

Experimental and Numerical Study of Impact Energy Absorption of Safety Important Honeycomb Core Sandwich Structures

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The experimental investigation of deformation behaviour of sandwich structures with honeycomb core was carried out in the cases of quasi-static and dynamic loading in this study. According to these results the numerical models were validated and the numerical modelling by finite element method of sandwich structures behaviour under impact loading was performed. The influence of geometrical parameters on the dynamical behaviour of sandwich structure was evaluated and the dependences of them upon dynamical properties of layered structure were carried out. In this study, the behaviour under impact loading of the sandwich composite made from woven glass fiber and polyvinylester resin composite facesheets and polypropylene hexagonal honeycomb core that can be used for safety important structures was investigated and the layered structure dynamical properties associated with energy absorption and impact loading suppression. Obtained impact energy absorption and impact loading suppression dependences of various structure geometric parameters allow the assessment and the prediction of sandwich structures safety important parameters under impact loading and the ensuring the efficient material expenditures.

Keywords: honeycomb, sandwich composite, impact, energy absorption, numerical modelling.

1. INTRODUCTION

The use of sandwich structure consisting of thick honeycomb core and thin laminated composite facesheets is prevailed in safety important objects such as aircrafts, transport means, vessels and pipes of a safety important class due not only to the various advantages in terms of stiffness, stability and weight savings, but the good energy absorption under impact, also.

Sandwich composites are widely used in lightweight construction in aerospace industries because of their high specific strength and stiffness [1]. In the service life of a sandwich panel, impacts are expected to arise from a variety of causes. Debris may be propelled at high velocities from the runway during aircraft takeoffs and landings. Other examples include tools dropping on the structure during maintenance or even collisions by birds. That loading cases were investigated by C. C. Foo et al. [2]. Visual inspection may reveal little damage on the sandwich panel, but significant damage may occur between the impacted facesheet and the core. Reduction of structural stiffness and strength can occur, and consequently, propagate under further loading. Their behaviour under impact is an important problem.

Tank cars carrying hazardous materials accidents that lead to rupture can cause serious public safety dangers. D. Tyrell et al. [3] investigated improving of tank car designs that are better equipped to keep the commodity contained during impacts. Authors presented a framework for developing strategies to maintain the structural integrity of tank cars during accidents. A conceptual design that can protect its lading at twice the impact speed of current equipment in the car-to-car impact scenarios was developed. Alternative means of absorbing impact energy

suggested by authors are the use of plastic foams, aluminium honeycomb, and steel sandwich structures.

The carbody of tilting train was developed using a hybrid design concept combined with a sandwich composite structure for bodyshell and a stainless steel structure for the under frame to match the challenging demands with respect to cost efficient lightweight design for railway carriage structures [4]. These components have to sustain considerable external forces without undergoing any local failure or critical deformation to guarantee safety of passengers.

A new concept of thermoplastics sandwich structure for extrusion-welded storage tanks was developed by E. Lagardere et al. [5]. It consists of a fibre-reinforced core (glass/polypropylene) and of neat polypropylene facesheets. Compared to regular neat polypropylene tanks, this sandwich structure provides improved impact resistance at low temperature, reduced creep under pressure and temperature, and minimized overall wall thickness. The use of composites in the tank structure also reduced material consumption by as much as 60 %, compared to the neat thermoplastic solution at identical industrial performances and use conditions.

A structural sandwich composite comprises of two thin facesheets adhered to a thick core [6–9]. The facesheets resist nearly all of the applied in-plane loads and flatwise bending moments and offer nearly all the bending rigidity to the sandwich. The core spaces the facings and transmits shear between them. The core also provides shear rigidity to the sandwich structure. To achieve high flexural strengths or flexural natural frequencies, the honeycomb core height is usually about 80 %–95 % of the total composite thickness [10, 11]. By varying the core, the thickness and the material of the face sheet of the sandwich structures, it is possible to achieve various properties and desired performance [12]. The core can be foam, honeycomb, truss, corrugated, or solid. The foam can be made of

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various polymers such as polystyrene, polymethacrylimide, polyvinylchloride, polyurethane, and polypropylene. The metallic foam can be used also [13, 14]. In honeycomb core sandwich composites, the honeycomb core material (composite, polymer, metal, paper) is expanded into hexagonal cells.

Characterization of sandwich materials has been carried out in scientific studies. The determination of the sandwich material behaviour under crushing loads and the measurements of the ductile fracture limits is normally done with the help of compression tests [15, 16]. Cores are the weakest part of sandwich structures and they fail due to shear. The shear strength properties of sandwich core are important in the design of sandwich structures subjected to flexural loading. Three-point bending tests are performed to find the flexural and shear rigidities of sandwich beams [17].

A mechanical behaviour of sandwich structures is strongly dependent on the loading rate [18, 19]. In the case of static loading the structure can have a ductile behaviour, but in the case of impact loading it may behave in a brittle manner and fail catastrophically. As the impact assessment needs to be considered, like in the transportation industry, it is very important to predict the impact behaviour and to collect data on impact resistance of materials. Such structures must be designed to withstand static and fatigue loads as well as to be able for maximum energy absorption in the case of an impact.

In comparison to quasi-static, studies of impact loading suggested that dynamic effects were significant due to a combination of more complicated crushing patterns, inertia effects and material strain rate sensitivity [20–23]. E. Wu and W. S. Jiang [24] founded that the final impact deformation of metallic honeycomb contained more irregular and extra folding mechanisms compared to those of the quasi-static. It was obtained that the dynamic crush strength was significantly higher by between 33 % and 74 %. Similar studies [25] showed that a 40 % and 50 % increase, respectively, from the quasi-static to dynamic cases.

Energy-absorbing capacities of sandwich structures with honeycomb under impact are closely linked to the core crushing. Core crushing is a complex mechanical phenomenon characterized by the appearance of various folds and failures in the hexagonal structure [21, 26].

Currently, the impact design problem is approached in two separated ways. The first one is experimental and requires several measurements of the impact behaviour of the studied material under different loading conditions and sample geometry. The second one is mainly related to the simulation of the impact phenomena using finite element methods and requires very powerful hardware and software resources [18].

The analysis of recent scientific studies showed that, investigation of honeycomb sandwich composites is talking point. While researches are numerous but in some materials combinations are pure.

The aim of this study is to investigate the impact behaviour of sandwich composite made from woven glass fiber and polyvinylester resin composite facesheets and polypropylene honeycomb core that can be used for safety important structures.

2. EXPERIMENTAL AND MODELLING

2.1. Materials and mechanical tests

The sandwich structures presented in Fig. 1 and Table 1 were used for experimental investigation.

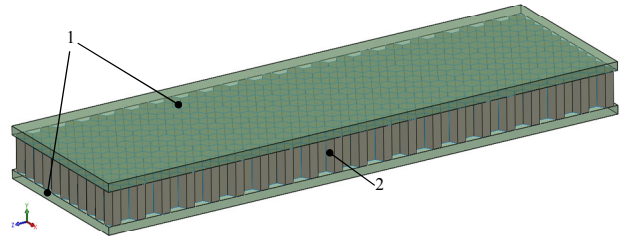


Fig. 1. Used sandwich structure: 1 – woven glass fiber and polyvinylester resin composite facesheets; 2 – polypropylene hexagonal honeycomb core

Table 1. Sandwich structures used in experimental tests

Sandwich structure with core of thickness, mm	Changeable facesheets thickness, mm		
	1.0	2.5	4.0
10	1.0	2.5	4.0
20	1.0	2.5	4.0

The mechanical properties of component materials were obtained according to applicable standards EN ISO 178:2003 [27], EN ISO 527-1:1994 [28]. The properties are presented in Table 2. As the sandwich structure core was used Nida Core H8PP honeycomb (USA). The thickness of honeycomb wall was equal to 0.4 mm. Core compression tests were executed according to standard EN ISO 844:2007 [16].

Table 2. Mechanical properties of sandwich structure component materials

Mechanical property	Facesheets material	Core material
Tension strength, MPa	380	–
Compression strength, MPa	280	–
Shear strength, MPa	130	–
Young modulus, GPa	19.2	1.75
Poisson ratio	0.13	0.42
Yield stress, MPa	–	24.0
Tangent modulus, MPa	–	4.4

2.2. Validation of numerical models

The experimental investigation of deformation behaviour under quasi-static and dynamic loading of sandwich structures components was carried out. According to these results the numerical models were validated. The code LS-DYNA v.971 was used for the finite element analysis (FEA).

The honeycomb material was defined by *MAT_PLASTIC_KINEMATIC model, which provide good agreement with experimentally obtained results (see Fig. 2).

After numerous investigations it was found that the most suitable model for the facesheets material is *MAT_COMPOSITE_DAMAGE as the length of finite element is equal to 2 mm. The model validation was

carried out using bending test results. The experimental and numerical results are shown in Fig. 3.

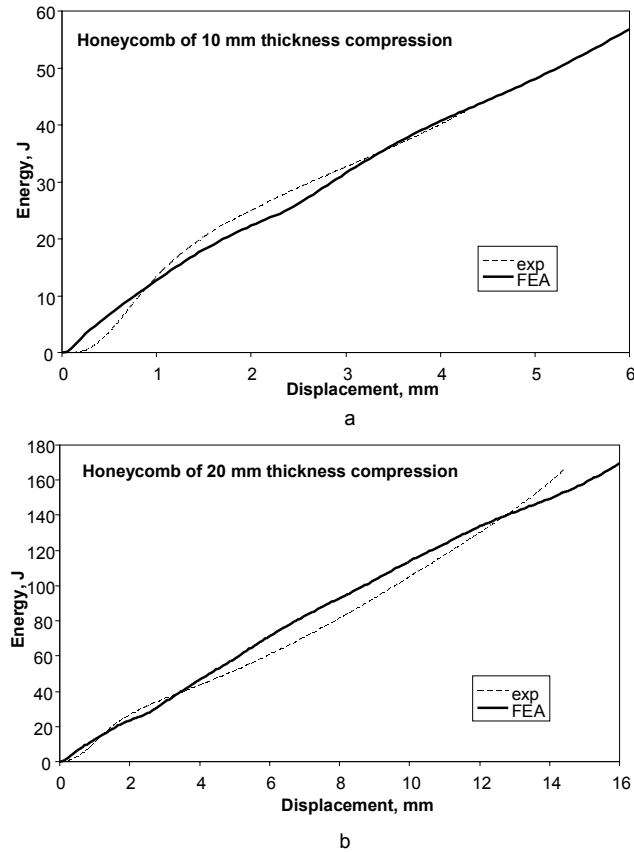


Fig. 2. Comparison of experimental and numerical compression results of honeycomb of 10 mm (a) and 20 mm (b) thickness

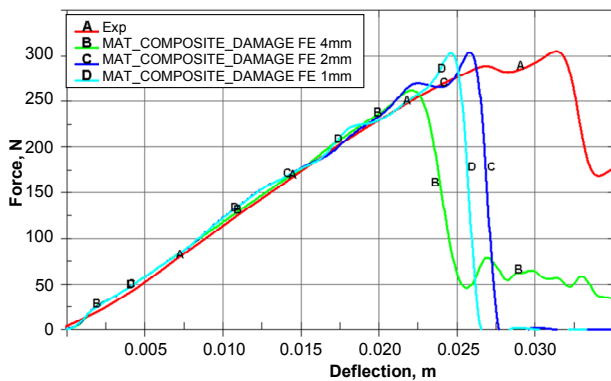


Fig. 3. Comparison of experimental and numerical bending results of facesheet material

2.3. Sandwich structure dynamic tests and modelling

The dynamical behaviour of sandwich structures was investigated by experimental testing and FE modelling under impact loading.

Specimens of varied length sandwich structures presented in Table 1 were tested on PEGASIL impact tester EL-99, that incorporates a striker of 25 kg mass, adapted to fall freely on vertical guides from a predetermined height to give the required impact energy (Fig. 4, a, b). Two values of 40 J and 100 J of impact energy were used. The impact loading velocity was

(1.80 ÷ 3.99) m/s. This impact tester does not incorporate measure equipment. Due to this the ADXL001 accelerometer and Tektronix TDS3014B oscilloscope were used for the measuring of the striker acceleration signal. The maximal deflection was assessed by residual strain of plasticine which was placed under specimen.

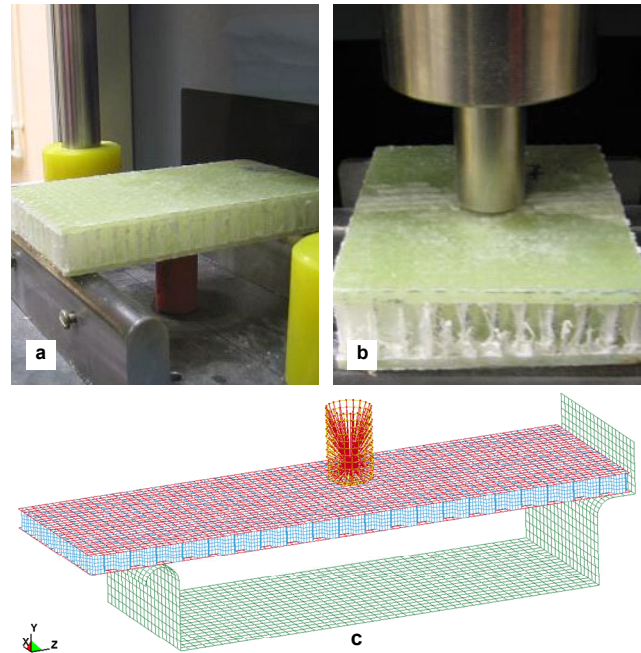


Fig. 4. The experimental testing of sandwich structure (a), (b) and numerical model of it (c)

According to test conditions the numerical modelling was carried out (Fig. 4, c) and the dependences of various geometrical parameters were obtained.

3. RESULTS AND DISCUSSIONS

The validated numerical models of sandwich structure were investigated by code LS-DYNA and the deformation behaviour of composite structure and separate components of it were analysed under low velocity impact loading.

The dynamical properties of sandwich structure define material behaviour under impact loading. The material parameters important for safety i. e., dynamical stiffness or deflection under impact loading, energy absorption, and impact load impulse were investigated in this study.

The deflection dependences upon thickness of facesheets are presented in Fig. 5. It seems that numerical results provide a good agreement with experimentally obtained ones. That indicates the suitability of finite element models for the dynamical analysis of sandwich structures. These deflection dependences define the dynamical stiffness and it increases in nonlinear character as the thickness of facesheets increases. Only by analysis of deflection it is difficult to obtain the rational geometrical parameters of composite sandwich structure. According to this the dependences of energy absorption upon geometric parameters were obtained.

It is important to evaluate which part impact energy is absorbed by separated structure components. Typical absorbed energy dependence on time is presented in Fig. 6. The analysis showed that the largest part of energy is

absorbed by honeycomb, the significantly smaller part is absorbed by top facesheet which is in contact with impactor, and the smallest part of energy is absorbed by bottom facesheet. Furthermore, both top and bottom facesheets deforms in elastic way due to this they do not absorb, but accumulate the energy. That follows from change of facesheets absorbed energy dependence. The amount of accumulated energy increases while the velocity of striker decreases. After this, it begins to grow down due to returning of elastic strain. The no null end value of strain energy shows that, the facesheets experience residual stress after impact.

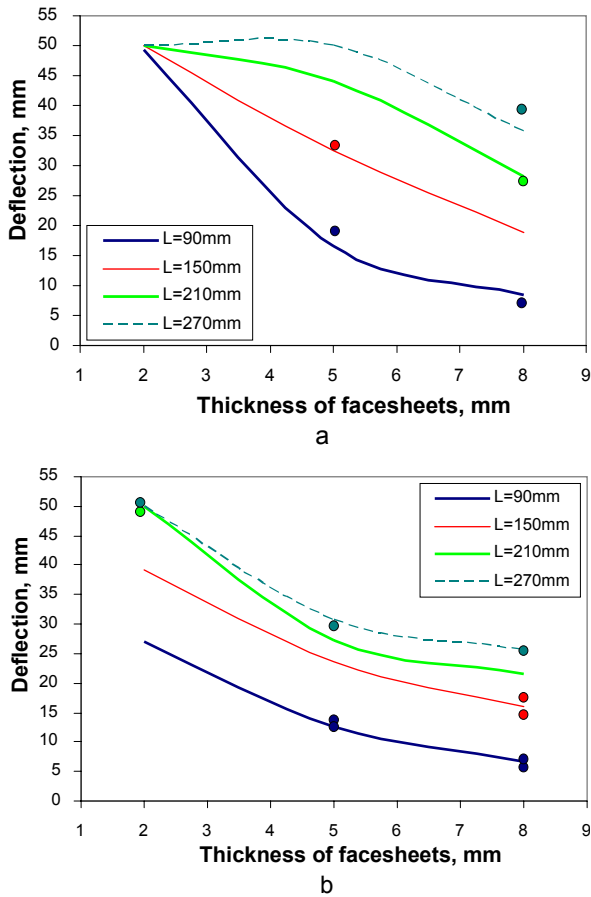


Fig. 5. The deflection dependences upon thickness of facesheets and length between supports (L); thickness of honeycomb is equal to 10 mm (a) and 20 mm (b); impact energy is 100 J; points represent experimental values

In Fig. 7 the dependences of honeycomb absorbed energy part upon the ratio of facesheets thickness to the honeycomb thickness as the length between supports is varied are presented. The honeycomb core can absorb by between 50 % and 95 % energy of all sandwich structure. From these dependences it is seemed that as the facesheets thickness increases the energy absorbed by honeycomb decreases due to thick facesheets larger energy absorption. The significant effect of length between supports is obvious. As this length increases the honeycomb absorbed energy part increases due to large shear deformations.

The dependences of top facesheet absorbed energy part upon the ratio facesheets and of honeycomb thickness as the length between supports is varied are presented in Fig. 8. The top facesheet absorbs by between 10 % and

35 % of total absorbed energy. As the length between supports increases the energy fallen to facesheet decreases. But as the thickness of facesheet increases the facesheet absorbed energy part increases.

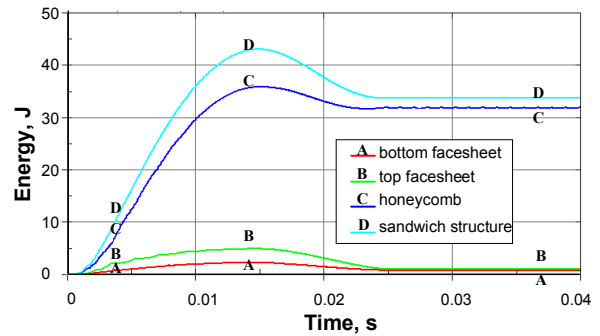


Fig. 6. The typical absorbed energy dependence on time; structure thickness 25 mm; honeycomb thickness 20 mm; length between supports 210 mm; impact energy 40 J

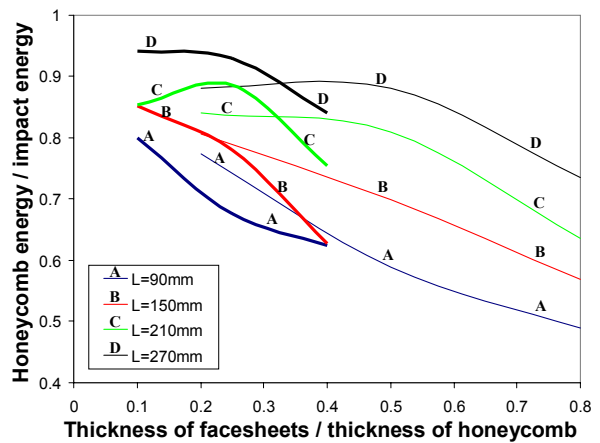


Fig. 7. The dependences of honeycomb absorbed energy part upon the ratio of facesheets thickness to the honeycomb thickness as the length between supports is varied; impact energy 100 J; thin curves represent sandwich structure with honeycomb of 10 mm; thick curves represent sandwich structure with honeycomb of 20 mm

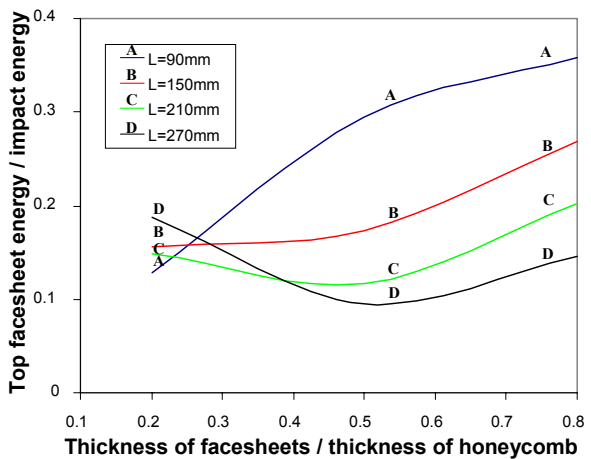


Fig. 8. The dependences of top facesheet absorbed energy part upon the ratio of facesheets thickness to the honeycomb thickness as the length between supports is varied; impact energy 100 J; thin curves represent sandwich structure with honeycomb of 10 mm

CONCLUSIONS

The behaviour under impact loading of the sandwich composite made from woven glass fiber and polyvinylester resin composite facesheets and polypropylene hexagonal honeycomb core that can be used for safety important structures was investigated.

The dynamical properties of sandwich structure as well as deformation behaviour depend upon the geometry of it. It was obtained that as the length between supports is low and facesheets are thin the buckling of core honeycomb in impact contact zone is dominating deformation mode. When the length between supports and the thickness of facesheets are increased the shear strains, which are more effective in a view point of energy absorption, become to dominate.

The analysis of energy absorption of sandwich structures and separate parts of them showed that the honeycomb core absorbs by between 50 % and 95 % energy of all sandwich structure. The top facesheet absorbs by between 7 % and 35 % and bottom facesheet the least.

REFERENCES

1. **Leijten, J., Bersee, H. E. N., Bergsma, O. K., Beukers, A.** Experimental Study of the Low-velocity Impact Behaviour of Primary Sandwich Structures in Aircraft *Composites: Part A* 40 2009: pp. 164–175.
2. **Foo, C. C., Seah, L. K., Chai, G. B.** Low-velocity Impact Failure of Aluminium Honeycomb Sandwich Panels *Composite Structures* 85 2008: pp. 20–28.
3. **Tyrell, D., Jacobsen, K., Talamini, B., Carolan, M.** Developing Strategies for Maintaining Tank Car Integrity during Train Accidents *Proceedings of the 1st Rail Transportation Division Fall Technical Conference* Chicago, Illinois, USA, 2007: pp. 1–10.
4. **Kim, J. S., Lee, S. J., Shin, K. B.** Manufacturing and Structural Safety Evaluation of a Composite Train Carbody *Composite Structures* 78 2007: pp. 468–476.
5. **Lagardere, E., Lacrampe, M. F., Skawinski, O., Krawczak, P., Ducret, C., Giletti, M.** A Novel Extrusion-welded Sandwich Structure for Thermoplastic Composite Storage Tanks *Proceedings of the 7th International Conference on Sandwich Structures*, Aalborg, Denmark, 2005: pp. 703–711.
6. **Shahdin, A., Mezeix, L., Bouvet, Ch., Morlier, J., Gourinat, Y.** Fabrication and Mechanical Testing of Glass Fiber Entangled Sandwich Beams: A Comparison with Honeycomb and Foam Sandwich Beams *Composite Structures* 89 2009: pp. 1–9.
7. **Vaidya, A. S., Vaidya, U. K., Uddin, N.** Impact Response of Three-dimensional Multifunctional Sandwich Composite *Materials Science and Engineering A* 472 2008: pp. 52–58.
8. **Russo, A., Zuccarello, B.** Experimental and Numerical Evaluation of the Mechanical Behaviour of GFRP Sandwich Panels *Composite Structures* 81 2007: pp. 575–586.
9. **Murthy, O., Munirudrappa, N., Srikanth, L., Rao, R. M. V. G. K.** Strength and Stiffness Optimization Studies on Honeycomb Core Sandwich Panels *Journal of Reinforced Plastics and Composites* 25 2006: pp. 663–671.
10. **Yu, S. D., Cleghorn, W. L.** Free Flexural Vibration Analysis of Symmetric Honeycomb Panels *Journal of Sound and Vibration* 284 2005: pp. 189–204.
11. **Das, M., Barut, A., Madenci, E., Ambur, D. R.** Complete Stress Field in Sandwich Panels with a New Triangular Finite Element of Single-layer Theory *Computer Methods in Applied Mechanics and Engineering* 194 2005: pp. 2969–3005.
12. **Steeves, C. A., Fleck, N. A.** Material Selection in Sandwich Beam Construction *Scripta Materialia* 50 2004: pp. 1335–1339.
13. **Qin, Q. H., Wang, T. J.** An Analytical Solution for the Large Deflections of a Slender Sandwich Beam with a Metallic Foam Core under Transverse Loading by a Flat Punch *Composite Structures* 88 2009: pp. 509–518.
14. **Styles, M., Compston, P., Kalyanasundaram, S.** The Effect of Core Thickness on the Flexural Behaviour of Aluminium Foam Sandwich Structures *Composite Structures* 80 2007: pp. 532–538.
15. **Shahdin, A., Mezeix, L., Bouvet, Ch., Morlier, J., Gourinat, Y.** Fabrication and Mechanical Testing of Glass Fiber Entangled Sandwich Beams: a Comparison with Honeycomb and Foam Sandwich Beams *Composite Structures* 90 2009: pp. 404–412.
16. LST EN ISO 844:2009 Rigid Cellular Plastics. Determination of Compression Properties (ISO 844:2007), 2009: p.11.
17. **Lingaihah, K., Suryanarayana, B. G.** Strength and Stiffness of Sandwich Beams in Bending *Experimental Mechanics* 31 1989: pp. 1–9.
18. **Torre, L., Kenny, J. M.** Impact Testing and Simulation of Composite Sandwich Structures for Civil Transportation *Composite Structures* 50 2000: pp. 257–267.
19. **Karger, L., Baaran, J., Teßmer, J.** Rapid Simulation of Impacts on Composite Sandwich Panels Inducing Barely Visible Damage *Composite Structures* 79 2007: pp. 527–534.
20. **Othman, A. R., Barton, D. C.** Failure Initiation and Propagation Characteristics of Honeycomb Sandwich Composites *Composite Structures* 85 2008: pp. 126–138.
21. **Castanie, B., Bouveta, C., Aminandab, Y., Barrauc, J. J., Thevenet, P.** Modelling of Low-energy/Low-velocity Impact on Nomex Honeycomb Sandwich Structures with Metallic Skins *International Journal of Impact Engineering* 35 2008: pp. 620–634.
22. **Raju, K. S., Smith, B. L., Tomblin, J. S., Liew, K. H., Guarddon, J. C.** Impact Damage Resistance and Tolerance of Honeycomb Core Sandwich Panels *Journal of Composite Materials* 42 2008: pp. 385–412.
23. **Vaidya, U. K., Nelson, S., Sinn, B., Mathew, B.** Processing and High Strain Rate Impact Response of Multi-functional Sandwich Composites *Composite Structures* 52 2001: pp. 429–440.
24. **Wu, E., Jiang, W. S.** Axial Crush of Metallic Honeycomb *International Journal of Impact Engineering* 9 1997: pp. 439–456.
25. **Zhao, H., Gary, G.** Crushing Behaviour of Aluminium Honeycombs under Impact Loading *International Journal of Impact Engineering* 21 1998: pp. 827–836.
26. **Ostergaard, R. C.** Buckling Driven Debonding in Sandwich Columns *International Journal of Solids and Structures* 45 2008: pp. 1264–1282.
27. LST EN ISO 178:2004 Plastics - Determination of Flexural Properties (ISO 178:2001), 2004: p.18.
28. LST EN ISO 527-1:2001 Plastics – Determination of Tensile Properties – Part 1: General Principles (ISO 527-1:1993 Including Corr 1:1994), 2001:p.10.