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INVESTIGATION OF THE STRENGTH PROPERTIES OF COMPOSITE MATERIALS BASED ON PAPER HONEYCOMB

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Abstract

Composite materials based on paper honeycomb structure do have a potential in today's fast changing markets and within the present context as sustainable products the demand for more economical and environmentally friendly products is highly increasing and stands out for environmental issues but must outstand the strength properties as the alternative products used in packaging industry. Strength properties of composite materials made of paper honeycomb were investigated experimentally. Static compression tests were made using testing machines "Zwick/Roell". Composite materials were made with different honeycomb properties: cell high, cell size, various grammage of laminate layer. Honeycombs were dried and soaked before testing their strength properties. It was confirmed and determined that moisture is important factor for paper honeycombs. It was determined that strength properties are quite different for dried honeycombs and depend signific on the drying time which was adjusted for the specimens. Dried honeycombs hade higher resistance to compression up to 70% and depended on the increased drying time and other honeycomb structure aspects as the cell height and the laminated layer in the composite structure. Strength of all investigated composite materials was higher using honeycombs with smaller size cells (with same cell high). Sandwich panels with bigger laminated layer grammage had higher strength characteristics especially panels with smaller cell high honeycombs.

KEY WORDS: honeycombs; composite material; sandwich; compression; strength properties.

Introduction

The main factor determining industry growth is the demand for products. If production of some products decreases in the case of composite materials it increases, new ones appear in the market. Promotional and packaging products take even bigger place in the market. With a consumption of about 40% of plastics and 50% of paper in Europe, the packaging sector is a large use of materials (Coelho et al. 2020). The packaging materials stand out with the variety of construction, design, and the required specifications. Among them become more prominent strength properties. But the unique issue now is the sustainability of reusable packaging products and paper honeycomb packages are among them with other eco-friendly materials - based packages.

The concept of composite material can be used for paper and cardboard honeycombs (Fig. 1). Characteristic feature of composite material is that it has the main component – matrix, which determine the main properties of material, which can be changed intentionally by addition of other components.

Fig. 1. Composite material based on paper honeycomb

Such structure ensures unique consumption properties, which can be changed in the large range by changing composition and structure of matrix as well as fillings and other addiadditives.

Theoretical framework

Potential of composite materials made from honeycombs are widely investigated and used in various industry types used in packaging industry for low weight, high strength, and good preservation characteristics (Han et al. 2016). Such materials are also used in aviation making fuselage of the plane. In furniture industry it is material for doors and table decks. In logistics composite materials with honeycombs are used as preservative materials by absorbing it from vibrations and bumps (Dongmei et al. 2015).

Honeycomb structures are widely used in structural, architecture, aviation, and packaging applications due to their efficient energy absorption capacity and high specific strength and stiffness (Li et al. 2021). Honeycomb structure can be used as a shield providing space from fragments flying supersonic speed. Also important for cosmic satellites and other research equipment. In its work (Liu et al. 2015) uses double aluminum honeycomb simulation using point method to find best distance between honeycomb sheets.

Composite materials with honeycombs can be used for better sound absorption (Yang et al. 2016). Some investigation observed that smaller cell sizes and thicker cell walls improved the insulation performance (Jung et al. 2018).

Geometric complexity of the honeycomb structure is defined as challenging the traditional manufacturing technology (Chen et al. 2021). Current scientific advances in micro- and nanotechnologies hold great promise for bioinspired honeycomb structures (Mishra et al. 2019).

Some research was made consisting of honeycomb structure and its interaction with environment. As today's market is focused on changing rapidly around the world within the present context as sustainable products, the demand for more economical and environmentally friendly products is highly increasing and stands out for environmental issues (Zaini et al. 2018).

It is important to to know that design of core structures depends in the application of the final composite material. Was stated that form of honeycomb cells and directions between them decide their strength properties (Smardezewski, 2019, Tekoğlu, 2007; Veltin, 2009). Mechanical properties also depend on the direction of the load and relative dencity (Khan et al. 2020, Erjavec, 2011). Tounsi et al. in his work made compression tests by changing the angle of load interacted to honeycomb. Composite materials with hybrid honeycomb showed higher compression resistance (Han et al. 2016). With increased compression we can see increased density of honeycomb (Deqiang et al. 2010). Deformation stages were investigated and defined elastic zones where packages could be damaged (Wang, 1991). More, over some authors indicate that rhombus indentation and cross-indentation has the greatest influence on the compressive strength of cartons (Gong et al. 2020).

Moisture is important factor for paper honeycombs. It was studied that strength properties decrease with increase of relative humidity (Phol, 2009). In this research also was found that impregnated honeycombs have higher strength properties than unimpregnated.

The aim of this work was to investigate in detail the strength properties of composite materials based on paper honeycombs changing comb properties. These properties are cell height, cell size, grammage of laminated layer and moisture of honeycomb.

Materials and Methods

Composite materials were made using designed device for honeycomb mounting, so that desirable cell size and height could be made. Using this device 6 composite sheets for compression tests can be made at one time. Compression samples: length – 140 mm; width – 140 mm. Amount of glue was measured with electronical scales. Paper surface was covered with glue and pressed.

Testing conditions were determined by using IKEA IOS-P-0010 and ASTM-393-00 standards. These standards are used to determine strength properties for composite materials made with paper honeycomb. Glue layer used for laminated layer was found in scientific articles (for compression tests - 2 x 2.61g). Standards and scientific articles also refer necessary amount of testing samples. Each test must be repeated at least three times.

Compression experiments were made using provided methods. Some parameters of honeycombs were changed in tests. Cell size of honeycomb 10 – 28 mm; laminated layer grammage 125 – 160 g/m²; height of honeycomb cell 15.2 – 46.6 mm. Honeycomb height was changed from 15.2 to 46.6 mm and size of cell from 10 to 28 mm when compression tests were performed. 111 tests were made during this investigation: 54 –compression of composite materials, 57 – compression oh honeycomb.

Compression tests were performed using "Zwick/Roell" universal testing machines Z020 and Z100 (Fig 2 and Fig. 3).

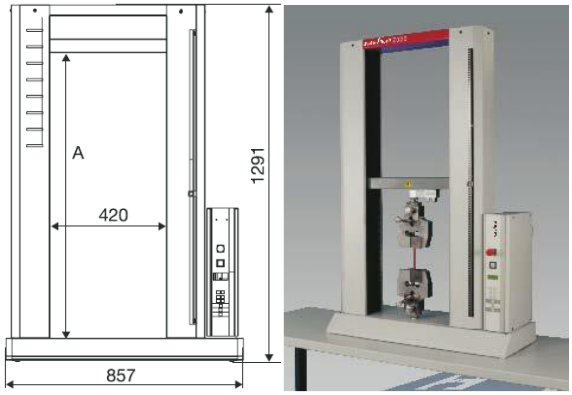


Fig. 2. Zwick/Roell Z020 testing machine [Zwick/Roell, 2022]

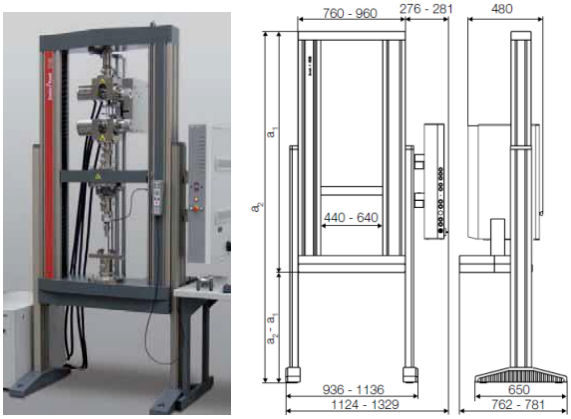


Fig. 3. Zwick/Roell Z100 testing machine [Zwick/Roell, 2022]

Results

During experiments it was decided to test that influence to honeycomb has absorbed amount of moisture. Honeycomb parameters for testing: grammage – 160g/m^2, high – 46,6mm, cell size – 22 mm. Sample weight – 19.21g. (relative humidity 62 %). First was determined maximum moisture weight that honeycomb can absorb. This experiment was made by soaking the sample for 5 min, weighting it after that and repeated till was no change in its weight. Same was repeated with dry honeycomb. Soaked sample was dried in 130°C temperature and weighted in 5 minutes. This was also repeated till was no change in weight. Results are showed in Fig. 4.

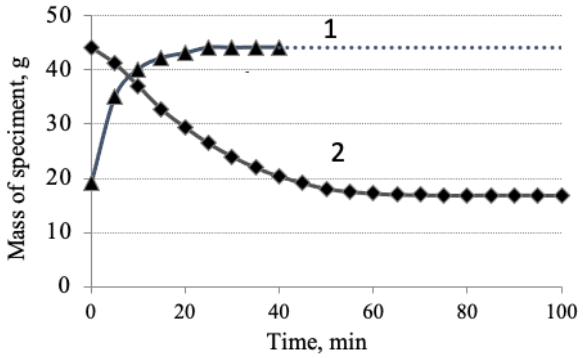


Fig. 4. Mass of specimen (1- moisture, 2 – drying)

Experimentally was tested how much moisture evaporates from honeycomb after dying process. Samples were tested in 19.5°C temperature and relative humidity was 63 %. Another test was made when samples were tested in 21.3°C temperature and relative humidity was 62 %. Results are showed in Fig. 5.

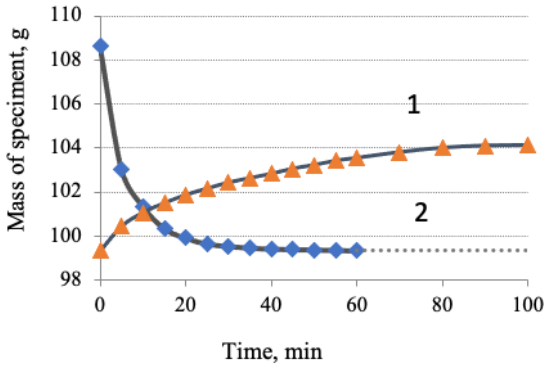
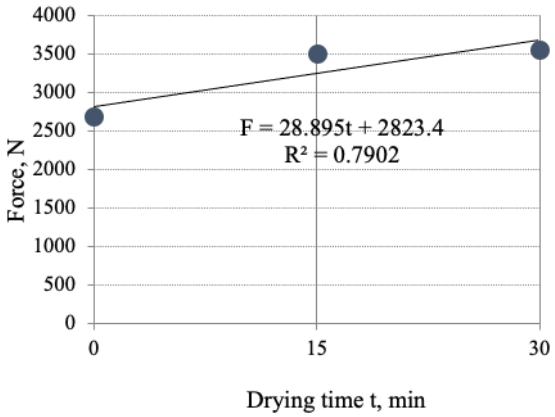


Fig. 5. Mass of specimen (1-moisture, 2-drying)

Before experiment sample weight oh honeycomb was 108.63g. From the results in picture, we can see that maximum amount of moisture (5.58g) evaporates in first 5 minutes. After 15 minutes 8.27 g of moisture evaporates from sample. Honeycomb drying process ends in 50 minutes (9,24g evaporated). After that were was no change in weight.

Compression tests were performed using samples with different amount of moisture. Test was made using undried, dried 15 min and dried 30 min honeycomb samples. Tests were made with honeycomb: grammage (K) – 160g/m^2, cell size (A) – 22 mm, high (H) – 15,2 mm; 32,2 mm; 46,6 mm. Compression results are shown in Fig. 6. and Fig. 7.



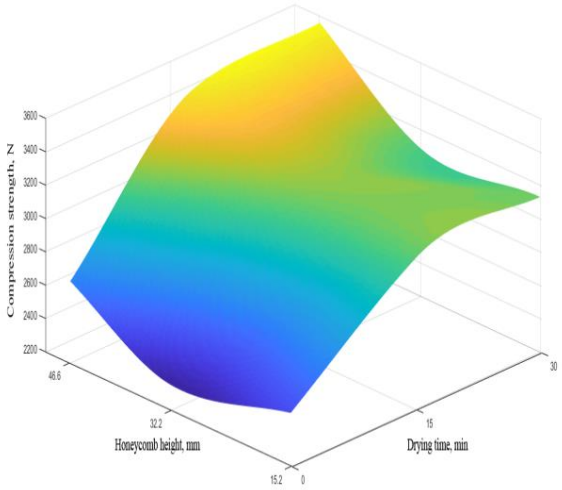


Fig. 6. Compression strength dependence on honeycomb cell height and drying time

Compression results showed in Fig. 6 refers that undried honeycomb resistance to compression is 2694.45 N, dried 15 minutes – 3514.67 N and dried 30 minutes – 3561.30 N. Compression loud increased 30.44% for honeycombs dried 15 minutes and, up to 32.17% for honeycombs dried 30 min.

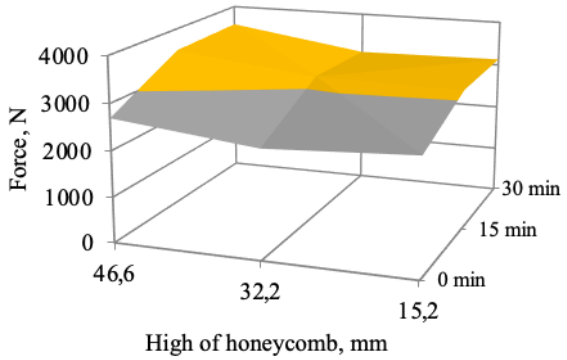


Fig. 7. Compression strength dependence on honeycomb cell height and drying time

Almost similar results we can see in Fig. number 7. Compression loud for honeycomb [K160_H15,2_A22] is about 2520,4 N, dried 15 minutes – 3104,2 N, dried 30 minutes – 3131 N. We can see those results for 15 minutes dried honeycomb samples increased 23.16% and 24.22% for dried 30 minutes. Data of honeycomb [K160_H32,2_A22] is the same. These results explain, that in 15 minutes most of moisture evaporates from sample and increase its resistance to compression. After additional 15 minutes evaporates relatively small amount of moisture and this is seen in compression results (1.06 – 1.73%). Suggesting these results additional tests were made using undried and dried for 15 minutes honeycombs.

Most important criteria for experiments with composite materials to determine resistance to compression is size of cell. Other parameters such as: amount of glue, laminated layer grammage, honeycomb structure grammage, form of cell and moisture stayed the same. Compression of material depends on surface area which is impact. That is why it was decided to change size of cell. In this experiment 0.0144m^2 honeycomb area was used. Honeycomb with lower cell size can resist higher compression strength.

For compression results was used honeycomb with these cell sizes: 10mm, 12mm, 16mm, 20mm, 28mm (Fig.8). Tests were made using undried and dried for 15 minutes honeycomb samples.

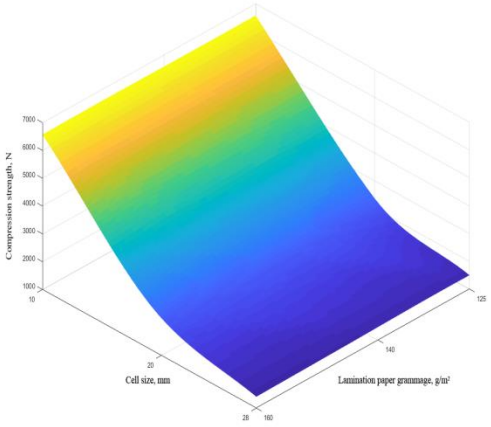


Fig. 8. Compression strength dependence on honeycomb cell size and laminated layer grammage

From results showed in figure 8 we can see that compressive strength results increase by lowering size of cell. Same results were stated for dried honeycomb samples, but in this case compression force values are higher. Compression resistance for 15 minutes dried honeycombs with 10 mm cells increased 70.06 %. For honeycombs with bigger size cells resistance to compression increased from 41.11 to 52.05 %. These results suggest that amount of moisture in honeycomb influence compression strength.

Laminated honeycomb samples were made using 3 different cell sizes: 10 mm; 20 mm; 28 mm. Also were used 3 different laminate layers (cardboard): 125 g/m^2; 140 g/m^2; 160g/m^2. Examined samples were named: L125_H322_A10. A – honey bond cell size, mm; H – cell high, mm; L – laminated layer (cardboard) grammage, g/m^2. Results of examined samples are showed in Figure 9.

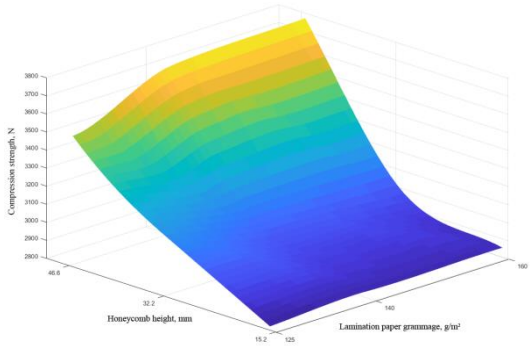


Fig. 9. Compression strength dependence on honeycomb cell height and laminated layer grammage

Results showed in Figure 9 suggest that strength compression results of laminated honeycomb are almost the same. Strength characteristics are almost the same using different grammage laminate layers (results vary from 0,04 to 2,37 %). Intermediate compression force values (honeycomb cell size 10 mm): 6568.65 N, with L125; 6573.74 N, with L140 and 6567.21 N, with L160. Similar results were found for honeycombs with 20 and 28mm cell size. It can be stated that grammage of laminated layer has no effect to compression. Another experimental fact is that low honeycomb size increases compression strength. Compression force increased 4.5 times (from 1459,94N to 6569,87N) using 2.8 times smaller size honeycomb cell.

Conclusions

Composite materials based on paper honeycomb structure do have a potential in today's fast changing markets and within the present context as sustainable products the demand for more economical and environmentally friendly products is highly increasing and stands out for environmental issues but must outstand the strength properties as the alternative products used in packaging industry.

It was confirmed and determined that moisture is important factor for paper honeycombs. It was determined that strength properties are quite different for dried honeycombs and depend signific on the drying time which was adjusted for the specimens. Dried honeycombs hade higher resistance to compression up to 70% and depended on the increased drying time and other honeycomb structure aspects as the cell height and the laminated layer in the composite structure.

In conclusions of the research results it may be maintained that strength characteristics were determined for composite materials with paper honeycombs. Experiments showed that compression strength depend on honeycomb cell size and height. Compression results showed that smaller size cells (cell high stayed the same) have higher resistance to compression. Honeycomb cell

size decreased 2.8 time and increased compression resistance 4.5 times.

Laminated layer has big influence on strength properties of composite materials. Experimentally it was found that laminated layer grammage has biggest influence on composite materials made with low cell high honeycombs (15.2 mm). For compression tests were no difference between grammage of laminated layer since all cases showed intermediate values.

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