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Compression strength and other mechanical properties of particleboards induced by density

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Abstract: *Compression strength and other mechanical properties of particleboards induced by density*. The aim of the paper was to investigate the contractual compression strength and modulus of elasticity under compression of six types of commercially available particleboards of various thickness, density and surface finish. The basic mechanical and physical characteristics of the tested panels (modulus of elasticity and modulus of rupture during bending, density and density profile) were also performed. The studies showed that the compression strength raises linearly with panels' density raise, and the modulus of elasticity under compression is linearly opposite, depending on the panels' density.

Keywords: particleboard, mechanical properties, compression, bending, MOR, MOE

INTRODUCTION

Particleboards are becoming more popular than solid wood in common applications. The wood industry values most of all their lower price and unified mechanical properties. Depending on which performances are required, the particleboards can be produced in a way to fulfil them. Nowadays, it is possible to produce such particleboards from various materials and with numerous technological methods. It all provides specific properties. Many researches on material's influence have already been done.

Atta-Obeng *et al.* (2012) tested the effect of microcrystalline cellulose, species and particle size on mechanical and physical properties of a particleboard. The species used in this study were: sweetgum (*Liquidambar styraciflua*) and southern pine (*Pinus spp*.). Wood-based materials were made at a small and large particle size and at 0 and 10% microcrystalline cellulose loading. Modulus of elasticity (MOE), modulus of rupture (MOR), thickness of swelling and work to maximum force when bending were measured for each combination. The study showed, that increasing of the particle size has a positive impact on mechanical properties but also provides higher thickness swelling. Conversely, mechanical properties and springback decreased with adding microcrystalline cellulose, while thickness swelling increased. On the basis of the tests results, the researchers suggested that hardwood species could be a feasible substitute for pine.

Mo *et al.* (2001) investigated the compression and tensile strength of low-density straw-protein particleboard. They wanted to create an environment-friendly material without using wood and UF (urea formaldehyde) resin (avoiding formaldehyde emission). The bonding of the particles was provided by soy protein. Factors that had the biggest impact on the results were: the type of adhesive, straw surface properties and the moisture content of straw. Treating straw surface with bleach gave better results than those for hydroperoxide – alone and combined with sodium hydroxide treatment. The best mechanical properties were shown by particleboards with sodium hydroxide-modified soy. The optimal initial straw moisture content providing good bonding was about 30–40%. Even though the materials produced with soy protein-based adhesive had lower mechanical properties than those made with methylene diphenyl diisocyanate (MDI) adhesive, they are more environment-friendly. They could be used, for example, in filters or light-weight core material where high mechanical strength is not required.

Sackey *et al.* (2008) carried out studies on improving the core bond strength of particleboard through particle size redistribution. The produced boards were 1- and 3-layer, at two density levels, made from four types of mixes. An unscreened industrial core furnish was used as the control particleboard. The measured parameters were: board mean, density, the modulus of rupture, the modulus of elasticity, internal bond (IB) strength, as well edge screw withdrawal resistance (SWR). Studies showed, 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 further increase in fines content. This trend was not followed regarding 3-layer particleboards. However, 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 customized mix of particles showed up to 40% higher IB and 18% better edge-SWR than boards produced with industrial furnish. Moreover, it turned out, that commercial particleboard's core-furnish may content too many fine particulates and dust, which is responsible for reducing edge-SWR. Increasing the amount of coarse particles (>2 mm) in contemporary boards and optimizing the particle-size mixture would improve IB strength and edge-SWR performances (especially for lower density boards). Flexural properties of the 3-layer boards were unaffected by core fines content. Authors suggest, that benefit in edge-SWR and IB strength could be reached by distinguishing three size-classes as regards particles (fine, medium and coarse).

Maku and Hamada (1955) carried out studies on the chipboard for the determination of the relation between moisture content, specific gravity, shearing strength, modulus of elasticity in compression and tension, tensile and compressive strength. Their researches included two basic types of wood particles (S-type: 50 mm long, 1.3 mm wide, and 0.28, 0.61 or 1.18 mm thick, shaved from beech veneer of 1.3 mm thick; R-type: 50 mm long, 12 mm wide, and 0.24 mm thick, shaved from 12 mm thick lumber of Japanese cypress). The weight of urea resin was 7.3% for S-type and 6.5% for R-type. The moisture content reached about 12–13% and moisture particles were hot pressed to specific gravity of 0.4–1.1. The results showed that with an increase in density, an increase in strength and MOE is observed as well. They also found that the produced panels' tensile strength was comparatively smaller than their compressive strength.

Riegler *et al.* (2012) conducted studies on the influence of hardwood on the vertical density profile and fracture energy of particleboards. These wood-based materials made of poplar, willow and black locust were investigated for their fracture mechanical properties. As a reference, the authors used virgin spruce wood (usually used as a raw material in the core layer of particleboards) and recycled wood chips. The results showed that the poplar and willow core particleboards performed higher fracture energy values. The explanation for this could be a better consolidation under pressing showed by lower density hardwood particles. The penetration of resin into particles is higher than by higher-density wood and the contact between the wood surfaces is closer. However, their core density was lower than of particleboards made from black locust or spruce particles.

Vital *et al.* (1974) researched how exotic hardwood species and board density affect properties of particleboard. The authors used four exotic hardwood species: kiri (*Paulownia tomentosa*), Virola (*Virola spp.*), limba (*Terminalia superba*), and afrormosia (*Pericopsis elata*) to make 3-layer particleboards (with one species and in combination of equal parts of two, three or four species). IB, MOE, MOR and dimensional stability properties were measured. The results of the study showed that MOE and MOR increased linearly with density (of wood and of a particleboard as well). There was no relation between dimensional stability and density observed, however, water absorption was inversely proportional to board density, so was thickness swelling. Boards with the same density showed higher MOR and MOE when treated with high compression. Moreover, properties of single-species particleboards and mixed-species boards were very similar in MOE and MOR – as measured for the weighted mean of the results noted for single species. There were small variations between particular species. Unfortunately, IB properties of mixed-species boards cannot be predicted from the weighted means of the results of the single-species particleboards. As for IB depending on density, regression lines were mostly not parallel – no good correlation between IB and the density of boards for afrormosia, limba, kiri-limba, kiri-virola and kiri-virola-limba was observed. What is more, IB is influenced by the geometry of particles; high IB strengths are related to a high content of small particles in a board.

However, not only the materials used in a particleboard production affect its mechanical properties. Another much important aspect is technology of the whole production process. Plenty of research have already been done in this field.

Chiang *et al.* (2016) researched effects of density of sago/urea formaldehyde particleboard towards its thermal stability, mechanical and physical properties. Several trials of mixing process were conducted. The most important elements influencing mechanical properties are density and compaction ratio. The study showed that the major factors which affect density profile of a particleboard are: particle configuration, pressing time, hot press temperature, moisture distribution, resin reactivity and the compressive strength of the sago particles component. Increasing the temperature of the hot-press caused bigger mass change of the board. Increasing density allowed to decrease that occurrence. The internal bond of the produced panels rose significantly (from about 0.22 to 0.55 N/mm^2) when the their density rose from 500 to 600 kg/m^3 , and the IB changes were not so significant when the density was increased to 800 kg/m^3. Also, the differences between the density of the core and the face layers of the tested panels decreased with the average panel density rise.

Suo and Bowyer (1994) made a simulation modelling of the particleboard density profile. The main idea was to find out how hot pressing process influences density of wood-based material. The factors affecting wood compressibility, temperature and moisture could be determined at any moment of pressing. The study allowed to model density profile based on the compressibility and the strain of the thickness of each board layer due to pressing. The system of particleboard modelling included a number of thin and uniform layers – their densities were determined by taking into consideration the temperature and moisture content during hot pressing. The authors claim that once the density profile is done, it can be used as a major factor in predicting and describing the properties of particleboars. Summing up, density can be modelled and is one of the most important features of a wood-based material.

Kawai *et al.* (1986) carried out their research on physical properties of a low-density particleboard. The main factors affecting the strength were pressure and time of pressing. Three density levels were adopted: 300, 400 and 500 kg/m^3. The raw material used in the study was Seraya (*Shorea spp.*) – end logs and core bolds with density of 400 kg/m^3. The results showed that MOE and MOR increase proportionally to density. Also the thickness of the particleboard increases proportionally to its properties. Veneer-overlaid wood-based materials showed improved MOE and MOR, competing with non-overlaid ones. Other factors did not seem to influence the mechanical properties that much.

Leng *et al.* (2017) studied the effects of density, cellulose nanofibrils addition ratio, pressing method and particle size on the bending properties of wet-formed particleboard. The materials used in the test were particles consisting of an 80 : 20 ratio of softwood : hardwood. Two pressing methods were evaluated: CT (constant thickness) and CP (constant pressure). Results showed, that density had the biggest impact on MOE, while the CNF influenced MOR the most. As regards panels with the low density

(< 640 kg/m^3), the MOR and MOE did not change much after manipulating particle size and pressing method. For wood-based materials with middle density (640–800 kg/m^3), the best properties were reached by using larger particles, higher CNF ratio and CT pressing method. Panels pressed with higher CP of 0.55 MPa showed better properties for higher densities. A higher hot-press pressure generated higher density which caused better interfibre bonding. Comparing with CP method, CT pressing method provided more acceptable (higher) bending performance, especially combined with higher CNF ratios. Summing up, increasing density and CNF volume at the same time would improve the performance of mechanical properties of a particleboard.

Miyamoto *et al.* (2002) made a research on the effects of press closing time on mat consolidation behaviour during hot pressing and on linear expansion of 10 mm thick particleboards. The properties were investigated at various press closing times (PCTs). The species used in this study was hinoki (Japanese cypress). Press pressure, temperature in the core layer of the mat and platen distance were measured. The results show, that peak density (PD) decreased with increasing PCT, while core density (CD) increased. The bending properties decreased with increasing PCT. IB strength increased with increasing CD in the PCT range 4–300 s. IB represents here the tensile strength of the core layer. Worth noticing is the fact that PCT of 900 s resulted in a lower IB despite its higher CD. That is because such a board did not have enough bonding strength (resin pre-curing started). MOE, MOR and density tend to decrease with increasing PCTs.

Kai *et al.* (2004) researched the influence of board density, mat construction and chip type on the performance of particleboard made from eastern redcedar. The authors adopted two types of chips (whole tree and pure wood), two types of mat constructions (single- and three-layer), and four density levels – 400; 500; 650 and 750 kg/m^3. Results showed that density and mat construction had the biggest impact on mechanical properties. Chip type did not affect properties significantly. 3-layer particleboards gave better results than single-layer ones, including MOR, MOE, IB and surface hardness.

Not only bending was the subject of studies on the mechanical properties of particleboards. There have been a few researches on compression strength and the modulus of elasticity when compressing.

Ferro *et al*. (2013) carried out a study on a verification of test conditions to determine the modulus of compression elasticity for wood. The investigated species were *Pinus elliottii* and *Corymbia citriodora*. According to the authors, the mechanical properties of wood depend on density, percentage of juvenile wood, the width of rings, the angle of microfibrils, moisture content, the intensity of insect attacks, and also the type, location and number of nodes. The aim of this study was to find the influence of positioning of dial gauges to determine MOEC parallel to the grain. The study showed not significant influence of dial gauges on modulus of elasticity calculations. The authors claim that because of the anisotropic character of wood, extrapolation to the same wood species or different species is not possible. They suggest using two different positions in the specimen to enable assessing equivalence of the obtained MOE.

Jiang *et al*. (2014) investigated compression strength and modulus of elasticity under compression parallel to the grain (MOEC) of oak wood at ultra-low and high temperatures. The influence of temperatures in the range of -196 to 220^{o}C on compression strength parallel to the grain and on MOEC in the range of -196 to 23^{o}C were researched. The species used in the study was *Quercus mongolica.* The authors found out that with a decrease of temperature compression strength and modulus of elasticity when compressing are raising. The correlation between compression strength and temperature and MOEC and temperature created a linear model and a polynomial model, respectively.

Xavier *et al*. (2011) carried out stereovision measurements on evaluating the modulus of elasticity of wood by compression tests parallel to the grain. The investigated species was maritime pine (*Pinus pinaster* Ait.*)*. Stereovision measurements turned out to be beneficial because an average value was less sensitive to the material heterogeneity since it could be calculated on the basis of a distance covering several annual growth rings.

Most of mechanical properties of particleboards, like bending strength, modulus of elasticity, internal bond, screw withdrawal resistance etc., are tested due to their high significance from the end user's point of view. The mentioned features are generally tested in accordance with the standardized procedures. There is no standard for testing the compressive strength of particleboards. However, it could vary depending on several factors mentioned above. This feature of particleboards is very often neglected, but it has influence on the panels, i.e. when the produced panels are stacked and stored in a few metre-high packages. Since the compressive strength of the panels, especially located in bottom zone, may be exceeded by loaded upper packages, these panels are destroyed locally by separators or have a lower thickness.

The aim of this research was to characterize the relation between contractual compressive strength, modulus of elasticity under compression and density of particleboards by measuring the compressive strength of commercially available panels of various density, and to provide the recommendation remarks in the range of compressive strength focused particleboards' stacking and storage.

MATERIALS AND METHODS

Particleboards in six different commercial types were prepared (Figure 1). For each type, there were 10 samples made. Bending strength (MOR), Young-module (MOEB) when bending and under compression (MOEC), density profile and compression strength were measured.

Density and density profile

The density of every sample was estimated in accordance with PN-EN 323:1999 standard. As many as three samples of each panel variant with a nominal size of 50 x 50 x thickness, mm^3, were used to measure the density profile. After the measurements, the profiles were compared within one panel type, and most representative one has been taken for further analysis with reference to the remaining panels. The study was carried out using a 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.

Bending strength and modulus of elasticity when bending

Ten samples with dimensions: length – (20x nominal thickness + 50) mm, width – 50 mm, of each panel-variant were tested in this study. The measurements were performed in accordance with PN-EN 310:1994 standard on a universal, computer-controlled testing machine.

Compression strength and modulus of elasticity under compression

For this study, ten samples of each variant were measured with a 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, 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 was selected following preliminary tests to reach the correct load when pressing wide range of tested particleboards beyond their elasticity zone. The strength was statically increased, till reached the plasticity deformation zone (what was visible on the real-time plot and registered by computer).

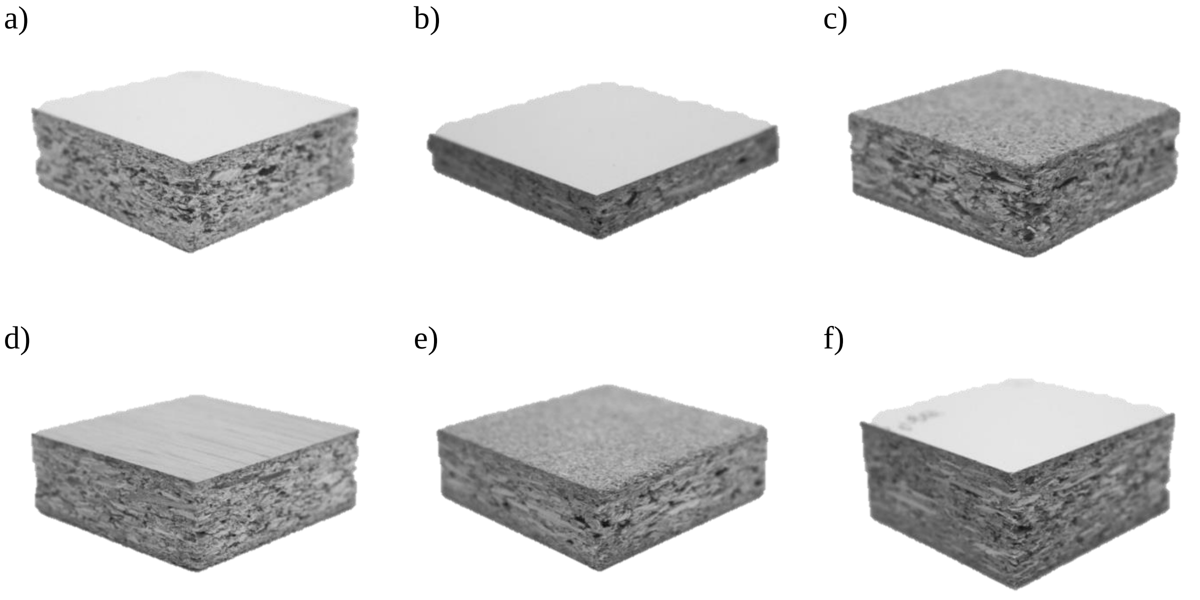

Figure 1. Pictures of the tested particleboards: a) laminated 18 mm, b) laminated 8 mm, c) raw 18 mm, d) laminated oak 18 mm, e) raw 16 mm, f) laminated 24 mm

The compression strength [N/mm^2], here called also “contractual compression strength” was 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] was calculated by a computer after the compression test for elastic deformation zone. The MOEC was defined in accordance with Jiang *et al.* (2014) using the following equation (1):

$$MOEC = \frac{(Load\ B - Load\ A) \times t}{a \times b \times (Deflection\ B - Deflection\ A)} \quad \frac{N}{mm^2} \qquad (1)$$

where:
MOEC – the 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 were examined by means of a variance analysis (ANOVA), then subjected to the Student’s test ($\alpha = 0.05$) so that the statistically significant differences between the factors could be determined.

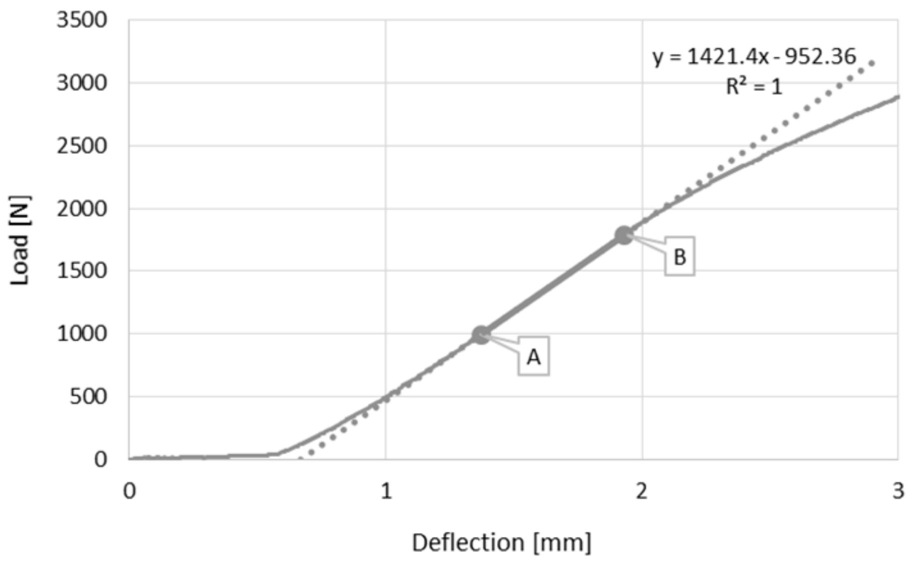

Figure 2. The load – deflection plot interpretation (A – B – elasticity zone; B –maximum load with elastic deflection)

RESULTS

Density and density profile

The results of density and density profile measurement have been presented on figure 3. The results show, that the investigated particleboards differed in their density profiles, even though their average densities were similar.

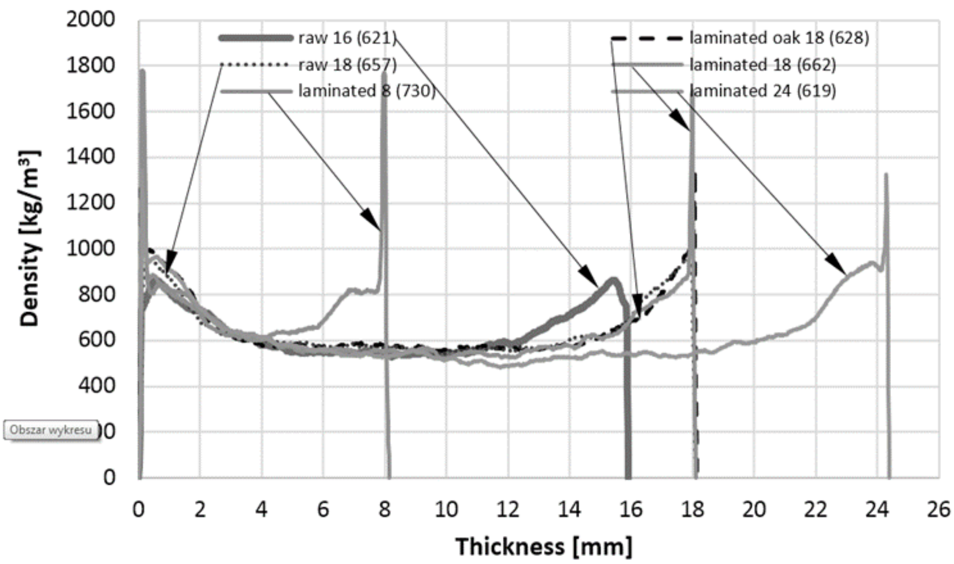

Figure 3. Density profiles of the tested panels (the average panel density in parenthesis)

All profiles were U-shaped. The highest peak density was observed in the laminated particleboard 8 (about 1800 kg/m^3) while the lowest – in the raw 16 (nearly half as big as that for the laminated 8) and raw 18 (about 1000 kg/m^3). The laminated particleboard 18 gave results nearly as high as the laminated 8 with regard to the peak layer. The laminated 24 and the laminated oak 18 showed peak densities very close to each other – all above 1200 kg/m^3.

The core layer-density in its lowest point had a similar value for each of the investigated particleboards. The laminated particleboard 8 reached bigger values in the core layer, equalling the minimal density only in the middle point. A fast increase of density towards the outer layers was observed there. The biggest contribution of the lowest density-values in the core layer of the particleboard occurred in the laminated 24. The particleboard raw 16 showed the lowest difference between the core and the peak layers.

Bending strength and modulus of elasticity when bending

Bending strength (MOR)

The results of bending strength and modulus of elasticity when bending tests have been presented on figure 4. As it can be seen, among particleboards with density up to 680 kg/m^3, laminated particleboard 24 gave biggest average values of modulus of rupture (17.2 N/mm^2), even though its density was the lowest.

The relation between MOR and density was the strongest for the oak laminated particleboard with a nominal thickness of 18 mm. Its MOR was second in value, following the laminated particleboard 24.The oak laminated board 18 showed a low density as well – 640 kg/m^3 on average. The white laminated particleboard 18 was third regarding MOR. Its density exceeded the densities of both previous boards (668 kg/m^3), but its MOR was not higher. The next sample with lower MOE values turned out to be the raw particleboard with a nominal thickness of 16 mm. Its density ranked between those of the laminated board 24 and the oak laminated board 18 – the average quantity was 633 kg/m^3. The lowest MOR was discovered for the raw particleboard with a nominal density of 18 mm. Its density-range showed to be the widest among the examined particleboards and was within the range of 637–664 kg/m^3. In case of laminated particleboard 8 with density above 730 kg/m^3, this particleboard showed the strongest correlation between MOR and density, when analyzing the individual samples results. Laminated board with nominal thickness of 8 mm could reach MOR values exceeding results of laminated board 24 – its highest value reached 19.6 N/mm^2 (when analyze the individual samples), while maximal MOR of laminated board 24 equalled 17.2 N/mm^2. The lowest value of this parameter for laminated particleboard 8 endured 11.6 N/mm^2. None of the rest of examined particleboards showed such as wide results-range as this one. This is presented on the plot by error bars (standard deviation). What is more, as regards density laminated particleboard 8 reached the biggest outcome (747 kg/m^3). Among all of investigated samples, only raw particleboard 18 did not meet the requirements for bending strength of P2-type particleboards characterized by PN-EN 312:2011. The statistically significant differences of average values of MOR have been found between following panels: laminated 24 against raw 16, laminated oak 18, raw 18 and laminated 18; raw 16 against laminated oak 18, raw 18 and laminated 18; laminated oak 18 against raw 18; raw 18 against laminated 18.

Modulus of elasticity (MOE)

Among particleboards with lower density (<680 kg/m^3) the highest modulus of elasticity was registered for the oak laminated particleboard 18 – an average of 2934 N/mm^2. This was followed by the white laminated board 18 (2770 N/mm^2), then the laminated 24 (2499 N/mm^2), the raw 16 (2526 N/mm^2) and the raw 18 (2317 N/mm^2). The same as with the modulus of rupture, also here the strongest correlation between MOE and density, when analyzing the individual samples, was shown by the laminated particleboard 8 – the one with the biggest density (>730 kg/m^3) and the smallest thickness. The range of noted MOE-results for this particleboard was the biggest (1988–3528 N/mm^2) and the maximal modulus of elasticity outperformed the maximal value of MOE gained for the oak laminated board 18 – 3014 N/mm^2. The raw particleboard 18 showed lowest results as regards MOR and MOE as well. All of the investigated particleboards met the requirements for the modulus of elasticity of P2-type particleboards in accordance with PN-EN 312:2011. Statistically significant differences of the mean values of MOE were found between the following panels: the laminated oak 18 against all the remaining panels; the laminated 18 against the laminated 24, the raw 16 and the raw 18.

Worth noticing is the fact that laminated wood-based materials occurred to have higher MOEB and MOR values. This phenomenon is very clear for particleboards with a nominal thickness of 18 mm. While the raw 18 particleboard reached an average of 2317 N/mm^2 for the modulus of elasticity and 9.84 N/mm^2 for the modulus of rupture, the same parameters for the laminated 18 and the oak laminated 18 were: 2770 N/mm^2; 14.2 N/mm^2 and 2934 N/mm^2; 15.0 N/mm^2, respectively). This occurs even though the density of the raw 18 is higher than of the oak laminated 18. The highest average MOR during bending, 17.2 N/mm^2, has been noted for the laminated panel of 24 mm nominal density. This can be influenced by both, laminate presence and the thickness of the panel. Since during bending, the face layers are mostly responsible for carrying the load, the strength of the bended material is higher when the position of these face layers is far from the middle of thickness.

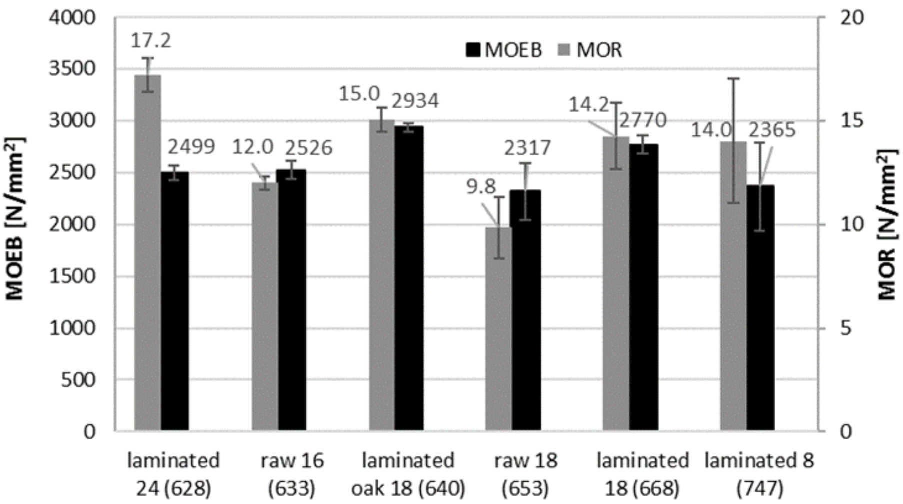

Figure 4. The modulus of elasticity when bending and the modulus of rupture of the tested panels (the average panel density in parenthesis)

Compression strength and modulus of elasticity under compression

Compression strength

The results of compression strength tests for the tested panels are presented in figure 5. According to the data displayed, the compression strength of particleboards is strongly related to density. This correlation can be confirmed by correlation coefficient R^2, which is here about 0.9. The compression strength increases linearly with increase of density. For values about 620 kg/m^3 (panels laminated 24 and raw 16) it equals average 3.31 N/mm^2, while for density in range of 730 kg/m^3 compression strength with value about 4.52 N/mm^2 was observed. The relative raise of compression strength in measured density range was about 39% (when calculated according to regression line). The compression strength change referred to density was 1.14 N/mm^2 / every 100 kg/m^3 density change (also calculated according to regression line). Statistically significant differences of the mean values of contractual compression strength were between the following panels: the laminated 8 against all the remaining panels; the laminated oak 18 against the laminated 24; the raw 16 against the laminated 24, the raw 18, the laminated 18.

According to Krzysik (1975), the following compression strength (contractual) across the fibres in intermediate (between radial and tangential) direction are characteristic: 4.31 N/mm^2 for pine (density 590 kg/m^3), 2.16 N/mm^2 for fir (density 500 kg/m^3) and 3.82 N/mm^2 for spruce (density 450 kg/m^3). It can be concluded that the results achieved for particleboards which are produced generally from coniferous species available in Poland are comparable to the mentioned literature. A higher density of the tested particleboards, with regard to solid wood, must compensate the structure of particleboards, which is not so continuous as in solid wood.

Modulus of elasticity under compression (MOEC)

The results for compression strength of the tested panels are presented in figure 5. According to the data displayed, MOEC was also strongly related to density. This correlation between MOEC and density is confirmed by coefficient R^2 = 0.86. However, the correlation was converse to the one regarding compression strength. MOEC decreased while density increased. For density of about 620 kg/m^3, values of about 73 N/mm^2 were noted. Investigating density in the range of 730 kg/m^3, measured MOEC gave less than 55 N/mm^2. The MOEC change coefficient, referred to the density in the measured range was about 16.6 N/mm^2 per 100 kg/m^3 of density change. Such a change in the measured density range (111 kg/m^3) is about 25% if referred to the higher value (for lowest registered density). When analysing the statistical significance of the mean values differences, the only statistically significant ones were found between the laminated 8 (density about 730 kg/m^3) and the remaining panels, as well as between the laminated oak 18 against the laminated 18.

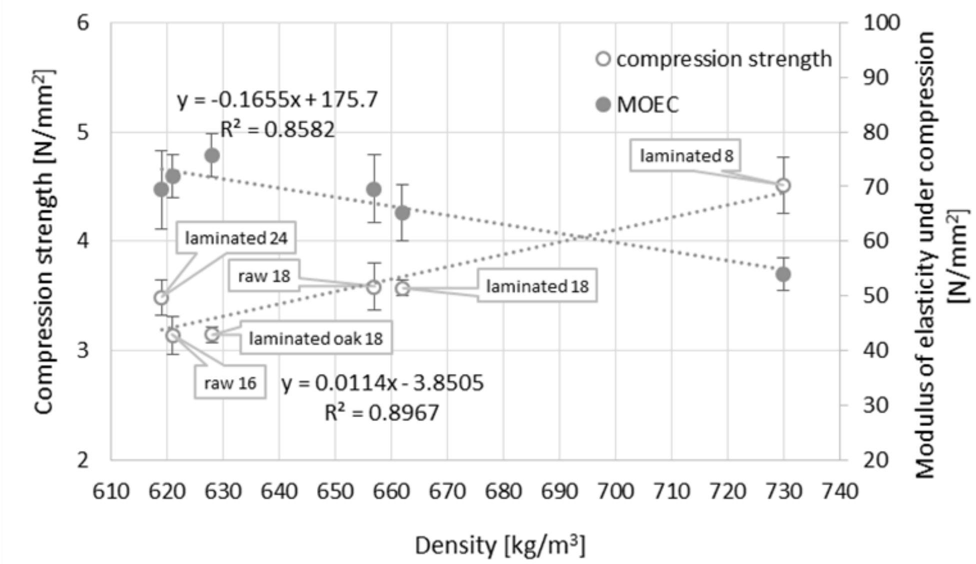

Figure 5. Compression strength and modulus of elasticity under compression (MOEC) of the tested panels of various density

As the results show, a deformation in high-density particleboards before damage can be higher than in low-density boards. This can be explained by a stronger affection of the particles in high-density boards due to closer distances between them. Moreover, particleboards with a higher density do not break as easily as low-density ones.

The studies showed that MOEB values are significantly higher than MOEC. For example, for a particleboard with the highest density, the modulus of elasticity when bending was nearly 2500 N/mm^2, while the modulus of elasticity when compressing was less than 70 N/mm^2. The same situation can be observed for bending and compression strengths. With regard to the mentioned particleboard, MOR was nearly 15 N/mm^2 and the compression strength was about 4.5 N/mm^2. This shows that the investigated particleboards were easier to compress than to bend.

This study provided some conclusions about particleboards storage. Based on the received results, the hypothetical conditions have been calculated. The calculations assumed an average density of 650 kg/m^3 and a compression strength of about 3 N/mm^2 (almost the lowest registered here), on the basis of the study results. It was found out that using four separators, each 2-m long and 10-mm wide, and having particleboards with mentioned average density and compression strength and exemplary dimensions of 2000 x 3000 x 18 mm^3, the pressure generated on the lowest located panel by every 1 meter of high stack is about 0.05 N/mm^2, which means about 1.7% of the achieved contractual compression strength of the particleboard. If so, to exceed the compression strength of the panel located directly on the separators (lowest panel) by stacking mentioned panels, the stack height should exceed 60 m.

The received values are enormous and rather non-realistic. This encourages an assumption that the reason for the damage of particleboards which were the lowest in the stack could be not immediate compressive strength but rather a longer-lasting load. Such a load causes rheological changes (creep). They can not be measured by normalized studies during 60+/-30 s loading. For this reason, due to the longer-lasting load, a lower charge is needed to deform a particleboard in the bottom of the stack.

CONCLUSIONS

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

1. Materials with higher compression strength show lower MOEC values.
2. There was a high correlation (R^2 about 0.9) found between the compression strength of the tested particleboards, MOEC and their density. Correlations between density and both of the measured while-compressing parameters were opposite to one another.
3. The real reason for the damage of panels in the lowest parts of a stack during storage could be a longer-lasting load (creep phenomena) – values of a load smaller than those calculated for immediate compression strength are needed to crush the panels.
4. Laminated particleboards have a higher modulus of both rupture and elasticity when bending, even though raw ones show a higher density.
5. With regard to raw samples, better mechanical properties when bending (MOR and MOEB) were observed for the particleboard with a nominal thickness of 16 mm, i.e. the thinner one.
6. No clear correlation between the thickness of the particleboard and its bending mechanical properties was observed.
7. The relation between MOR and MOE is proportional – only with the raw 16 was it converse.

8. The best mechanical properties for bending (MOR) were displayed by the particleboard laminated 24. This could be explained basing on its profitable high thickness and laminate presence.

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Streszczenie: *Wytrzymałość na ściskanie i inne właściwości mechaniczne płyt wiórowych w zależności od ich gęstości*. Celem badań było określenie umownej wytrzymałości na ściskanie i modułu sprężystości przy ściskaniu sześciu rodzajów dostępnych na rynku płyt wiórowych o różnej grubości, gęstości i wykończeniu powierzchni. Przeprowadzono także charakterystykę podstawowych właściwości mechanicznych i fizycznych badanych płyt (moduł sprężystości przy zginaniu i wytrzymałość na zginanie, gęstość i profil gęstości). Badania wykazały, że wytrzymałość na ściskanie rośnie liniowo wraz ze wzrostem gęstości płyt wiórowych, a liniowa zależność modułu sprężystości podczas ściskania od gęstości płyt jest odwrotnie proporcjonalna.

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