MECHANICAL PROPERTIES OF THERMAL INSULATING SANDWICH MATERIALS

Petr Valasek, Petr Chocholous, Miroslav Muller
Czech University of Life Sciences Prague
valasekp@tf.czu.cz, muller@tf.czu.cz

Abstract. Sandwich materials are materials consisting of a filling with low density, which is rigidly coupled to the two fixed plates. The sandwich materials consist of materials with different mechanical characters coupled so that this arrangement creates advantageous properties for the construction as a whole. This paper deals with bonded sandwich materials. The aim of the experiment was to evaluate interaction between the layers and determine the behavior and compressive properties of the sandwich materials under load. The experiments described in this paper confirm the suitability of the proposed method and testing device for determination of the compressive properties of the sandwich materials with polyurethane core and with sandwiches with different composition (honeycomb core) as well. The results may be used for design and construction of sandwich systems.

Keywords: axially loading conditions, bonding technology, manufacturing, polyurethane.

Introduction

In the last ten years the bonding technology and related research of adhesives and their properties have been developed rapidly. The manufacturing process is different in various industries, but usually it has one common element and that is cutting and joining materials [1]. Adhesive bonding technology is an increasingly used process of material joining. The advantage of adhesive bonding is a possibility to join together two or more materials with different thicknesses or with different chemical and physical properties. One of the major applications of the adhesive bonding technology are sandwich structures – sandwich materials. These materials excel in their wide usage in many industry areas. In many cases sandwich materials are able to satisfy wide range demands of designers and engineers. The sandwich materials are made of several materials what are divided into coating materials (faces) and filler materials (cores). These materials have different properties and they are bonded together with the adhesive. By combining the properties of these materials a sandwich material arises, the final characteristics of which are given by synergistic sum of the properties of the coating and filling materials. A similar synergistic effect is achieved with composite materials what combine the properties of the filler and matrix [2].

The design, construction and composition of layers of the sandwich materials depend on the application for what these materials are intended. There are many ways of classification sandwich materials but the most important is distribution according to the type of the filling material. [3] When honeycomb cores are used, sandwich materials achieve high compressive and bending strength together with low weight. These properties are used in construction of aircrafts and vehicles. Each saved kilogram on the vehicle reduces the consumption of fuel and increases its power. When using a thermal insulating material as a core like polyurethane, polystyrene or mineral wool, we receive a sandwich material with excellent thermal insulating properties together with low total weight of the bonded structure. The polyurethane foam as a filling material has thermal conductivity lambda ($\lambda = 0.02$ W·m^{-1}·K^{-1}) many times smaller than the conventional materials. A unique advantage of polyurethane foam is in its production, when wide variety of materials can be produced. Changing the ratio of incoming chemicals polyols, isocyanates and additives can create foam in a wide range of densities from 6 to 1220 kg·m^{-3} and in various forms from flexible elastomer to hard rigid plastic [4].

Sandwich materials are very often produced by using the bonding technology in hydraulic or pneumatic presses during the curing process. For proper and safe application of sandwich materials it is necessary to perform appropriate tests that define the behavior and quantify properties of these materials.

Materials and methods

For the experiment sandwich materials from the manufacturer PSP izoterm s.r.o. (polyurethan sandwich panels) were used. The company uses these materials for construction of truck bodies and for construction of small industrial facilities such as gatehouses and habitable containers. To determine the suitability of the designed method different sandwich materials with different properties and usage

from other manufactures were used. The characteristic properties of sandwich materials are described below. The obtained values were statistically evaluated and the *F*-test for variances and t-test for calculated value were used (significance level chosen p-value 0.05). Each test series was made of six test specimens.

Testing equipment

The testing equipment (Fig. 1) consists of a universal testing machine LabTest 5.50ST with connection to PC and the apparatus allows testing specimens by perpendicular compressive force. The design of the testing method simulates load of the sandwich material in certain applications. The design of the method and the fixing apparatus were made by the team of the authors.

Fig. 1. **Testing equipment:** 1 – testing machine; 2 – fixing apparatus; 3 – specimen

As a filler material polyurethane foam with density 35 kg·m^{-3} (PUR 35) was used. As cover materials birch plywood and fiber glass sheets with different thicknesses were used. These sandwich materials were bonded by using two-component polyurethane adhesive SikaForce 7723 L175. The curing process took place in the vacuum press. Dimensions of the specimens were determined according to construction of the fixing apparatus and the testing machine. Several different specimens with different composition were prepared. The aim of the experiment was to determine the influence of the cover materials such as thickness of fiber glass sheets and thickness of birch plywoods on compressive stress. For wider range assessment of suitability of the designed testing method other sandwich materials with different properties from other manufactures were used. Materials with filler materials consist of styrofoam, polycarbonate triangular honeycombs and hexagonal honeycombs, cover materials consisting of fiberglass sheets with different thicknesses were used for testing. In case of the sandwich materials with polyurethane core, different widths of specimens were used for determination of the influence of the specimen width on behavior of the sandwich materials under load. The slenderness ratio was the same for both dimensions. The dimensions and composition of the specimens for testing are stated in Table 1.

Table 1

Dimensions and composition of testing specimens

Core	Faces	Thickness, mm	Width, mm
PC honeycomb	Fiberglass 2 mm	17	300
Honeycomb	Fiberglass 1.3 mm	18	300
Styrofoam	Fiberglass 1.6 mm	24	300
PUR 35	Fiberglass 1.5 mm	35	300
	Fiberglass 1.5 mm	35	50
	Fiberglass 2.0 mm	35	300
	Fiberglass 2.0 mm	35	50
	Fiberglass 1.5 mm + Plywood 4 mm	35	300
	Fiberglass 1.5 mm + Plywood 4 mm	35	50
	Fiberglass 1.5 mm + Plywood 9 mm	35	300
	Fiberglass 1.5 mm + Plywood 9 mm	35	50

Note: Fiberglass 1.5 mm (FIB), Fiberglass 2 mm (FIB2), Plywood 4 mm (PL4), Plywood 9 mm (PL9)

Test procedure

Before the test the specimens were measured and subsequently placed symmetrically into the fixing apparatus of the testing machine. The maximum value of the load was reached in 300 ± 120 seconds after the test starts. After the test, the critical force, the transom movement, type and mechanism of destruction were noticed. From the measured values the tension when the specimen lost stability characterized by deviation of the specimen from the vertical axis was calculated. According to formula (1) the compressive stress was calculated.

$$\sigma_{vz} = \frac{F\max}{A_0},$$
(1)

where σ_{vz} – compressive stress, MPa;
$F_{\max}$ – maximum force when the specimen lost stability, N;
A_0 – cross section of the specimen, mm^2.

Results and discussion

The experiment was carried out to confirm the suitability of the designed method and for determination of the influence of the cover materials thicknesses. The length of the specimens was same in all cases. In Fig. 2 the compressive stress and maximum force are shown when the specimen lost stability what is characterized by the specimen deflection from the vertical axis. The maximum force in Fig. 2 clearly shows positive influence of the higher cover and reinforcing layer thickness on the strength properties with the same thickness of the test specimens. Change of the fiber glass thickness from 1.5 mm to 2 mm leads to increase of the compressive stress up to 24%. Increase of the reinforcing layer form 4 mm to 9 mm leads to change of the compressive stress up to 62%.
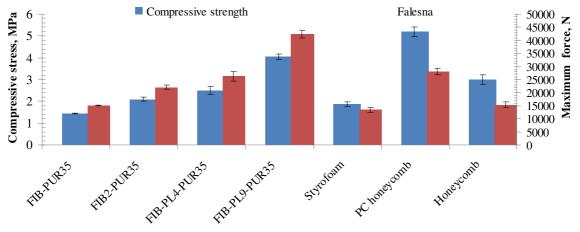

Fig. 2. **Compressive stress and maximum force**

The sandwich materials are not loaded by pressure (buckling) as conventional steel rods in trusses, where the slenderness ration must be higher over the value 100, so deformation of the test specimen is in elastic buckling. The sandwich materials are used in the form of boards and panels (two dimensions of the material are larger than its thickness). To verify the behavior of thermal insulation panels under buckling, identical test specimens with different widths were made. Instead of the original width 300 mm, the test specimens with width 50 mm were used. Slenderness ration of the used specimens reached the value 79 in both cases. This experiment was used to determine the influence of the width of the test specimens on the compressive properties. The following Fig. 3 graphically displays the calculated compressive stress of the test specimens with the same thickness and length but different widths.

Conformity or difference in the compressive stress of the test specimens with different widths was evaluated by the statistical method. Zero hypothesis was stated that the values obtained from measures of specimens with different widths are comparable (H_0: $\mu 1 = \mu 2 = \mu 3$) on p-level 0.05. Calculated statistical data of the F-test and T-test are shown in Table 2. Graphical interpellation shows that dispersion of the measured file is slightly different but zero hypothesis cannot be declined and with

95 % conformity it can be stated that specimen width does not have influence on the compressive stress and the results obtained by different widths of specimens are comparable.
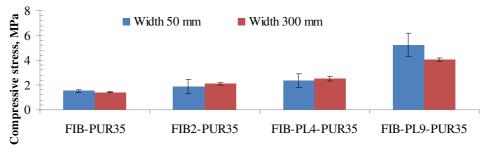

Fig. 3. **Compressive stress assessment of test specimens with different widths (50 and 300 mm)**

Fig. 4 shows characteristic stress diagrams, where the curves describe the loading force depending upon the crosshead shift. Trend and shape of the curves were similar for the specimens with widths 50 and 300 mm. That confirms the hypothesis that specimens with different widths have comparable values of the compressive stress. The sandwich materials with fiberglass and polyurethane composition had a curve characterized by initial linear rising of load until the specimen lost stability. Subsequently, there was rapid decrease of the loading force and rising deflection of the specimen from the vertical axis (Fig. 4-a). Such as in case of bend load destruction of the specimen occurred at the interface of fiberglass and polyurethane foam (delamination) together with rupture of the polyurethane core (Fig. 5-a). [5] Fig. 4-b) shows the stress diagram for the specimens made of polyurethane foam, fiberglass and plywood. After initial rapid increase, maximum (critical) force was reached when the specimen lost stability. When increasing deformation first rupture of the individual layers of plywood has occurred what is represented by a sudden drop in the stress diagram. Subsequently, destruction at the interface of materials and rupture of polyurethane foam have occurred (Fig. 5-b). The specimens composed of laminate, plywood and polyurethane foam had the stress diagram shown in Fig. 4-b).
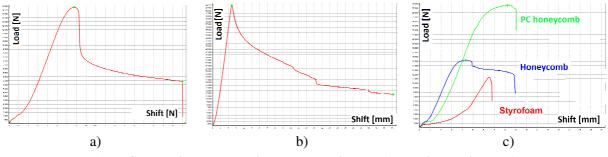

| a) | b) | c) |

Fig. 4. **Stress diagrams during compressive test (buckling resistance)**

Table 2

Results of F-test and t-test for values of compressive stress of specimens with different

F-test: H_0: $\sigma_1^2 = \sigma_2^2$, ($p > 0.05$) **T-test: H_0: $\mu 1 = \mu 2 = \mu 3$, ($p > 0.05$)**	**F-test**	**t-test**
FIB-PUR35	0.069	0.267
FIB2-PUR35	0.042	0.653
FIB-PL4-PUR35	0.203	0.752
FIB-PL9-PUR35	0.045	0.230

The test specimens made of styrofoam, PC honeycomb and honeycomb showed a completely different trend of the load than the sandwich materials with the polyurethane core what is shown in Fig. 4-c). Unlike the sandwich materials with polyurethane core, these materials do not show initial linear increase. After the load reached the maximum (critical) force, the specimens lost stability and consequently the loading force decreased. Sandwich materials with honeycomb create distortions in the shape of "S" (Fig. 5-c). For the material with PC honeycomb core failure occurred in destruction of individual walls of the honeycomb and delamination at the interface honeycomb / fiberglass faces. In the case of the material styrofoam, rupture of fiberglass faces leads to subsequent delamination at the interface of the core / face material (Fig. 5-d).
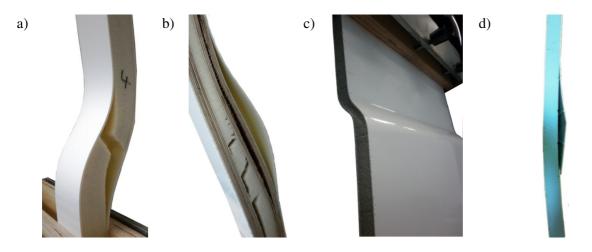
Fig. 5. **Types of destructions after compressive test (buckling resistance)**

Conclusions

The sandwich materials allow a useful bonded connection of dissimilar materials, where convenient properties of individual layers are used. Sandwich structures provide cheaper and faster production of many products. The sandwich materials are inhomogeneous substances (several dissimilar layers), where tension is spreading in different ways than in homogeneous materials. That is the reason that it is necessary to carry out relevant experiments for proper and safe usage of these materials. With suitable composition of the material layers sandwiches became to be self-supporting. The experiments confirmed the suitability of the proposed method and testing device for determination of the compressive properties of the sandwich materials with polyurethane core and with sandwiches with different composition (honeycomb core) as well. The results may be used for design and construction of sandwich systems. The results of the experiments can be summarized as follows:

1. Maximum load was achieved when the specimen lost stability what is characterized by deflecting the material from the vertical axis,
2. The width of the specimens has not a statistically significant effect on the values of the compressive stress and the compressive stresses obtained with the specimens of different widths are comparable,
3. Increasing the thickness of the coating materials (laminate) and the reinforcing layers (plywood) increases the final compressive stress,
4. Initiation of specimen failure occurs at the interface between two materials (the adhesive layer delamination) together with subsequent rupture of the filler and the coating materials.

Acknowledgement

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