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Compression strength-focused properties of wood composites induced by structure

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Abstract: *Compression strength-focused properties of wood composites induced by structure.* The aim of the following study was to examine the contractual compression strength and modulus of elasticity when compressing (MOEC) of three different wood composites with various structure types: softwood (coniferous) plywood, OSB and laminated particleboard 24 mm thick. The biggest MOEC value was performed by the particleboard laminated 24 mm MOEC equalling 70.00 N/mm^2. The second was found by the OSB panels, equalling 63.03 N/mm^2. Last, but with MOEC value close to OSB, was softwood plywood with MOEC of 62.44 N/mm^2. The lowest compression strength was observed by OSB samples, with a value of 2.75 N/mm^2. The second lowest value has been performed by coniferous plywood (2.80 N/mm^2). The highest compression strength occurred by the particleboard laminated 24 mm, equalling 3.31 N/mm^2. Density shares and density profiles of the samples were also analysed, all of the examined composites performed U-shaped density profile The results of the study showed that there is no significant correlation between density and obtained parameters under compression. Observation of density share let the Authors conclude conversely than the results showed. It is supposed that the key factor affecting the compression performance of samples was the adhesive area and solid glue content within the composites. It is assumed that the bigger total contact surface of wood particles coated with adhesive resin, so the sum of the effective (gluing particles) surfaces of the adhesive joint is the better mechanical properties can be performed. This is why the laminated particleboard gave the best mechanical properties, while the worst were observed by the softwood plywood.

Keywords: wood-composite, structure, mechanical properties, compression

INTRODUCTION

When discussing the structure of particleboards, the most essential aspect is particle size. ATTA-OBENG *et al.* (2012) tested the effect of microcrystalline cellulose, species, and particle size on the mechanical and physical properties of particleboard. on sweetgum (*Liquidambar styraciflua*) and southern pine (*Pinus spp*.). The study showed that increasing the particle size has a positive impact on mechanical properties. Conversely, mechanical properties and springback decreased with adding microcrystalline cellulose.

SACKEY *et al.* (2008) found out that single-layer boards indicated only a slight increase in bond strength and edge-SWR by replacing 40% of the coarse particles with medium and fine ones, and decreased by a further increase in fines content. The effect of fines in the particle mix of 3-layer boards worked in those compressed to low density. What is more, boards made using cores containing a customized mix of particles showed up to 40% higher IB and 18% better edge-SWR, than boards produced with industrial furnishings. Flexural properties of the 3-layer boards were unaffected by core fines content.

Nowadays, oriented strand particleboards are an important engineering composite, so that it is expected from this material to have possibly the best mechanical properties. JIVKOV *et al*. (2004) investigated the ultimate bending strength under arm opening test of some corner joints from OSB. In their studies they used five types of end corner joints with Minifix and Rafix connectors; mounting screws, one-piece connector Confirmat, and dowels. The results showed that joints with a one-piece connector “Confirmat" with size 7 x 50 mm have the highest ultimate bending moment under compression and arm opening test, equaling

17.50 N/mm^2 and 19.64 N/mm^2, respectively. Moreover, corner joints with screws and dowels performed higher strength than those with conventional connectors.

CHEN and HE (2017) claim that OSB subjected to compressive loading behaves elastically at the initial stage, which is followed by plastic deformation up to ultimate strength. After that, the load begins to slowly drop until failure.

PLENZLER *et al*. (2005) tested the behavior of OSB-webbed I-beams subjected to short-term loading. The Authors examined beams made of two flanges each, all of the pine wood (*Pinus sylvestris* L.) and 10 mm thick OSB/3 web. OSB plates used in the study were glued on both sides of the web and transmitted very well bending moment and vertical shear. The Authors conclude that lateral buckling and failure of composite I-beams made of wood and OSB plates may be caused by the occurrence of big knots in the compression flange with not large cross-sections.

Species are one of the most significant factors in the OSB process. The effect of wood species and layer structure on physical as well mechanical properties of strand boards were examined by HIDAYAT *et al*. Very satisfactory properties were observed by three species: *P. falcataria*, *M. eminii*, and *A.mangium.* The most excellent properties were performed by panels with a perpendicular layer structure when compared to the parallel and random layer structures. The obtained values as regards *P. falcataria* for the perpendicular structure were as follows: 50.41 N/mm^2 as regards MOR parallel to the grain, MOE equaling 5716.20 N/mm^2 in the same direction, and IB with the value of 0.78 N/mm^2. Mentioned parameters were, for *M. eminii*, respectively: 36.28 N/mm^2; 5313.14 N/mm^2 and 0.95 N/mm^2. In the case of *A.mangium*, the Authors observed the following values: 47.27 N/mm^2; 5300.69 N/mm^2, and 0.86 N/mm^2.

According to CHEN and HE (2017), there are three phases, in which the failure process of OSB in compression was classified. Those are the following: the elastic stage, elastic-plastic stage, and descending stage. At the initial stage, specimens behave elastically and with increasing loading, the deformation increases linearly. At the end of the elastic stage, the first vertical hairline cracks parallel to the loading direction could be observed, appearing near the steel head of the testing machine, rather than the top of specimens. The Authors claim, it occurred due to the horizontal hooping strengthening of the steel head.

Also by plywood, the species of used veneers plays an important role. KALLAKAS *et al*. (2020) compared veneer using birch, grey alder, black alder, and aspen wood species. The samples consisted of either birch only or birch in combination with other species. Birch plywood performed the highest average bending strength (114.3 N/mm^2) in parallel to the wood grain direction. The Authors observed that hardwood species used in the study show lower strength values, but the proper lay-up scheme can provide the required properties.

CHOI *et al*. (2018) analyzed mechanical properties of cross-laminated timber (CTL) with plywood using Korean Larch (*Larix kaempferi* Carr.). The Authors examined hybrid wooden-core laminated timber (HWLT) made from existing CTL and plywood. MOR, as well as MOE results, were higher for 3-ply plywood than for 5-ply plywood, for all samples. While the number of plies increased, plywood's as well HWLT's bending strength decreased.

There were studies where alternative adhesives have been examined. MOUBARIK *et al*. (2010) characterized a formaldehyde-free cornstarch-tannin wood adhesive for interior plywood. Such adhesives performed good mechanical properties as for the plywood and would be relevant to pass international standards characterization.

The following study aimed to examine the contractual compression strength and modulus of elasticity when compressing (MOEC) of three different wood composites with various structure types.

MATERIALS AND METHODS

Wood composites in three different commercial types were prepared (Figure 1): coniferous plywood 12.5 mm thick, OSB 18 mm thick, laminated particleboard 24 mm thick. For each type, there were 10 samples made. The samples were chosen for the study regarding their similar average densities, where no statistically significant differences were found. The panels varied based on their structure. Modulus of elasticity by compression (MOEC) and compression strength were calculated and density profiles were defined.

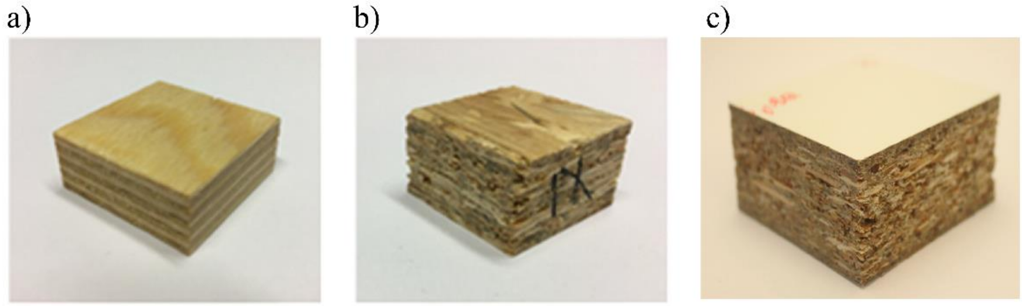

Figure 1. The pictures of the tested composites: a) coniferous plywood, b) OSB, c) particleboard laminated 24 mm

Density and density profile

The density of every sample subjected to further tests has been estimated according to PN-EN 323:1999 standard. As many as three samples of each panel variant with nominal size 50x50xthickness, mm^3, were used to measure density profile. After the measurement, the profiles were compared within one panel type, and the most representative one has been taken to further analysis in reference to the remaining panels. The study was carried out by using the X-Ray density analyzer DA-X (GreCon). The study was conducted at 0.10 mm/s speed and the sampling step was 0.02 mm.

Compression strength and modulus of elasticity under compression

For this study, ten samples of each variant were measured with the universal, computer-controlled testing machine. The deformation speed was set to reach the maximum load within 60±30 s, and the starting load was 0 N. Samples of nominal dimensions (a x b x t) of 23 x 23 x thickness, mm^3, were installed between flat, a tiltable bottom surface and flat stable upper surface, both larger than sample surface, to provide the uniform compression on the whole panel. The above-mentioned sample size has been selected according to preliminary tests, to reach the correct load when pressing a wide range of tested particleboards beyond their elasticity zone. The strength was statically increased, till it reached the plasticity deformation zone (what was visible on the real-time plot and registered by computer). The compression strength [N/mm^2], here called also “contractual compression strength” has been calculated as a maximum load [N] registered in the elasticity zone (the “B” point in A – B zone on Figure 2) when pressing, referred to the sample surface a x b [mm^2]. The modulus of elasticity when compressing (MOEC) [N/mm^2] has been calculated by computer after the compression test for elastic deformation zone. The MOEC has been defined according to JIANG *et al.* (2014) by equation (1):

$$MOEC=((\text{Load B}-\text{Load A})\times t)/(a \times b \times (\text{Deflection B}-\text{Deflection A}) \quad [N/mm^2] \quad (1)$$

where: MOEC – modulus of elasticity when compressing (MOEC) [N/mm^2]; Load A, Load B – load values at A and B points (see figure 2) [N]; t – the initial height of sample (panel thickness) [mm]; a, b – sample dimensions [mm]; Deflection A, Deflection B – deflection values at A and B points (see figure 2) [mm]

Statistical analysis

The obtained results, where applicable, were examined through one-way analysis of variance (ANOVA) to study the effect of the above-mentioned parameters on the properties of the tested panels at the 0.05 significance level ($p = 0.05$), so that the statistically significant differences between the factors could be determined. All the statistical analyses were performed using the software of IBM SPSS Statistics 22.

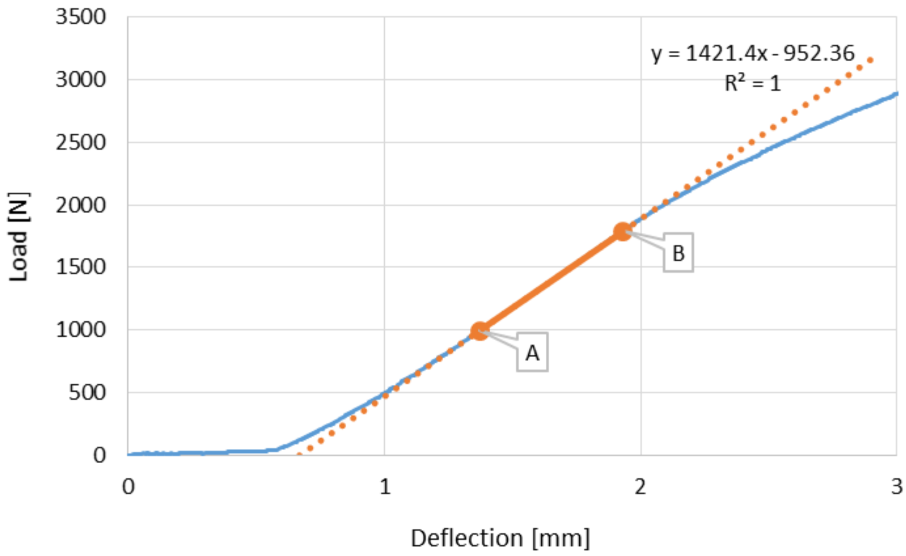

Figure 2. The load-deflection plot interpretation (A – B – elasticity zone; B – maximum load with elastic deflection) (JEŻO and KOWALUK 2020)

RESULTS AND DISCUSSION

Density profiles of examined panels have been shown in figure 3. Even though the average densities were similar for all composites, particular layers of them varied as regards density. Both particleboard and OSB performed U-shaped profiles. The outer layers in OSB had a density of more than 800 kg/m^3 while the inner one showed a value of about 500 kg/m^3. Particleboard 24 mm reached a density of over 1200 kg/m^3 in outer layers. This can appear due to laminate on panel surfaces. The inner density of the mentioned sample type performed similarly to OSB panels - the values were very close. The plywood had a slightly different density profile, the high density layers alternated with lower density ones. The last ones had values congenial to both other panel types. High density, reaching about 1000-1100 kg/m^3, can be caused by the presence of a binder between the veneers.

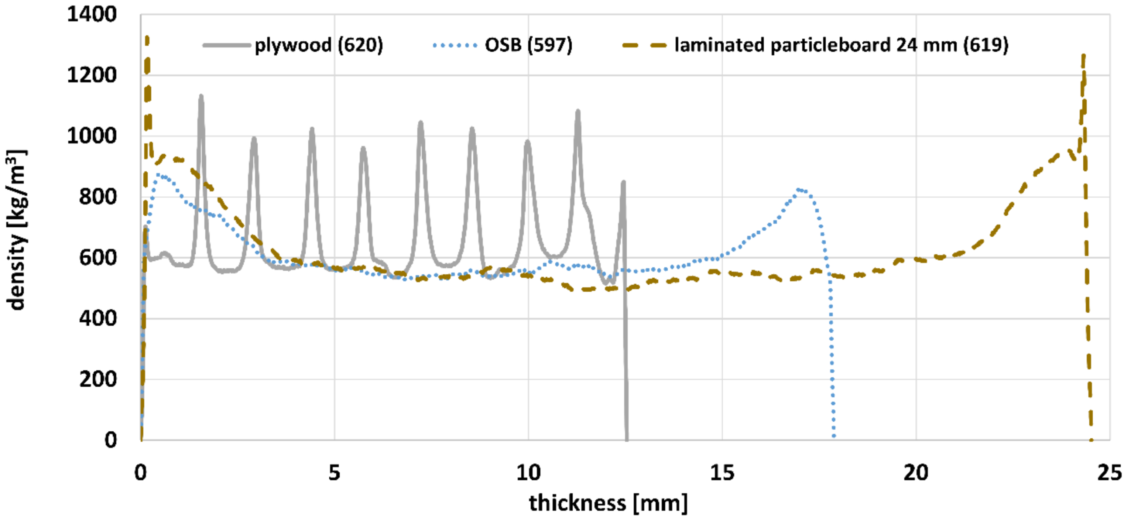

Figure 3. Density profiles of tested panels (average panel density in parenthesis)

In figure 4 the density share of tested panels has been presented. Essentially, the particleboard had the biggest amount of low density (about 500 kg/m^3). Even though the mentioned density share equals little more than 5%, it is significant, because other panel-types performed nearly 0% low-density share. The average density of all composites was about 600 kg/m^3. This density has the biggest share (25-30%). When considering high-densities, the OSB panel showed the biggest share of the density of 700-800 kg/m^3 (nearly 5%). The lowest share of mentioned densities was performed by the particleboard. The highest density share of about 1000 kg/m^3 as regards particleboard is connected to the presence of laminate on the surfaces, which does not much determine the compression properties of the panel. When considering density share as a key factor determining compression properties, the laminated particleboard is supposed to perform the lowest values due to the low-pitched high density share. Therefore, the oriented strand board would show the biggest parameter values because it gave the most significant results regarding high density share.

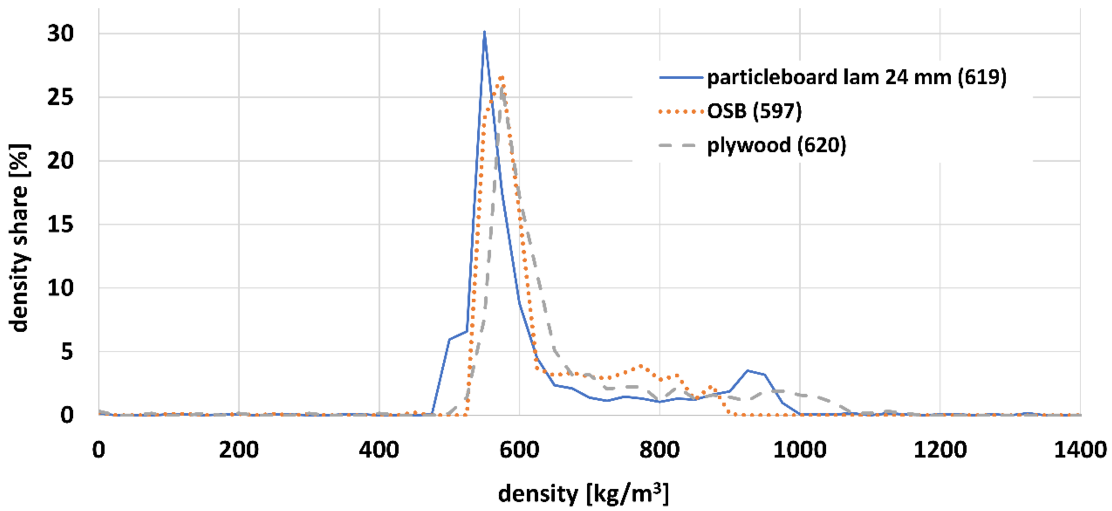

Figure 4. Density share of tested panels (average panel density in parenthesis)

On figure 5, the results of compression strength and MOEC testing have been presented. The biggest MOEC value was performed by the particleboard laminated 24 mm MOEC equalling 70.00 N/mm^2. The second was found by the OSB panels, equalling 63.03 N/mm^2. Last, but with MOEC value close to OSB, was softwood plywood with MOEC of 62.44 N/mm^2. The lowest compression strength was observed by OSB samples, with a value of 2.75 N/mm^2. The second lowest value has been performed by the softwood plywood (2.80 N/mm^2). The highest compression strength occurred by the particleboard laminated 24 mm, equalling 3.31 N/mm^2. The correlation between density and obtained results is not significant. The measure of the quality of the fit of the model R^2 shows the correlation between density and compression strength of 30.87% which means the only little impact on the obtained values. For MOEC mentioned correlation equals only 17.72%. The statistically significant differences have been found either between particular values of MOEC, as well as between compression strength values.

Considering the obtained results there is no correlation between density share and compression properties observed. The panel with the lowest share of high density performed the best mechanical properties, contrary to what was expected by the Authors. The OSB panel, which showed a bigger high-density share (figure 4), had lower compression strength, while MOEC worked conversely.

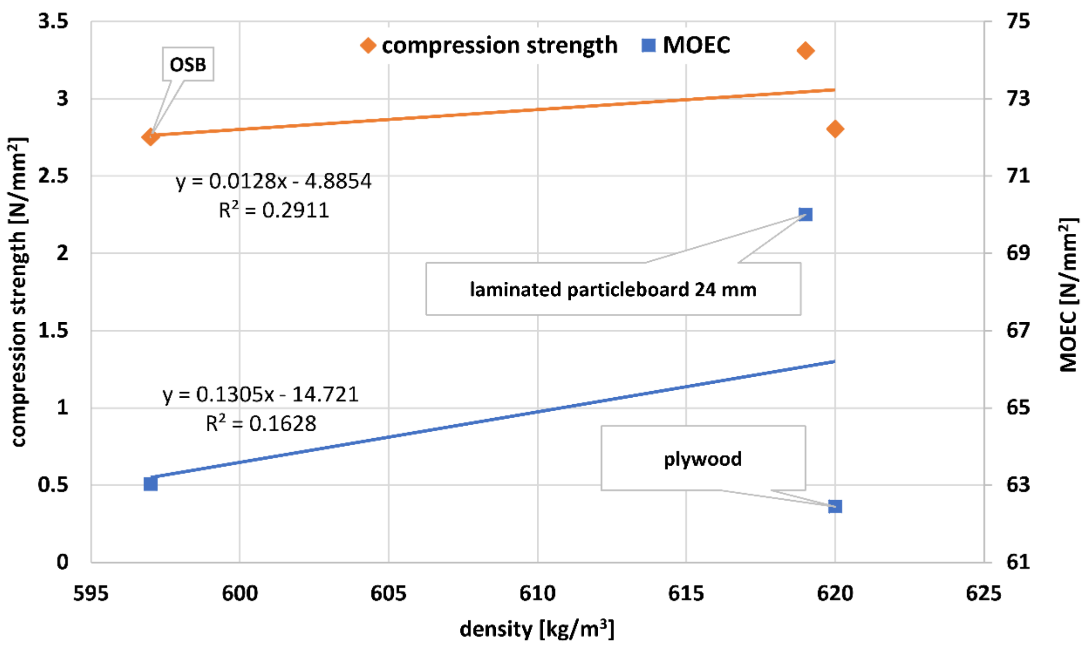

Figure 5. The compression strength and modulus of elasticity under compression (MOEC) of tested panels of various density

On figure 6 there are schematic representations of the structure of composites presented. The Authors suggest explaining the obtained results by considering the adhesive positions in particular panels. The particleboard is the composite with the smallest particles which determines the biggest adhesive inner surface. The OSB panel is the second as regards particle size. OSB contains bigger particles than regular particleboard, which results in smaller contact surface between particles and glue. Plywood, as the composite produced of veneers, contains the least amount of resin. The resin can be considered as a hard shell surrounding the particles and provides improving mechanical properties of composites. It is assumed the greater total contact surface of wood particles coated with adhesive resin, so the sum of the effective (gluing particles) surfaces of the adhesive joint is, the better mechanical properties can be performed. Based on the MOEC results, it can be seen that the MOEC value increases as the proportion of glue increases. In the case of compressive strength, it is not so obvious, although the particleboard is also the most durable (3.31 N/mm^2), the intermediate is plywood (2.80 N/mm^2) and the least durable is OSB (2.75 N/mm^2). The differences between the last two values are so small that they can be ignored. It should also be noted that the density of OSB is 23 kg/m^3 lower than that of plywood (3.7% difference).

The obtained results allow finding a correlation between the resin content and the strength parameters obtained in the test. Attention should be paid to the structure of the materials and the method of distribution of the resin on the cross section of the samples. The highest MOEC was obtained for laminated particleboard, where the wood fragments are the smallest considering all three examined materials. In the case of a smaller particle, there is the possibility of more contact points of the glue-coated wood, which in turn results in a larger area of "effective" glue joints. The second largest MOEC was shown by OSB, the wood fragments of which are the second largest. Here, the share of wood-glue surfaces is no longer as large as for particleboard due to the larger dimensions of the wood pieces. The third place in terms of the modulus of elasticity in compression is softwood plywood, where wood is the largest size among the tested composites because veneer sheets are used instead of particles. In addition, it is worth paying attention to the way the glue is distributed between the veneers compared to the previous two materials. The resin does not surround the wood fragments but lies alternately with the veneers. Thus, no resin layer strengthens the compression of the board in a direction perpendicular to its surface.

Summing up, there is a visible correlation between the size of wood particles/ veneers, the way of distribution of glue between them, gluing surface size and the strength parameters during compression.

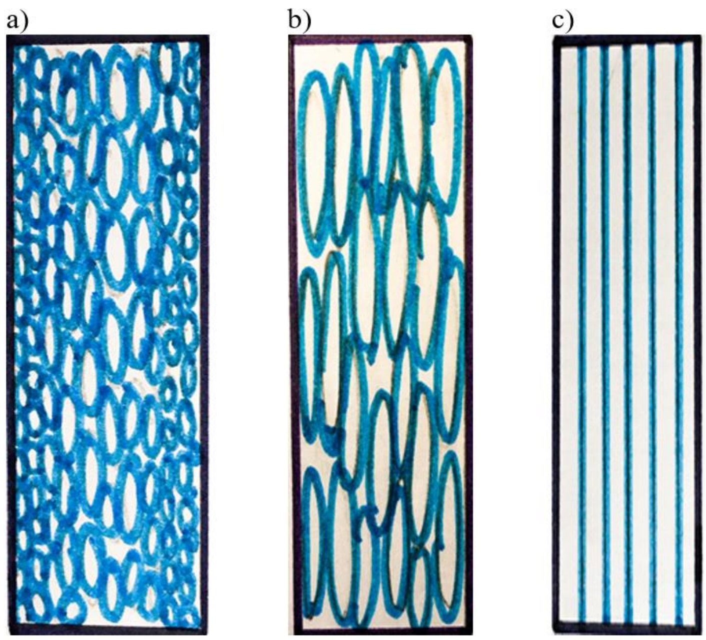

Figure 6. Schematic representation of the structure of composites: a) particleboard laminated 24 mm, b) OSB, c) plywood

The results of the calculation of the amount of solid content of glue in tested panels referred to panel volume have been shown in figure 7. The calculation has been done basing on the following data:

- plywood thickness 12.5 mm, density 620 kg/m^3, application of adhesive mass 180 g/m^2, number of veneer: 9
- OSB thickness 18 mm, density 597 kg/m^3, resination 10%
- particleboard thickness 24 mm, density 619 kg/m^3, face layers share 32%, resination face/core layers equalling 12/10%, respectively

The calculations of the recipes were made for the assumed thickness of the actual boards of size 1 x 1 m^2 and then converted to a pile of boards with a height of 1 m.

The above-mentioned calculations and their results presented in figure 7 seem to be highly correlated with achieved MOEC values. When compare the MOEC data presented in figure 5 and values of the calculated mass of solid content of glue referred to one cubic meter of tested composite, it can be concluded that the MOEC raises with increasing of total particles' surface covered with glue.

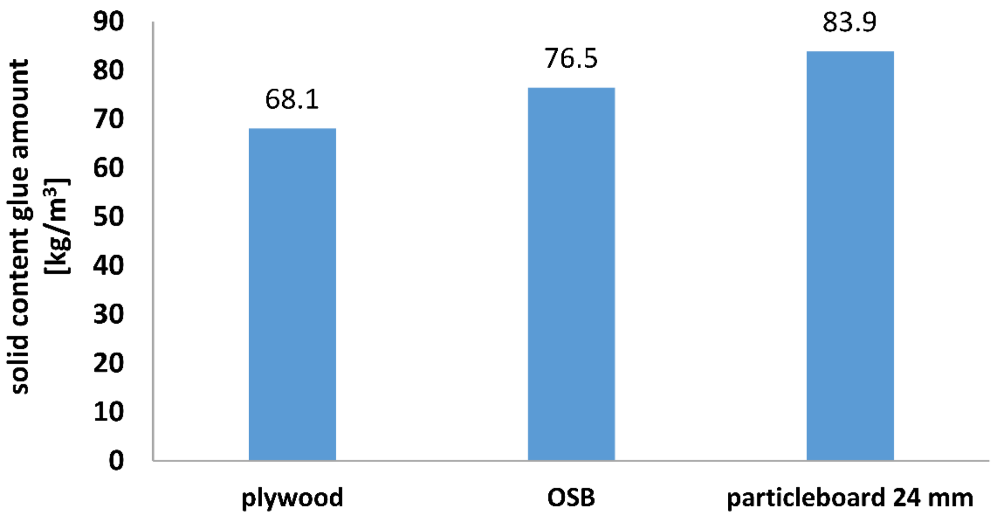

Figure 7. The calculated amount of solid content of glue in tested panels referred to panel volume

CONCLUSION

According to the conducted research and the analysis of the achieved results, the following conclusions and remarks can be drawn:

1. Particleboard showed better mechanical properties, it is assumed this can be due to the adhesive area and glue distribution within the mentioned composite.
2. It can be concluded that the MOEC values of tested panels are highly correlated with the binder solid content amount in the tested panels; the MOEC values raise with glue amount increase.
3. .It can be concluded that the MOEC values of tested panels are highly correlated to the gluing surface between particles size in the tested panels; the MOEC values raise with increasing of particles' surface covered with glue

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Streszczenie: *Właściwości kompozytów drzewnych przy ściskaniu indukowane strukturą.* Celem badań było określenie umownej wytrzymałości na ściskanie oraz modułu sprężystości przy ściskaniu (MOEC) trzech różnych kompozytów drzewnych o różnych typach struktury. Przeanalizowano również udział gęstości i profile gęstości próbek. Wyniki badań wykazały, że nie ma istotnej korelacji pomiędzy gęstością a uzyskanymi parametrami przy ściskaniu. Obserwacja udziału gęstości pozwoliła stwierdzić odwrotne niż spodziewane zależności pomiędzy udziałem gęstości a wartościami wytrzymałościowymi przy ściskaniu. Przypuszcza się, że kluczowym czynnikiem wpływającym na charakterystykę ściskania próbek była powierzchnia adhezyjna oraz zawartość suchej masy kleju w kompozytach. Dlatego najlepszymi mierzonymi właściwościami mechanicznymi charakteryzowała się płyta wiórowa laminowana, a najgorszymi - sklejka iglasta.

Słowa kluczowe: kompozyt drzewny, struktura, właściwości mechaniczne, ściskanie

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