprising) finding is the nonlinear behaviour observed in experimental solution and only for deflections. The relationship of normal stress and loading force is perfectly linear. The nonlinearity is relatively small in SCP compositions 1/2+B-50 and relatively large in compositions 1/2+A-30. This nonlinearity could be caused by more reasons, but probably it is caused by foam core and its material characteristics. As the GFRP facings behaviour is perfectly linear (as it was proved in previous tests made in the frame of the research program), the layer of glue joining GFRP facings ad PUR core together is very small and deflections increasing is faster with loading force increase, these effects do not cause the nonlinearity. Unfortunately, the producer of PUR core does not offer detailed information about deformation characteristics or P-Δ diagrams.

An interesting point of the research is to define and predict shear deflections of SCP members. Shear deflections are caused by shear deformation of small element subjected to shear force. The simplified illustration of shear deformation is that edge lines of the small element are still straight after loading and only angles between edges are changed. But actually, there are dependent deformations of edge lines between the next elements so this effect is commonly taken into account by replacement of shear stiffness GA by GA^* where A^* is reduced shear area (different theoretical approaches lead to different value of reduction factor, e.g. 5/6 for rectangle may be commonly used). Results of finite element analysis show that there is no need to reduce the shear area of the core to obtain correct results. Even the standard [1] does not use the reduced area for evaluation of experimental results – see Eq. (1).

Parametric study on the influence of variable input parameters does not give surprising results since the relations between input parameters and resulting stresses and deflections are well known. But obtained results and conclusions may be interesting, for example, the same shear deflection is obtained for foam core 100 mm thick from $G = 2$ MPa material or for foam core 10 mm thick from $G = 20$ MPa material.

6. Conclusion

In the frame of study on sandwich composite panel members experimental testing, numerical simulations, and theoretical analysis were performed. Parametric study was also carried out. Twenty specimens were tested by four-point bending, results were evaluated and used as input parameters for numerical simulations or theoretical investigations. An interesting observation was the strongly nonlinear behaviour of SCP beams made of weak foam core material in comparison of not so nonlinear behaviour of SCP members made of the tougher core material. Possible causes of this nonlinear behaviour was discussed. Based on test results the nonlinear theoretical solution was developed and the results give good agreement with the experiment.

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