IMPACT TEST OF ALUMINUM HONEYCOMB

ZUZÁNEK Lukáš, SOBOTKA Jiří, SOLFRONK Pavel, KOLNEROVÁ Michaela

TUL - Technical University of Liberec, Liberec, Czech Republic, EU,
Lukas.zuzanek@seznam.cz

Abstract

The paper deals with the aluminum honeycomb that is very successfully used as applications in the transport industry and engineering production. Based upon its ability to absorb the large amount of energy, aluminum honeycomb has also found its utilization as the kinetic energy absorber. At low weight it has quite high compressive resistance and bending stiffness. The focus of this paper was to determine material behavior at impact loading and that is why the whole experiment was carried out on the special device (drop weight tester - drop tower), which makes possible to define magnitude of impact rate on the testing sample. As an observed factor there was magnitude of force and strain arising from the impact test. Based upon these values is possible to determine magnitude of absorbed energy by the honeycomb sample. Tests were performed by means of the visual analysis on the particular samples and by the quantitatively expression of measured data as graphs.

Keywords: Aluminum honeycomb, impact test, strain, drop tower, energy

1. INTRODUCTION

Honeycomb panels utilize the sandwich structure which is created from the different types of simple or compound materials having different characters. Honeycomb structures are derived from their similarity with the hexagonal structure of the true honeycomb and have found their utilization in many branches. Core has a double-side shell to improve strength and mainly to keep the required shape. Because of that, there are used mainly aluminum sheets or composite materials from cloths and resins. Connection of the core and shell is done by the adhesives. High bonded strength is achieved by utilization of the epoxy adhesives. At joints of lower strength, polyurethane basis adhesives are used. Individual adhesives are used acc. to demands on the product cost and joint strength. Aluminum honeycombs have a high ratio of strength and weight which fulfills the technical demands set on the modern materials. Aluminum honeycombs reveal quite high compressive resistance in the given direction and quite high bending stiffness under the low weight.

All-aluminum honeycomb sandwiches are designed mainly to be used as structural elements for demanding applications at transport aircrafts design - e.g. for floor, flaps, walls, doors and so on. They are also used at production some parts for the rail and road car-body vehicles. They have already found their utilization in the machinery production as supporting structural elements of tools and jigs. Regarding their ability to absorb a great amount of energy, they are also used as kinetic energy absorbers. Another application possibility for the aluminum honeycomb can be found also in the non-contact vented exteriors of houses, due to their excellent mechanical, acoustic and thermal-insulating properties [1, 3].

Own experiment was performed on the drop tower Instron Ceast 9300 (**Figure 1**). Such device is designed for the high-speed testing of materials. As a great advantage there is precise determination of impact velocity and energy arising just from the definition of impact cross-bar weight and its height before releasing. For the high impact velocities it is possible to use pre-loaded springs. There wasn´t necessary to use these springs for analyzes of tested aluminum honeycomb, acceleration of impactor just by gravity was enough. Impactor had a shape of wedge. Because of description honeycomb deformation behavior at dynamic loading, there were used different impact velocities (namely 1, 1.5, 2 and 3 $m \cdot s^{-1}$).

2. METHODOLOGICAL BASES AND EXPERIMENTAL PART

To define material behavior at impact conditions, it is in many cases very important to carry out such tests under the higher velocities. Material behavior at dynamic loading is totally different in comparison to its behavior under low and uniform velocities. That is why there are used sophisticated devices (termed as drop towers) which make possible to release the cross-section beam with weight from the different heights. Based upon the mass and chosen height of beam, it is possible to determine the impact velocity (thus also the energy acting on the tested material). Principle of this method is based on gravity. However, if there´s need to apply much higher velocities, compressive springs are used. Springs are compressed (pre-loaded) and when they are unloaded, their energy is transferred onto beam which is accelerated against tested material. Maximal impact velocity achieves up to 25÷30 $m \cdot s^{-1}$. Device can be used for a wide range of tests due to its possibility to precisely define impact velocity and energy. Moreover, by utilization of different jigs there can be tested samples in many loading directions - e.g. tensile, compressive, shear or their combination [2].

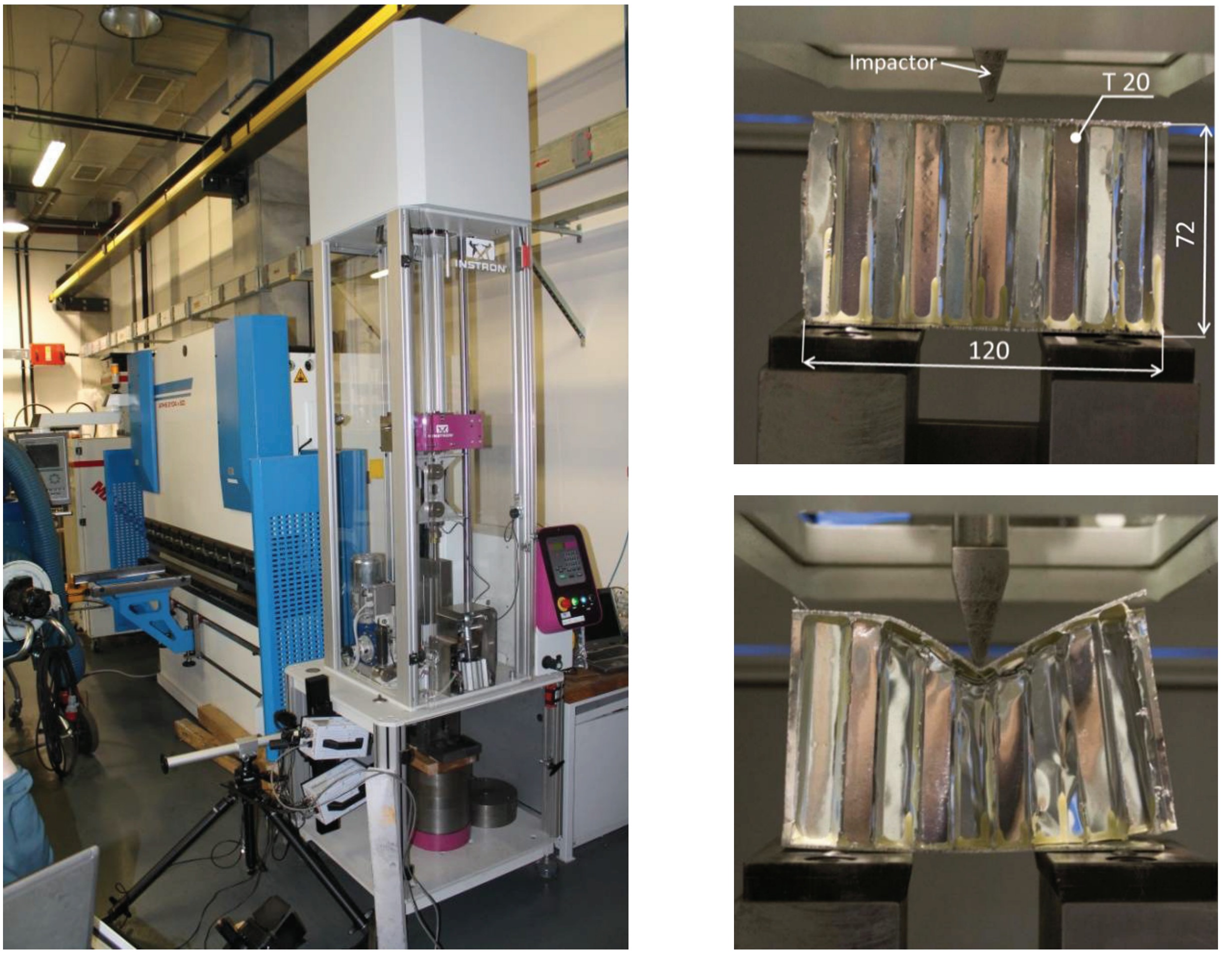
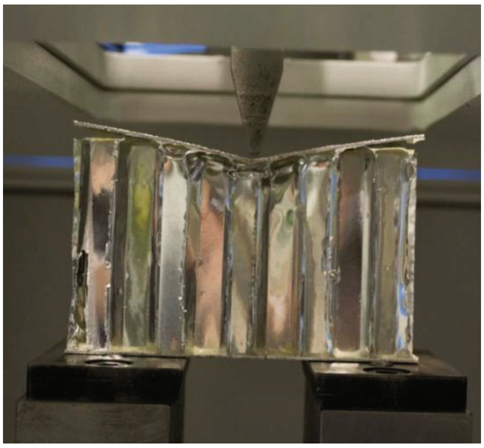


Figure 1 Drop tower (left) and testing samples (right)

Experiment was carried out with the aluminum honeycombs, where the core was produced by the stretching method. Double-sided shell was made from the aluminum sheet of thickness 1 mm that was bonded by the adhesive on the polyurethane basis. Own testing samples for the impact test were cut by band-saw on the sizes as 120x72-T20 (**Figure 1**). Sample width (20 mm) arises from the size of the impactor which has width of 25 mm and is necessary that this width (25 mm) is higher than the sample´s width. During the preparation of sample, there was very important not to deform walls of aluminum hexagonal core. Own cut in the direction of testing sample length was lead thought the center of hexagon, thereby to prevent deformation of these hexagonal walls and thus not to influence results of test.

2.1. Determination of force and deformation

The following sections show the images of the test specimens after the test for two impact velocities. To the right of the image, force F (Y-axis) is plotted on the magnitude of the deformation (X-axis). Differences for each deformation vary considerably for each impact velocity, so the scale on the X axis is changed to offer a more detailed view (see **Figures 2** and **3**).



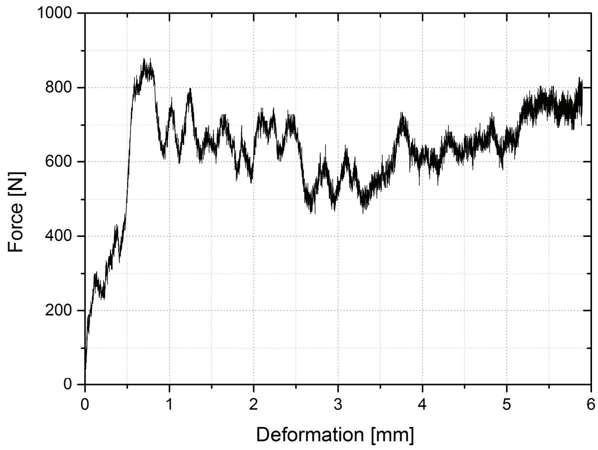
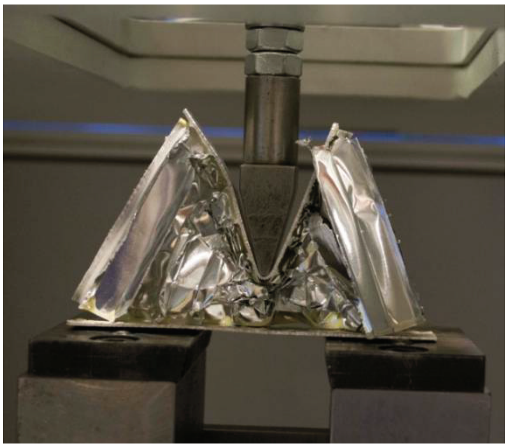


Figure 2 Test specimen after impact velocity 1 m·s^{-1} and record of measured force magnitudes in dependence on the deformation

Figure 2 shows a test specimen after impact velocity of impactor 1 m·s^{-1}. There was a bending of the upper aluminum sheet and a slight deformation of the honeycomb core. In the upper part there is visible debonding of sheet from the core in the outer zones. The lower part remained free both of deformation and bonded joint failure. The impactor penetrated into a specimen approx. by the depth of 6 mm.



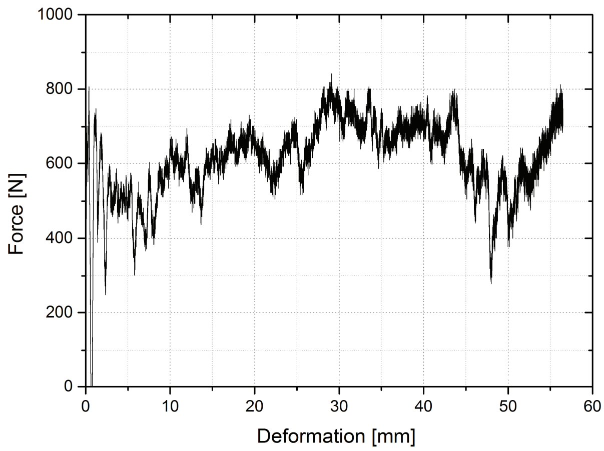


Figure 3 Test specimen after impact velocity 3 m·s^{-1} and record of measured force magnitudes in dependence on the deformation

Figure 3 shows a test specimen after impact velocity of impactor 3 m·s^{-1}. There was a significant bending of the upper aluminum sheet and its pressing into the sample. The honeycomb core is most distorted in the impact force axis, but there is already a large deformation in the entire part except the outermost area. The structure is completely collapsed. There isn´t almost any debonding of sheet from the core. Small debonding can be observed in the outermost area. The lower sheet isn´t almost deflected. The impactor penetrated into a specimen approx. by the depth of 57 mm.

2.2. Amount of absorbed energy (energy absorbed by the honeycomb specimen)

Very important quatity at honeycomb parts analysis is magnitude of the absorbed energy. Courses of curves which show magnitude of energy for the given deformation have found their utilization mainly at parts which are in practice used as deforamtion elements (absorbers). From the graph displayed in **Figure 4** is evident that the highest absorption of energy was for impact velocity 3 m·s^{-1}. There is obvious deviation from the other curves in the case of curve for impact velocity 2 m·s^{-1}. Such deviation means lower absorbed energy at the same deformation, which can be caused by failure of bonded joint between sheet and core. If there is debonding of sheet, deformation will not occur in the hexagonal structure. Thus it doesn´t restrain the impactor in the motion into the material. There is different loading of the honeycomb core during the test. The upper sheet is bended during the first impact and subsequently there is compression of core in combination with shear loading caused by the bonded joint between sheet and core. As a result, combination of all loading types determines the final magnitude of absorbed energy.

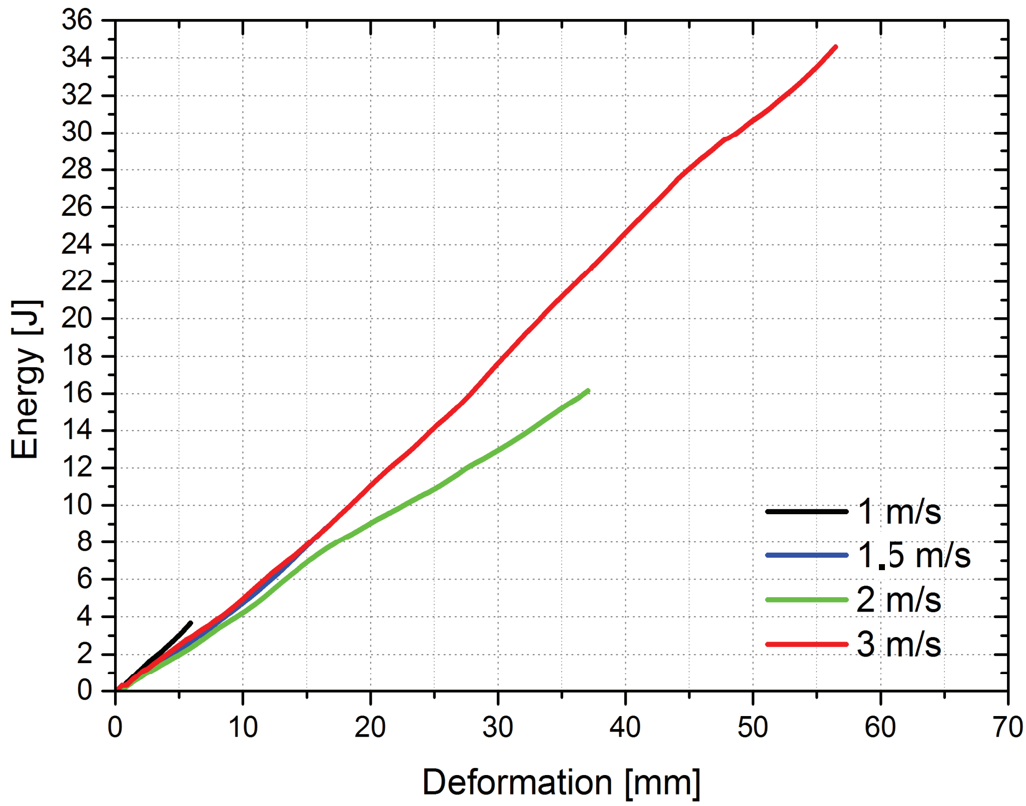


Figure 4 Magnitude of absorbed energy vs. deformation for impact velocities: 1, 1.5, 2 and 3 m·s^{-1}

Regarding the previously mentioned conclusions, as the greatest issue there is always influence of the used adhesive, thereby strength of honeycomb core and shell (aluminum sheets). In **Figure 5** is shown the major influence of adhesive bonded joint on the honeycomb sample final behavior at impact velocity 3 m·s^{-1}.

Figure 5 (left) shows quite good bonding between sheet and core. Thus sheet is pressed into the material and due to such good cohesion, the whole honeycomb structure participates on the total deformation process (so it means that great amount of honeycomb sample is used to absorb impact energy).

Figure 5 (right) shows a poor bonded joint, causing deformation only at the center of the honeycomb core and the outermost area are almost undeformed. The upper sheet is at the beginning of the deformation broke away along the whole contact plane and subsequently is only pressed into the material without any serving as the energy carrier for the entire specimen.

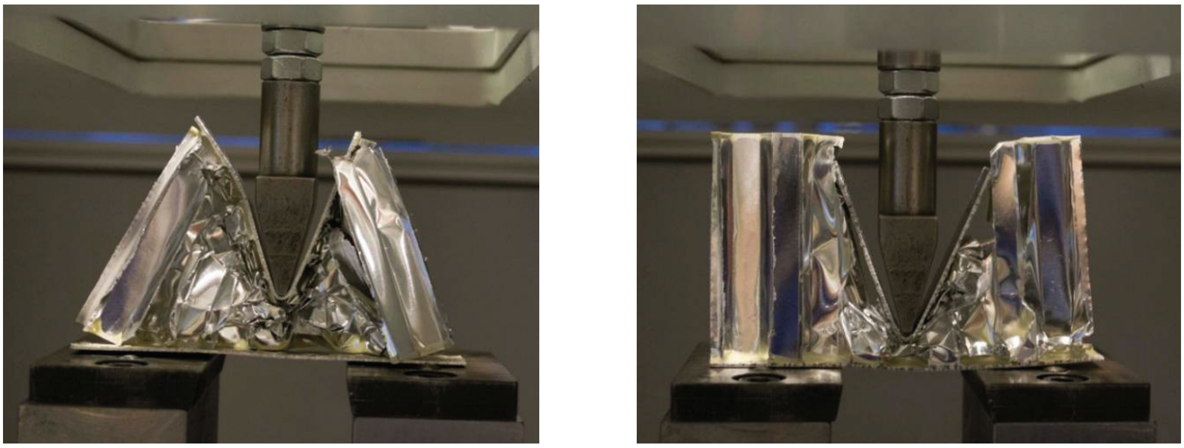


Figure 5 Testing specimens after test at impact velocity 3 m·s^{-1}

The difference among absorbed energies is evident from the graph in **Figure 6** which shows the energy dependence on the magnitude of deformation under the same impact velocity. The difference is only in the strength of the adhesive bonded joint between the upper sheet and the honeycomb core. For 10 mm deformation are values of energy nearly the same. With increasing deformation, the energy difference varies considerably in favor of the bonded sheet. For deformation of 55 mm, the difference in energy is 12 J, i.e. the difference is about one third.

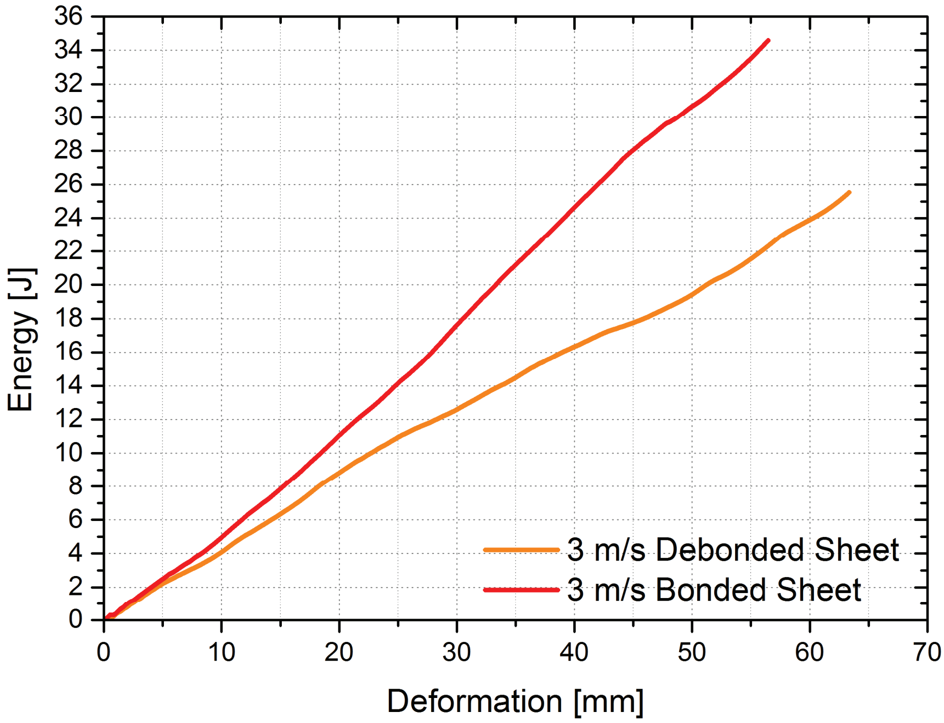


Figure 6 Magnitude of absorbed energy in dependence on deformation at impact velocity 3 m·s^{-1}

In light of energy, the curved for debonded sheet is situated lower, but in the area of deformation it achieves higher values than sheet which was still bonded to the core. Due to the debonding of the upper sheet, impactor could easily penetrate into material and the resistance of the hexagonal blocks can't fully prevent in its passing through it. The distance of the penetration depth from the specimen´s surface is 57 mm for the bonded sheet and 64 mm for the debonded sheet.

3. CONCLUSION

The described experiment was carried out on the honeycomb samples where aluminum core had a shape of regular hexagon and double-sided aluminum sheets of thickness 1 mm. Complete honeycomb sample had height of 72 mm. From such "block" there were prepared samples of sizes 120x20 mm by means of the band-saw. Proper preparation of samples is quite complicated, because the own cut has to be perform without any deformation of honeycomb core hexagonal walls. If there was such failure of wall, final behavior of sample would not be relevant, because of their early collapse. Own tests were performed on the drop tower Instron Ceast 9300 under the impact velocities of impactor as follows: 1, 1.5, 2 and 3 $m \cdot s^{-1}$.

At first, results can be evaluated directly in the visual point of view. It means directly from images where were obvious magnitudes and directions of honeycomb samples deformations. As another quantity for evaluation, there were a force, deformation and energy values recorded during the test. After plotting these values into graphs, there are transparent and predicative information about honeycomb behavior at impact loading. It is possible to state that the higher impact velocity, the higher deformation of testing sample. Magnitude of absorbed energy depends on the honeycomb sample cohesion - mainly of the bonded joint between sheet and core. In this paper were parts bonded by the adhesive on the polyurethane basis and that is why the final joint didn´t achieve strength that is typical of e.g. epoxy adhesives.

There were monitored two cases under the impact velocity of impactor 3 $m \cdot s^{-1}$. The first situation occurred when the upper aluminum sheet was still bonded to the honeycomb core and the second one happened when there was debonding of such sheet. From comparison of these two cases both in light of visual and quantitative (magnitude of deformation and energy) is evident that in all directions revealed better values sample with the bonded upper sheet. The reason can be found in reality that only total deformation of the whole sample can restrain the deep penetration of the impactor into material. Maximal total energy which was absorbed by the testing sample was 34.7 J. Such energy was absorbed under impact velocity 3 $m \cdot s^{-1}$ and there wasn´t any debonding of upper sheet.

ACKNOWLEDGEMENTS

This publication was written at the Technical University of Liberec as part of the Student Grant Contest "SGS 21121" with the support of the Specific University Research Grant, as provided by the Ministry of Education, Youth and Sports of the Czech Republic in the year 2017.

REFERENCES

[1] HAZIZAN. A., CANTWELL, W. J. The low velocity impact response of an aluminum honeycomb sandwich structure. *Elsevier Composites*, 2013, vol. 34, no. 8, pp. 679-687.

[2] XUE-CHAO, Z., HAN, Z., HAO-RAN, L. Drop-weight impact test on U-shape concrete specimens with statistical and regression analyses. *Materials*, 2015, pp. 5877-5890.

[3] KŘEČEK, V. *Výzkum crush-core technologie.* Thesis. Zlín: Univerzita Tomáše Bati ve Zlíně, 2013. In Czech.