

The influence of defibration pressure and fibres drying parameters on the properties of HDF made with recovered fibres

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Abstract: *Defibration pressure and fibres drying parameters influence on the HDF properties made with recovered fibres.* The objective of this study was to investigate the defibration pressure and fibres drying process parameters (influence on the mechanical, physical properties and on formaldehyde content (FC) of ultrathin (2.5 mm) industrial high-density fibreboards (HDF) produced with 5% of recovered HDF (rHDF) addition. For this investigation the fibres were produced in industrial defibrator under four different set points: 0.65 MPa (V1), 0.90 MPa (V2), 1.00 MPa (V3) and 1.06 MPa (V4), dried in industrial two stage dryer with four different dryer inlet temperatures set points: 100°C (V00), 111°C (V11), 122°C (V22) and 133°C (V33). The results indicated that pressure is a significant factor and affects for all HDF properties. Too low defibrator pressure negatively influences HDF mechanical and physical properties as well as FC (high level). Regarding fibre drying temperature influence on HDF properties, no straight correlation was found. Linear negative correlation was found for modulus of rupture – 10% decrease comparing V00 to V33, internal bond – 23% decrease comparing V00 to V22 and surface soundness – also 23% decrease comparing V00 to V33.

Keywords: wood-based panel; HDF, recovered fibre; pressure, defibrator, drying

INTRODUCTION

European production of medium density fibreboards (MDF) has more than doubled over last 20 years reaching yearly production ~17.8 bln m³ (in 2018) that makes fibreboard production one of the fastest developing sector of wood-based panels (WBP) industry (“Food and Agriculture Organization. Forestry Production and Trade.” 2020). Different usage and surface finishing are probable reasons for such fast sector development (NICEWICZ, SALA 2014). Growing production output increases raw material supply. In Polish conditions fibreboards are predominantly made of pine and spruce wood, as well as from less popular species, like alder, birch or beech (NICEWICZ, SALA 2013). Growing demand for raw material causes price increases; based on Polish State Forest data, the price of pine wood has grown over 15% from 2013, reaching 260 zł/m³ in 2017 (www.drewno.pl).

Round wood for MDF production may be substituted with such materials as recovered wood, however, newsprint, plantation wood species, straws or post use wood-based panels may also be effectively used (ONISKO 2011). This helps to reduce the costs of fibreboards production and make these products competitive on the wood-based panels market. Eco-friendly trend has made post used wood reuse into the fibreboard production more popular in recent years. The total amount of this waste material used in particleboard industry in UK has increased for over 25% from 2015 to 2018 and will further increase next years (Tolvik Consulting 2018). However, reintroducing recovered materials negatively influence MDF mechanical and physical properties (HWANG et al. 2005), so, to obtain the best panel properties produced with post used boards addition, it is important to optimize production parameters (WAN et al. 2014).

The quality of a future wood-based panel is created on each manufacturing step, beginning from material parameters, such as wood species and age, storage method and time,

as well as raw material moisture content (AURIGA, BORUSZEWSKI 2013; AYRILMIS et al. 2017; KHALIL et al. 2008; SHI, SHANG 2005). Not only do raw wood materials characterization define wood-based product, but prepared fibres shape, quality and size are translated into resulting panel quality (KLIMCZEWSKI, NICEWICZ 2013; PARK et al. 2001). Additionally, a glue type and its amount have also a crucial meaning (HONG et al. 2017; NICEWICZ, MONDER 2011). What is more, assumed parameters of the produced panel are taking part in defining final MDF properties – together with panel moisture content or density change, the quality of the product also changes (BEKHTA, NIEMZ 2009; HONG et al. 2017). Nearly all of material variables may be compensated by proper process parameters setup and adaptation. It has been confirmed that by tuning defibrator parameters, e.g. time and pressure in heater, the board parameters may be adjusted for the customer needs (AYRILMIS et al. 2017; XING et al. 2007; NICEWICZ, SALA 2013). Refining pressure during defibration plays an important role during HDF production. It is responsible for good fibres quality (GROOM et al. 2008), which affects the performance of final board properties (IBRAHIM et al. 2013). In general, the MDF mechanical properties increase with an increase in fibre length, whereas physical properties decrease (BENTHIEN et al. 2014). However, together with a refining pressure increase, different fibre damage can be observed. Fibres subjected to relatively low pressures (0.2–0.4 MPa) give no obvious damage to the cell walls. Fibres cell wall has nano-cracks when they are subjected to pressures of 0.6–1.2 MPa and micro-cracks can be found in fibres subjected to high pressure of 1.4–1.8 MPa. Additionally, fibres become shorter and thinner while fibre length-to-width ratio is increasing (XING et al. 2007). Due to the fact that fibre quality greatly influences the performance of MDF, based on gathered data and defibrator setup, there have been many different algorithms developed and investigated during refining in order to evaluate and predict fibre quality more accurately (JIAO et al. 2016; GAO et al. 2018). It is also very important to recognize the correlation between refining parameters and outcome fibre quality of wood mix with recovered HDF (rHDF) addition. Second main factor influencing fibreboards properties, is wooden material drying process. The next factor is pressing parameters. In case of drying, it is important to reach the proper fibre moisture content on the forming line (NICEWICZ, MONDER 2013), because this feature is responsible for heat transfer during hot pressing (THOEMEN et al. 2006), crucial for mat preheating and resin curing in hot press (SALA 2020; MEYER, THOEMEN 2007). This also helps to form board density profile that later transfers to different level of modulus of rupture, internal bond or surface quality – significant for target wood-based panel application (GUL et al. 2017; NOURBAKHSI et al. 2010; WONG et al. 2000). The fibre drying process is an essential step of fibreboard production. Dryers for MDF production may be single- or two-stage, however the second version offers the following benefits: busts the capacity, has 25% lower heat energy consumption, requires smaller power plant, has more precise fibre moisture control ($\pm 0.5\%$), provides lower dust emission and less losses connected with resin precuring (“Fibre Drying Process” 2010; “Food and Agriculture Organization. Forestry Production and Trade.” 2020). No matter which one is used, both can have automatic adjustment of final dried material moisture content, related to downstream processes, that is based on a set dryer inlet temperature. Its parameters selection is very important, not only from the point of view of the correctness of the production process, but also from economy, because proper drying setup can bring up to 15% of energy cost savings (“Flash Tube Dryer”).

Considering that MDF production is still developing, and new usages of these boards are implemented on the market, as well as the fact that reintroduction of post used materials into the production will be more and more common in the future, the aim of this research was to evaluate the factors important with regard to HDF panel properties: defibrator heater

pressure and fibre dryer inlet temperature influence on selected mechanical and physical properties of high density fibreboards (HDF) produced with 5% of recovered HDF addition.

EXPERIMENTAL

Considering the fact two process parameters have been evaluated for this work, the investigation was divided into: part 1 – the influence of the defibrator heater pressure and part 2) – the influence of fibres drying temperature. However, the tested material and methods applied have several parts in common.

MATERIAL

Raw 2.5 mm HDF panels with a target density of 860 kg/m³ were produced in industrial scale for this investigation. Boards were made of Polish State Forests pine (*Pinus sylvestris* L.) wood, delivered Polish State Forests, with 5% addition of recovered high density fibreboards (rHDF), as cutoffs and production leftovers. The standard requirement of the formaldehyde emission was CARB 2 directive, with the formaldehyde content <5.0 mg/100 g measured with perforator method (EN 12460-5; IOS-MAT-0003). After three months of seasoning round wood raw material at the wood yard, logs were chopped with 10 knives Metso disc chipper, while fibres were produced on industrial Metso defibrator EVO56 from these chips with rHDF addition. These have been mixed with wood chips on defibrator feeding conveyer. Defibrator hydrothermal parameters were as follow: preheating pressure depending on the variant: V1: 0.65 MPa, V2: 0.90 MPa, V3: 1.00 MPa, V4: 1.06 MPa as maximum available during production time. The preheating temperature was 160°C, 174°C, 179°C, 182°C accordingly to the variant. For the remaining trial, the pressure was 0.94 MPa. Preheating time: 3.2 min, an average defibrating energy consumption: ~145 kWh/t. Paraffin emulsion was added into the defibrator milling chamber in the amount of 0.5% of dry weight of paraffin calculated with reference to the weight of the oven-dry fibres. Next, the fibres were glued on high steam pressure Blow Line system with commercial MUF resin (melamine content 5.2%, molar ratio 0.89, solid content 66.5%) with the following composition: 11.0% of dry resin weight referred to dry wood, urea 21.0%, hardener 3.0% (ammonium nitrate water solution), both calculated as dry content to dry glue weight ratios. For this investigation, four different temperatures of Sunds two stage fibre dryer inlet were used, depending on the variant, as follow: V00–100°C, V11–111°C, V22–122°C and V33–133°C.

METHODS

The adjustment of wooden material amount dosage with regard to cutoffs and trims addition is described by SALA et al. 2020.

Raw material fraction

Fraction of pine wood chips was examined on IMAL vibrating laboratory sorter with 9 sieves sized: 40, 20, 10, 8, 5, 3.15, 1.0, 0.315, <0.315 mm. The amount of material for each fraction analysis was ~100 g and set time of conducting the vibrating was 5 minutes. Gathered results were shown as an average of three examinations.

Chips moisture content

Chips moisture content was examined in accordance with the factory internal method with scales and an oven. The amount of material for each examination was ~50 g, oven

temperature was 103°C and heating time was about 4 h for stable weight. The obtained results were shown as an average of eight examinations.

Defibrator heater pressure setup

Depending on the variant, Metso defibrator heater pressure was set on industrial PLC visualization as a set point controlled by defibrator software and automatic control steam valve. Remaining defibrator parameters were kept by the software on assumed level. The reference pressure was 0.94 MPa. When analysing the influence of defibrator heater pressure on the properties of fibres and produced panels, the following heater pressure levels were tested: 0.65 MPa (V1), 0.90 MPa (V2), 1.00 MPa (V3) and 1.06 MPa (V4).

Fibre drying temperature setup

Dryer temperature

Sunds two stage fibre drying temperature, depending on the variant, was set on industrial PLC visualization as a set dryer inlet temperature. Air flow and fibre transportation air temperature were adjusted to defibrator capacity using Dieffenbacher software to reach final fibre moisture content on forming line at the level of 9.5% +/-0.5%. The reference dryer temperature was 122°C. When analysing the influence of fibres' inlet drying temperature on the properties of the fibres and produced panels, the following dryer temperature levels were tested: 100°C (V00), 111°C (V11), 122°C (V22) and 133°C (V33).

HDF examination

The produced HDF boards were conditioned before the examination and all sample variants were cut according to EN 326 (EN-326-1 1994). The modulus of rupture (MOR) and modulus of elasticity (MOE) when bended were determined according to EN 310, internal bond (IB) was determined following EN 319 while surface soundness (SS) was determined according to EN 311. All of mechanical properties were examined on IMAL laboratory testing machine. From physical properties HDF board density was determined following EN 323 on IMAL testing machine, moisture content according to EN 322 and thickness swelling (TS) due to EN 317 while surface water absorption was conducted according to EN 382-1. Surface roughness measurement was performed with the use of a Surtronic 25 – TAYLOR HOBSON device and the results of surface roughness were shown as an average from 10 measurements for each examined surface variant. The board formaldehyde content was examined according to EN 12460-5 (called the perforator method) using an Hach Lange DR 3900 spectrophotometer.

One-way analysis of variance (ANOVA) was conducted to study the relation between the above-mentioned parameters and the properties of the tested panels at the 0.05 significance level (P=0.05). All the statistical analyses were performed using IBM SPSS Statistics 22 software.

RESULTDS AND DISSCUSSION

PART 1 Defibrator heater pressure setup

Fibres mass characterization

Fibre bulk density and fibre moisture content from online forming line sensors are gathered in Tab. 1. Although wood age and mix was constant, as it can be seen, fibre bulk density differed, what might have been caused by different defibrator heater pressure parameter during material preparation, because defibrator pressure has an influence on fibre dimensions and quality (XING et al. 2007).

Tab. 1 Fibre bulk density and moisture content from V1, V2, V3 and V4

	V1	V2	V3	V4
Fibre bulk density [kg/m ³]	18.21	18.38	19.48	20.62
Fibre moisture content [%]	9.53	9.68	10.00	9.78

The fibre bulk density has an influence on the properties of MDF technology panels. It depends on such characteristic of wood-fibres, as fibre length and its distribution (PARK et al. 2001). Based on data in Tab. 1, it can be seen, that together with defibrator pressure increase, the fibre bulk density was increasing as well. The lowest density reading was for V1 – 18.21 kg/m³. Defibrator pressure increase for 0.25 MPa caused slight fibre bulk density increase to 18.38 kg/m³. Fibres produced from wooden material treated with 1.00 MPa of hydrothermal treatment in defibrator heater had nearly 7% higher bulk density comparing to V1 reaching 19.48 kg/m³. The highest fibre bulk density was measured for V4 – 20.62 kg/m³, which was 12% more than the minimum for V0. The difference of 2.41 kg/m³ between minimum and maximum fibre bulk density from the variant may be responsible for mechanical and physical properties of produced HDF, similar to MDF properties (BENTHIEN et al. 2014).

The fibre drying process was set to the final fibre moisture content at the level of 9.70% and, as it can be seen in the Tab. 1, the results of the readings from forming line moisture content sensor were within the supplier accuracy specification of +/-0.5%. The highest fibre moisture content had fibres from V3 – 10.00% and the lowest from V1 – 9.53% which was about 5% lower comparing to the maximum moisture content reading. The minimum and maximum fibre moisture contents for V2 (9.68%) were ~+2% and ~-3% while for V4 (9.78%) were ~+3% and ~-2%, respectively. The described fibre moisture content differences should not had significant influence on mechanical or physical properties of examined HDF boards.

Mechanical and physical properties

HDF testing results from all variants and standard deviations (SD) were gathered and shown in the Table. 2. Assumption of HDF boards density from all of the variants was on the level of 860 kg/m³. However, an average achieved density of produced panels was on the level of 867 kg/m³. Despite panel density has a meaning for its final wood-based panel properties (HONG et al. 2017), considering, that in this investigation, the difference between minimum and maximum HDF density was only 4 kg/m³ (0.5%) it should not have any influence on HDF properties.

Table. 2 HDF boards properties results from V1, V2, V3 and V4

Variant	Density [kg/m ³]	SD	MOR [N/mm ²]	SD	MOE [N/mm ²]	SD	IB [N/mm ²]	SD	SS [N/mm ²]	SD	MC [%]	SD	TS [%]	SD	FC [mg/100g]
V1	868	18	47.5	3.1	4218	185	0.67	0.09	0.94	0.17	5.6	0.4	38.69	2.40	5.23
V2	865	19	51.8	2.9	4275	191	0.81	0.18	1.18	0.20	6.1	0.4	36.60	2.00	4.97
V3	869	19	50.7	2.6	4255	202	0.87	0.15	1.23	0.21	5.4	0.4	35.49	2.08	4.89
V4	865	15	49.2	2.4	4181	197	0.83	0.14	1.06	0.19	5.8	0.3	27.58	1.31	4.62

Figure 1 shows results of modulus of rupture. All of tested samples from Part 1 met minimum MDF requirements of EN 622-5 that is ≥ 23.00 N/mm².

Despite the fact, that results were more than two times higher than the specified, the minimal MOR was achieved for V1 (47.52 N/mm^2). Increasing defibrator heater pressure to 0.90 MPa caused MOR increase for 8% reaching 51.82 N/mm^2 . Further pressure increase to 1.00 MPa resulted in bending strength decrease to the level of 50.73 N/mm^2 that was 6% more than the minimum and 2% less than the maximum. Boards from V4 had MOR on the level of 49.22 N/mm^2 . Decreasing of MOR together with defibrator pressure increase above 0.90 MPa might have been caused by damaging fibre cell wall with nano-cracks (XING et al. 2007). Additionally based on fibre bulk density together with defibrator pressure increase there might have been more fraction with smaller particle size. The bigger amount of fines increases the surface area of the fibres what results in decreasing the resin coverage per unit surface area (HWANG et al. 2005). Hence, the strength of the final panel might be decreased. There were no statistically significant differences of MOR average values found for the variants.

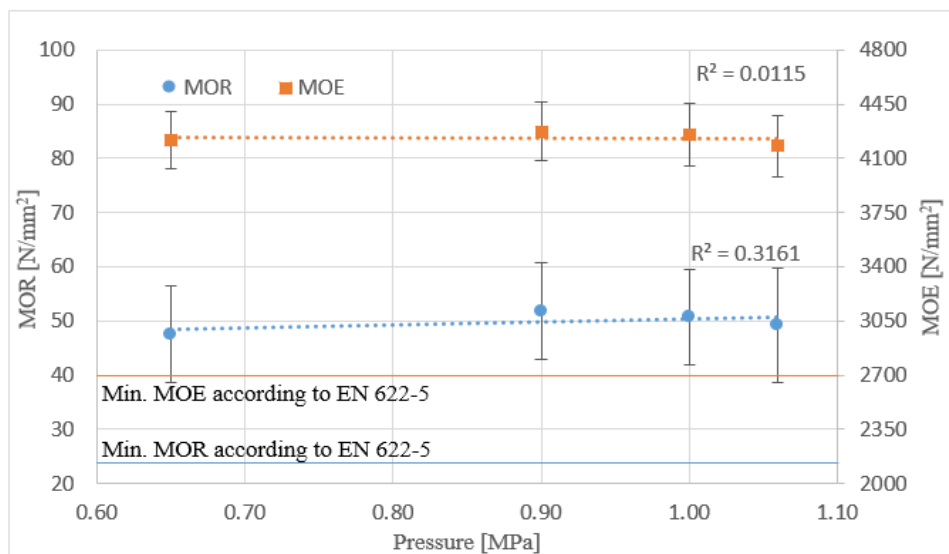


Figure 1 Different defibrator heater pressure influence on HDF MOR and MOE

Although European standard EN 622-5, regarding fibreboards properties is not specifying any minimal requirement for modulus of elasticity for boards of thickness of up to 2.5 mm , together with MOR examination, the MOE was defined shown in Figure 1 and gathered in Table. 2. MOE values were correlated with MOR, but the differences between the variants were not significant. Boards from V1 had MOE on the level of 4218 N/mm^2 , that was only about 1.5% less than the maximum from V2 - the highest result reached 4275 N/mm^2 , although panel moisture content from that variant was the highest (6.1%). According to CAI et al. 2006, low board moisture content positively influences on MOE outcome. Considering, that the remaining panel variants moisture content was $<6.0\%$, the higher influence on MOE result had defibrator pressure. Increasing pressure to 1.00 MPa in V3 resulted in MOE on the level of 4255 N/mm^2 , that was comparable to V2. As the defibrator pressure is increasing, the produced fibres become shorter and thinner (Xing 2007). This might have been the reason, why the lowest MOE was obtained for V4 (4181 N/mm^2), that was slightly more than 2% less the maximum. It would mean that defibrator pressure had negligible influence on HDF MOE, produced with 5% of rHDF addition

The minimal requirement of IB regarding MDF specified in European standard EN 622-5 for boards in thickness of up to 2.5 mm is on the level of $\geq 0.65 \text{ N/mm}^2$. Measured IB results have been gathered and shown in the Table. 2 and the Figure 2.

Boards from all variants met minimal requirement however, V1 only slightly exceeded minimal demand (0.67 N/mm^2). Increasing pressure to 0.90 MPa from V2 resulted in IB increase to 0.81 N/mm^2 , what was 17% more comparing to V1. Boards from V3 had the highest IB - 0.87 N/mm^2 that was 23% and 7% more accordingly to V1 and V2. Further defibrator pressure increase did not cause further IB increase. Boards from V4 had IB on the level of 0.83 N/mm^2 , which was 19% higher comparing to V1 and 5% less comparing to maximum. There were no statistically significant differences of IB average values found for the tested variants.

Though European standard EN 622-5 regarding MDF properties is not specifying any minimal requirement for surface soundness however, some of European furniture producers are demanding this parameter to be on the level of $\geq 0.80 \text{ N/mm}^2$ (Swedwood Technical Standard Specification of HDF). Based on the results shown in Figure 2 it can be seen that the behaviour of this parameter was comparable to IB.

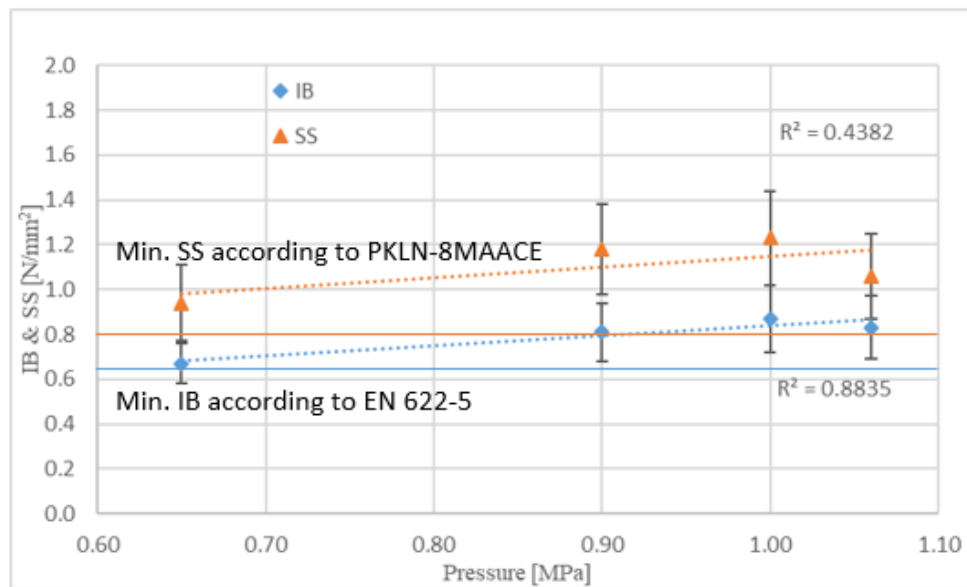


Figure 2. Different defibrator heater pressure influence on HDF IB and SS

Boards from all variants met minimal requirement. V1 had SS on the level of 0.94 N/mm^2 , which was the lowest value among the achieved results. Increasing pressure to 0.90 MPa in V2 resulted in SS increase to 1.18 N/mm^2 what was 20% more comparing to V1. Boards from V3 had the highest SS - 1.23 N/mm^2 that was nearly 24% and 4% more accordingly to V1 and V2. Further defibrator pressure caused SS decrease. Boards from V4 had IB on the level of 1.03 N/mm^2 that was 9% more comparing to V1 and 16% less comparing to maximum. There were no statistically significant differences of SS average values found for the variants.

As the refining pressure is increasing, the fibre cell wall becomes more damaged. Fibres become shorter, rougher, and less stiff and tensile strength of individual wood fibres drops. There is a proportional relationship between fibre and panel properties at refiner pressures above 1.00 MPa (GROOM et al. 2008). What is more, worse fibres resin coverage per unit surface area, growing with fibre bulk density, results in worse board mechanical properties (HWANG et al. 2005) such as IB or SS. Those might be the reasons of internal bond and surface soundness results. There were no statistically significant differences of IB average values found for the variants.

Results of thickness swelling after 24h were shown in the Table. 2 and visualized in the Fig. 3. European standard EN 622-5 regarding MDF specifies maximum allowed TS 24h for boards of up to 2.5 mm thickness on the level of <45%.

Boards from all variants met EN 622-5 minimal requirement of TS24. As it can be seen in the Fig. 3 the highest swelling was for V1 – 38.69%. Together with defibrator pressure increase thickness swelling was nearly linearly decreasing. Boards from V2 had 5% lower swelling comparing to V1. Boards from V3 had swelling on the level of 35.49% what was 8% lower than the maximum. Defibrator pressure change from 1.00 MPa to 1.06 MPa caused further 22% drop resulting in minimal swelling on the level of 27.58% what was nearly 29% less than TS 24h for V1. There was strong linear negative correlation between defibrator pressure increase and thickness swelling decrease. This may be due to the removal of hydrophilic hemicelluloses that is a result of refining process (XU et al. 2006). Previously mentioned higher refining pressure generates more individual and short fibres and increases the effective surface area which, on the other hand, absorbs less water (XING et al. 2009). This is due to the fact that shorter fibres make denser structures between fibres lowering MDF porosity (IBRAHIM et al. 2013). These conditions resulted in HDF with better dimensional properties (reduced TS 24h). There is statistically significant difference between average values of TS 24h for V4 and remaining panels, where no statistically significant differences of average TS 24h values have been found for V1, V2 and V3 samples.

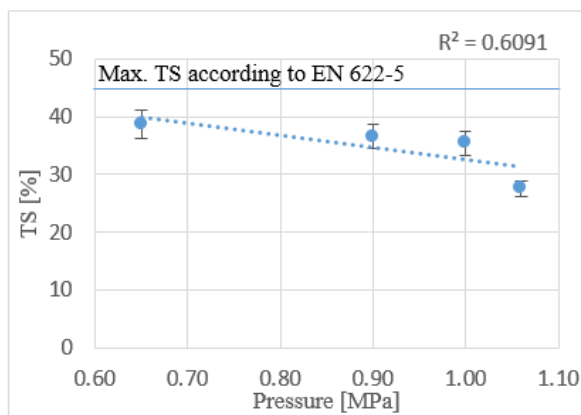


Figure 3. HDF thickness swelling 24h results

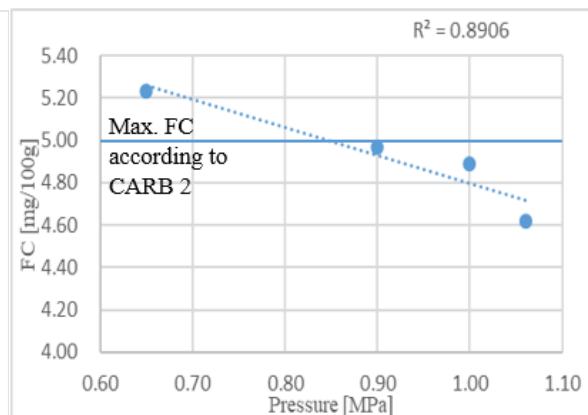


Figure 4. HDF formaldehyde content results

Panels for this examination were produced in CARB 2 formaldehyde emission standard that with perforator method is requiring formaldehyde content (FC) below 5.0 mg/100g. Based on the results shown in Fig. 4 it could be stated that not all variants met that requirement. The one exceeded maximum FC was V1 with the formaldehyde content of 5.23 mg/100g. 0.25 MPa defibrator pressure increase allowed boards from V2 to be within the limit of FC being only slightly below 5.0 mg/100g (4.97 mg/100g) what was 5% less than the maximum FC. A defibrator pressure increase from 0.9 MPa to 1.0 MPa resulted in small FC reduction (2%) comparing to V2, to the level of 4.89 mg/100g, however V3 content was 7% lower with respect to V1. Minimal FC had boards produced from wooden material after the highest (1.06 MPa) defibrator hydrothermal treatment – V4. Its FC was on the level of 4.62 mg/100g that was 12% less comparing to V1. There was very strong linear negative correlation between defibrator pressure increase and formaldehyde content decrease. The higher defibrator steam pressure, the higher defibrator preheating temperature. Together with temperature increase the wooden material pH decrease can be observed (LATIBARI et al. 2012; ROFFAEL 2012). As growing fibre acidity is enhancing hardening of the resin, less free formaldehyde stays in ready wood based panel. This might be the reason of lowering

HDF formaldehyde content together with defibrator pressure increase during fibre preparation.

PART 2 Fibre drying inlet temperature

Fibres mass characterization

Fibre bulk density and fibre moisture content from online forming line sensors were gathered in the Table 3. As it can be seen, the fibre bulk density did not differ significantly, which might be caused by constant wood age and mix but also by constant defibrator parameters during material preparation.

Table 3. Fibres bulk density and fibre moisture content of V00, V11, V22 and V33

	V00	V11	V22	V33
Fibre bulk density [kg/m ³]	18.62	18.38	18.21	18.25
Fibre moisture content [%]	9.78	9.68	9.53	9.44

Fibre bulk density depends on such characteristic of wood-fibres as fibre length and its distribution and is influencing MDF performance (PARK et al. 2001). Although the difference between maximum fibre bulk density for V00 (18.62 kg/m³) and minimum for V22 (18.21 kg/m³) was on the level of 2% it should not had any influence on final HDF properties. Despite the fact, that fibre moisture content set point was on the level of 9.6%+/-0.2% as it can be seen in the Table 3 results of the readings from forming line moisture content sensor were slightly different depending on the variant. The highest fibre moisture content had fibres from V00 – 9.78% (dried in the lowest dryer temperature of 100°C) and the lowest from V33 – 9.44% (dried in the highest drying temperature of 133°C) what was about 4% lower comparing to V00. Moisture content of V11 (9.68%) was lower but comparable to V00 (about 1% lower) while V22 (9.53%) was more close to V33 (about 1% higher). Described fibre moisture content differences were probably connected with different drying temperature setup. The higher dryer temperature set point, the lower fibre moisture content.

Mechanical and physical properties

Table 4. HDF boards properties results from V00, V11, V22 and V33

Variant	Density [kg/m ³]	SD	MOR [N/mm ²]	SD	MOE [N/mm ²]	SD	IB [N/mm ²]	SD	SS [N/mm ²]	SD	MC [%]	SD	TS [%]	SD	WA [g/m ²]		FC [mg/100g]
															Top	Bottom	
V00	876	18	52.4	3.52	4150	201	0.82	0.09	1.45	0.19	6.3	0.42	27.69	1.49	191	207	4.22
V11	868	18	51.6	2.70	4335	198	0.85	0.15	1.03	0.27	5.2	0.38	33.11	2.61	179	201	4.97
V22	854	19	47.6	3.16	4275	204	0.63	0.11	1.05	0.17	5.3	0.41	39.59	1.59	213	205	4.54
V33	867	20	47.0	2.60	4120	200	0.69	0.15	1.12	0.21	5.2	0.33	41.15	1.88	220	209	4.31

HDF results from all variants and standard deviations (SD) were gathered and shown in the Table 4.

In the Fig. 5 the MOR results have been shown. All of variant samples met minimum MDF requirement of EN 622-5 that is ≥ 23.00 N/mm², and, what is more, the results were more than two times higher than minimal in the mentioned standard.

The highest MOR values had board made of fibres dried in the lowest temperature of 100°C and it was on the level of 52.4 N/mm². Additionally, its density was also the highest (876 kg/m³). Increasing the drying temperature to 111°C caused MOR strength decrease.

Boards from V11 had slightly (2%) lower MOR (51.6 N/mm²) comparing to V0. Further drying temperature increase (V22) caused further MOR decrease to the level of 47.6 N/mm², what was about 9% less than the maximum and 8% less than V11 while its density was the lowest - on the level of 854 kg/m³. The minimal result was obtained for board made of fibres dried in the highest temperature of 133°C, and it was on the level of 47.0 N/mm², what was more than 10% less, referring to maximum from V00. However, its density (867 kg/m³) was not the lowest. According to CAI et al. 2006, the panel density increase has a positive effect on such panel properties as MOE and MOR. Although lower panel moisture content is positively affecting MDF mechanical properties (GANEV et al. 2003), together with drying temperature increase, the final board moisture content was decreasing (from 6.3% to 5.2%), while MOR was also decreasing. It would mean, that not only could the panel density have an influence on HDF MOR but also the drying temperature increase from 100°C to 130°C resulted in almost linear decrease of MOR. Similar behaviour have MDF boards, where while drying temperature increase from 110°C to 150°C, is causing MOR decrease of up to ~20% (LATIBARI et al. 2012). What is more, based on SARI et al. (2013) findings, increasing particles drying temperature from 100°C to 180°C is also negatively affecting the panels' mechanical properties. This might have been caused by resin precuring and its damaging processes in high temperatures (CAMPANA et al. 2018). Considering, that the V00 panel moisture content had been lower, it would have given similar to MOR linear correlation between fibre drying temperature increase and MOE decrease. There were no statistically significant differences of MOR average values found for the tested variants.

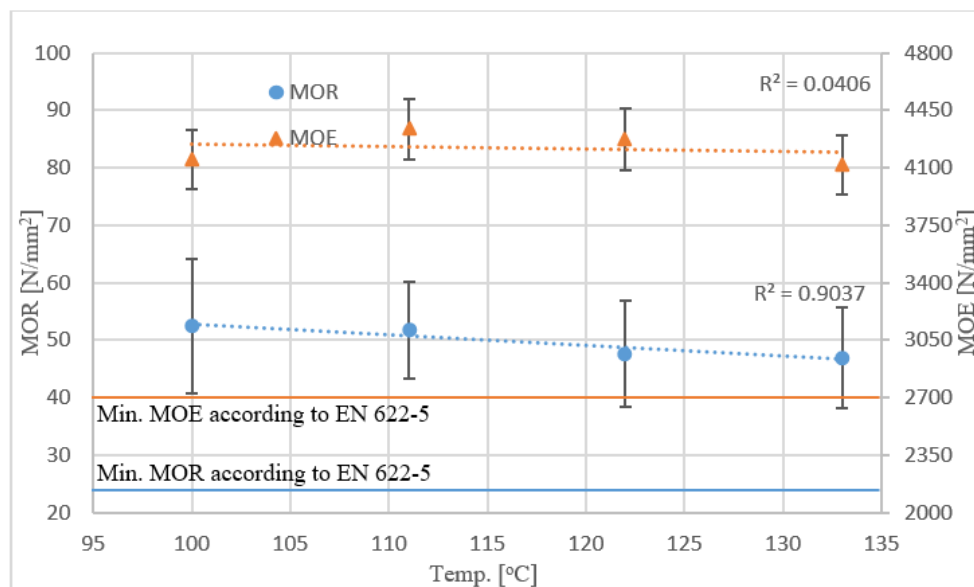


Figure 5. HDF MOR and MOE results

For this paper, together with MOR examination, MOE was also defined, shown in the Fig. 5 and gathered in Table 4. European standard EN 622-5 regarding fibre boards properties is not specifying any minimal requirement for modulus of elasticity for boards in thickness of up to 2.5 mm. boards from V00 high MOE on the level of 4150 N/mm², which panel moisture content was the highest (6.3%). The highest MOE (4335 N/mm²) was achieved for V11 and was ~4% lower comparing to V00, while its panel moisture content was on the level of 5.2% what was about 17% less than V0 panel moisture content. Further fibre drying temperature increase caused MOE decrease relatively for V22 and V33 on the level of 4275 N/mm² and 4120 N/mm² while V22 and V33 panel moisture was kept on constant level and comparable to V11 level (5.2-5.3%). In general, low board moisture content results positively on MOE

result (CAI et al. 2006). This could explain why V00 MOE was on a relatively low level, however, based on V11-V33 results; negative influence of fibre drying temperature increase on MOE results could be noticed.

Minimal requirement of IB regarding MDF specified in European standard EN 622-5 for boards in thickness of up to 2.5 mm is on the level of $\geq 0.65 \text{ N/mm}^2$. Results of IB measured from all of the variants were shown in the Table 4 and visualized in the Fig 6.

As it can be seen in Fig. 6, the highest IB had board from V11 (0.85 N/mm^2) while V00 IB result was comparable and on similar level (0.82 N/mm^2). There were also no statistically significant differences of IB average values for those two variants. Increasing fibre drying temperature to 133°C resulted in up to 19% drop of IB for V33 comparing to V11 reaching 0.69 N/mm^2 IB what was a little bit higher than the minimal requirement. As it can be seen not all HDF variants met minimal EN622-5 requirement of IB. Boards from V22 had the lowest result that was on the level of 0.62 N/mm^2 what was 26% and 9% lower, accordingly to V11 and V33. This might have been caused by the lowest from examined variants density (854 kg/m^3) (HONG et al. 2017), what, on the other hand, influences relatively low panel core density (CD) from the density profile, that results in decreasing IB (WONG et al. 2000). There were statistically significant differences for V22 and variants V00 and V11. Increasing fibre drying temperature caused IB decrease, but also fibre moisture content. Additionally, in reference to NICEWICZ, MONDER 2014, the relatively low fibre moisture content has a negative influence on final IB results. This could lead to dry resin curing, that causes its degradation (MENEZES et al. 2003), and the worse fibres resin coverage per unit surface area, the worse mechanical properties (HWANG et al. 2005).

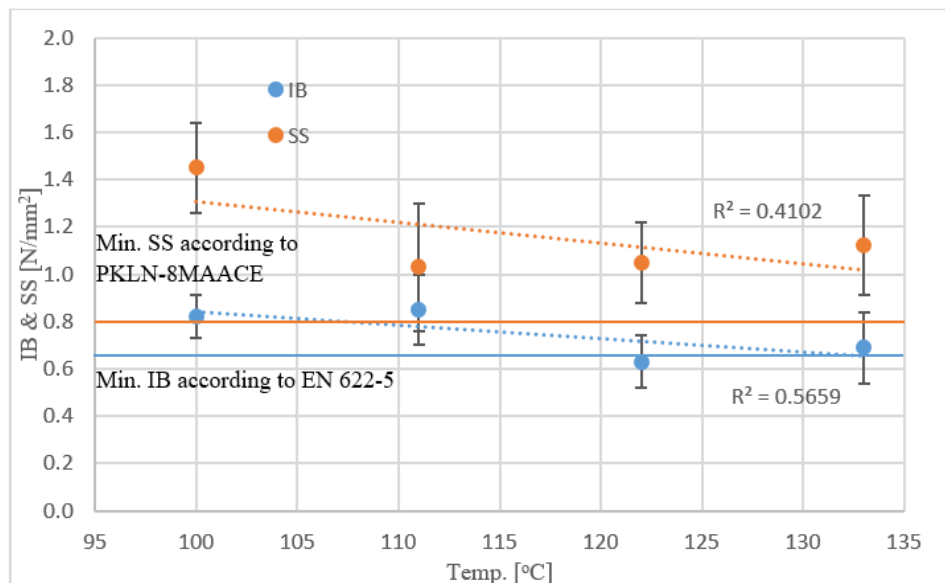


Figure 6. HDF IB and SS results

The European standard EN 622-5, regarding MDF properties does not specify any minimal requirement for surface soundness. However, in Figure , those results were shown for better fibre drying temperature influence evaluation on HDF boards properties, produced with rHDF addition. What is more, some of European furniture producers are demanding this parameter to be on the level of $\geq 0.80 \text{ N/mm}^2$ (Swedwood International Standard Specification of HDF 2011). Based on the results, it can be seen, that the behaviour of this parameter differs to other parameters. The highest SS was obtained for V00 and was on the level of 1.45 N/mm^2 , while the lowest for V11 – 1.03 N/mm^2 , what was nearly 30% less comparing to maximal value. Increasing drying temperature from 111°C to 133°C caused ~8% SS increase

to the level of 1.12 N/mm^2 , what was 23% less comparing to V00. This might be caused by higher fibre temperature from V33, comparing to V11, and easier mat preheating. This leads to better panel performance. Boards from V22 had comparable to V11 surface soundness (1.05 N/mm^2). SS is dependent on the density profile and its surface layer density (SLD) (WONG et al. 2000). Considering, that panel density in V11-V33 was about 2% lower comparing to V00, this could cause lower SLD, and be one of the reasons influencing SS decrease in V11-V33. Additionally, about 17% lower panel moisture content of V11-V33 comparing to V00 could cause worse resin curing, due to worse heat transfer, what could result in worse SS results than in V00 (THOEMEN et al. 2010). There were statistically significant differences between average values of SS for V00 and V11 and V22, without significant differences for V33, while there was no statistically significant difference of SS average values between V11, V22 and V33 samples.

The maximum allowed swelling after 24h for MDF boards with thickness of up to 2.5 mm, specified in European standard EN 622-5 is on the level of 45%. The results of TS24 are shown in Table 4 and visualized in Fig. 7.

As it can be seen in the Figure , all board variants met the minimal requirement of TS24 described in EN 622-5 norm. However, some of furniture producers require HDF thickness swelling 24h to be <35% (Swedwood International Standard Specification of HDF 2011). Considering such requirements, only the V00 and V11 boards met this strict specification. The lowest TS24 had boards from V00 (27.69%) where moisture content was the highest (6.3%). A rise of the fibre drying temperature to 111°C caused a 14% increase of TS24 to the level of 33.11%, comparing to V00. The moisture content of the V11 panel was 17% lower comparing to V0, which could be the reason of the TS increase, because the relation between board moisture content and swelling is rather proportional (TRECHSEL et al. 2010): together with an increase of the initial moisture content in the wood-based panels, their swelling decreases (CARLL 1996). The V11, V22 and V33 board variants had moisture content on nearly the same level, so this could mean that not only panel moisture content but also fibre drying temperature have an influence on the final TS24 of the panels produced with rHDF addition because a further increase of the dryer temperature to 122°C caused 16% and 30% increase of TS24 to the level of 39.59% for the V11 panel and the V00 panel, respectively. The highest thickness swelling had board from V33 (41.15%), where the fibre drying temperature was the highest. Together with an increase/decrease of the fibre drying temperature, the wettability of the fibres decreases (LATIBARI et al. 2012) which causes lower bonding potential between the fibres and resin (KOWALUK et al. 2008). This could be the reason of worse fibre connection at higher drying temperatures, which resulted in easier water HDF penetration, leading to higher swelling. There was a statistically significant difference between average values of TS for V00 and remaining panels, as well as for V11, where no statistically significant differences of TS24 average values were found for V22 and V33 samples.

The HDF water surface absorption, together with surface roughness, had been thought to be influenced by fibre drying temperature change, so this was why these parameters were also examined. However, it turned out that the fibre drying temperature did not have any significant influence on surface properties of HDF made with 5% addition of rHDF.

The panels for this examination have been produced in CARB 2 formaldehyde emission standard that require formaldehyde content (FC) below 5.0 mg/100g , examined with so-called “perforator” method (“EN 12460-5” 2016). Based on the results shown in Table 4 and in Figure 8, it can be seen that all variants met that requirement. However, the highest value was obtained for V11 (4.97 mg/100g). The lowest formaldehyde content was found for V00 – 4.22 mg/100g , which was 15% less comparing to the maximum value. Prior to hot pressing, the raw material is one of the factors influencing wood-based panel formaldehyde

content (AYDIN et al. 2006) due to a different heat transfer during the pressing process and thus different resin curing. In this work, the V00 fibre moisture content was about 2.5% higher, compared to an average from V11, V22 and V33.

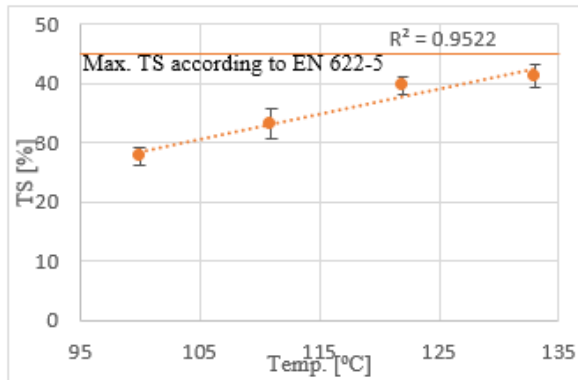


Figure 7. HDF thickness swelling 24h (TS) results

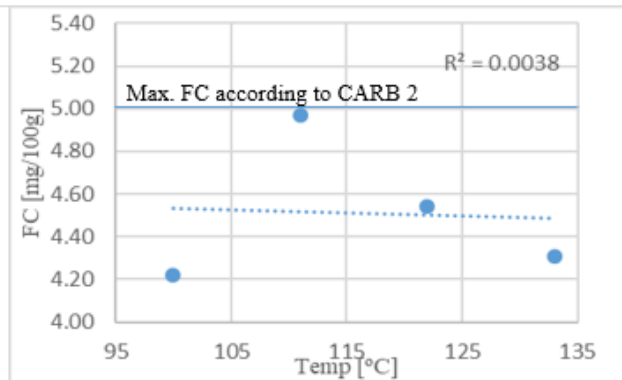


Figure 8. HDF formaldehyde content (FC)

Additionally, the calculation of the FC takes into consideration the tested board moisture content – the higher HDF moisture content, the lower the FC. This could explain why V00 FC was the lowest. The fibre drying temperature increase from 111°C to 122°C resulted in 9% FC decrease to the level of 4.54 mg/100g. The formaldehyde content in V33 was 13% lower referring to V11. Together with temperature increase, the fibre acidity is growing (decrease in pH can be observed) (ROFFAEL 2012; LATIBARI et al. 2012), as lower pH-values enhance hardening intensity of the resin. If the panel moisture had been lowered in V00, the FC might have been above 5.0 mg/100g, what would give nearly linear correlation between fibre drying temperature increase and FC decrease in HDF boards, produced with 5% of rHDF addition.

CONCLUSIONS

Based on the results of this study, the following conclusions can be drawn concerning the properties of HDF panels produced with 5% of recycled HDF addition:

PART 1 Defibrator heater pressure setup

Together with defibrator pressure increase during fibre preparation from 0.9 to 1.06 MPa there was a negative influence on the mechanical properties and positive on the physical HDF properties, defibrator pressure increase above 0.90 MPa has a negative influence on HDF MOR, defibrator pressure increase from 0.65 to 1.00 MPa during fibre preparation has a positive influence (35% increase) on HDF IB, defibrator pressure above 1.00 MPa has a negative influence on HDF IB and its increase during fibre preparation from 0.65 to 1.00 MPa has a positive influence (24% increase) on HDF SS, defibrator pressure above 1.0 MPa has a negative influence on HDF SS, while defibrator pressure increase during fibre preparation from 0.65 to 1.00 MPa HDF, causes TS 24h and FC decrease accordingly for up to 29% and 12%.

PART 2 Fibre drying inlet temperature

Fibre drying temperature increase from 100°C to 133°C has a negative impact on mechanical and physical properties of HDF. Together with fibre drying temperature increase from 100°C to 133°C the MOE of HDF decreases up to 5%, and the IB of HDF decreases as well (up to 26% – depending on the variant). Together with fibre drying temperature increase from 100°C to 111°C the SS of HDF decreases down to 29%, while increasing drying temperature from 111°C to 133°C causes a slight SS increase of up to 8%, when the TS of HDF increases up to

33%. No significant influence of fibre drying temperature increase from 100°C to 133°C on WA of HDF have been observed, and temperature rise from 111°C to 133°C has a positive impact on FC reduction in HDF for up to 13%.

REFERENCES:

1. AURIGA R. and BORUSZEWSKI P. 2013. Influence of Storage Raw Material in the Form of Wood Chips on the Properties of Particleboard; *Annals of Warsaw University of Life Sciences – SGGW Forestry and Wood Technology* 82: 27–30.
2. AYDIN I., GURSEL C., SEMRA C. and CENK D. 2006. Effects of Moisture Content on Formaldehyde Emission and Mechanical Properties of Plywood. *Building and Environment* 41 (10): 1311–16. <https://doi.org/10.1016/j.buildenv.2005.05.011>.
3. AYRILMIS N., BENTHIEN J. T. and OHLMEYER M. 2017. “Effect of Wood Species, Digester Conditions, and Defibrator Disc Distance on Wettability of Fibreboard.” *Journal of Wood Science* 63 (3): 248–52. <https://doi.org/10.1007/s10086-017-1620-9>.
4. BEKHTA P., NIEMZ P. 2009. Effect of Relative Humidity on Some Physical and Mechanical Properties of Different Types of Fibreboard. *European Journal of Wood and Wood Products* 67 (3): 339–42. <https://doi.org/10.1007/s00107-009-0330-4>.
5. BENTHIEN J. T., BAHNISCH C., HELDNER S. and OHLMEYER M. 2014. Effect of Fibre Size Distribution on Medium-Density Fibreboard Properties Caused by Varied Steaming Time and Temperature of Defibration Process. *Wood and Fibre Science* 46(2), 175–185.
6. CAI Z., MUEHL J. H. and WINANDY J. E. 2006. “Effects of Panel Density and Mat Moisture Content on Processing Medium Density Fibreboard.” *Forest Products Journal* 56 (10): 20–25.
7. CAMPANA C., LEGER R., SONNIER R., FERRY L. and IENNY P. 2018. Effect of Post Curing Temperature on Mechanical Properties of a Flax Fibre Reinforced Epoxy Composite. *Composites Part A: Applied Science and Manufacturing* 107: 171–79. <https://doi.org/10.1016/j.compositesa.2017.12.029>.
8. CARLL C. G. 1996. Review of Thickness Swell in Hardboard Siding Effect of Processing Variables, United States Department of Agriculture, Forest Service, General Technical Report FPL-GTR-96.
9. HWANG C., HSE C., SHUPE T. F. 2005. Effects of Recycled Fibre on the Properties of Fibreboard Panels. *Forest Products Journal* 55. No. 1 (9828): 61–64.
10. EN-326-1: Wood Based Panels – Sampling, Cutting and Inspection. 1994.
11. EN 12460-5: Wood-Based Panels – Determination of Formaldehyde Release – Extraction Method (Called the Perforator Method). 2016.
12. EN 310: Wood-Based Panels. Determination of Modulus of Elasticity in Bending and of Bending Strength. 1993.
13. EN 311. 2003. Wood-based panels — Surface soundness — Test method, issued 2003.
14. EN 317: Particleboards and Fibreboards – Determination of Swelling in Thickness after Immersion in Water. 1993.
15. EN 319: Particleboards and Fibreboards – Determination of Tensile Strength Perpendicular to the Plane of the Board. 1993.
16. EN 322: Wood-Based Panels – Determination of Moisture Content. 1993.
17. EN 323: Wood-Based Panels – Determination of Density. 1993.
18. EN 382-1. 1993. Fibreboards. Determination of surface absorption. Test method for dry process fibreboards, issued 1993.
19. EN 622-5: Fibreboards. Specifications. Requirements for Dry Process Boards (MDF).

- 2009.
20. Fibre Drying Process. 2010. 2010. pdf.directindustry.com/pdf/dieffenbacher/fibre-drying-process/70088-325081.html.
 21. Flash Tube Dryer. Accessed February 3, 2020. www.dieffenbacher.com/en/wood-based-panels/products/energy-systems-and-drying/flash-tube-dryer.
 22. Food and Agriculture Organization. Forestry Production and Trade. 2020. 2020. <http://www.fao.org/faostat/en/#data/FO>.
 23. GANEV S., CLOUTIER A., BEAUREGARD R. and GENDRON G. 2003. Effect of Panel Moisture Content and Density on Moisture Movement in MDF. *Wood and Fibre Science* 35 (1): 68–82.
 24. GAO Y., HUA J., CHEN G., CAI L., JIA N., ZHU L. 2018. Com Prediction of Fibre Quality Using Refining Parameters in Medium-Density Fibreboard Production via the Support Vector Machine Algorithm. *BioResources* 13(4): 8184–97.
 25. GROOM L. H., SO C.-L., ELDER T., PESACRETA T. and RIALS T. 2008. Effects of Refiner Pressure on the Properties of Individual Wood Fibres. In *Characterization of the Cellulosic Cell Wall*. <https://doi.org/10.1002/9780470999714.ch17>.
 26. GUIMEI J., GUO T. and DING Y. 2016. A New Hybrid Forecasting Approach Applied to Hydrological Data: A Case Study on Precipitation. <https://doi.org/10.3390/w8090367>.
 27. GUL W., KHAN A. and SHAKOOR A. 2017. Impact of Hot Pressing Temperature on Medium Density Fibreboard (MDF) Performance. *Advances in Materials Science and Engineering* 2017. <https://doi.org/10.1155/2017/4056360>.
 28. HONG M. K., LUBIS M. A. R. and PARK B. D. 2017. Effect of Panel Density and Resin Content on Properties of Medium Density Fibreboard. *Journal of the Korean Wood Science and Technology* 45 (4): 444–55. <https://doi.org/10.5658/WOOD.2017.45.4.444>.
 29. <https://Www.Drewno.Pl/Artykuly/10837,Rekordowo-Wysokie-Ceny-Za-Drewno-w-i-Kwartale-2017.Html>., Accesed 03 2020
 30. IBRAHIM Z., AZIZ A. A., RAMLI R., MOKHTAR A. and LEE S. 2013. Effect of Refining Parameters on Medium Density Fibreboard (MDF) Properties from Oil Palm Trunk (*Elaeis Guineensis*). *Open Journal of Composite Materials* 2013 (October): 127–31. <https://doi.org/10.4236/ojcm.2013.34013>.
 31. IOS-MAT-0003 Formaldehyde Requirements of Wood, Wood-Based and Wood-like Natural Materials and Products. 2020. Vol. 1.
 32. KHALIL H. P. S. A., NUR FIRDAUS M. Y., ANIS M., RIDZUAN R. 2008. The Effect of Storage Time and Humidity on Mechanical and Physical Properties of Medium Density Fibreboard. *Polymer-Plastics Technology and Engineering* 47 (10): 1046–53.
 33. KLIMCZEWSKI M. and NICEWICZ D. 2013. Wybrane Właściwości Mas Włóknistych Przeznaczonych Na Płyty Hdf z Dodatkiem Włókien Poużytkowych. *Drewno* 189 (189): 89–100. <https://doi.org/10.12841/wood.1644-3985.012.06>.
 34. KOWALUK G., SANDAK J., PALUBICKI 2008. Wettability of Chosen Alternarive Lignocellulosic Raw Material for Particleboard Production. *International Panel Products Symposium Preceeding*, 2008.
 35. LATIBARI A., GHASEBINASAB H., ROOHNIA M. and KARAGARFARD A. 2012. The Effect of Fibre Moisture and Drying Temperature on Hardwood Fibre Physical Chemistry and Strength of Medium Density Fibreboard. *Lignocellulose Journal* 1 (1): 3–12.
 36. MENUES P., BELGACEM N., COSTA C. A. V., COSTA A. P. 2003. Influence of Impulse Drying on the Curing of Polyamide. *Cellulose Chemistry and Technology*

- 37(5): 439–451.
37. MEYER N. and THOEMEN H. 2007. Gas Pressure Measurements during Continuous Hot Pressing of Particleboard. *Holz Als Roh - Und Werkstoff* 65 (1): 49–55. <https://doi.org/10.1007/s00107-006-0140-x>.
 38. NICEWICZ D., MONDER S. 2011. The Influence of the Kind of Glue Resins on the Properties of MDF. *Annals of Warsaw University of Life Sciences - SGGW Forestry and Wood Technology* 75: 127–29.
 39. NICEWICZ D., MONDER S. 2014. “The Influence of Moisture of Fibre Mats on the Properties of MDF Boards.” *Annals of Warsaw University of Life Sciences – SGGW Forestry and Wood Technology* 88: 174–77.
 40. NICEWICZ D., SALA C. M. 2013. *Technologiczne Aspekty Produkcji MDF. Skrypt Dla Studentów*. Warszawa: Wydawnictwo SGGW.
 41. NICEWICZ D., SALA C. M. 2014. *Właściwości i Zastosowanie Płyt MDF. Skrypt Dla Studentów*. Warszawa: Wydawnictwo SGGW.
 42. NOURBAKHS A., ASHORI A., LATIBARI A. J. 2010. “Evaluation of the Physical and Mechanical Properties of Medium Density Fibreboard Made from Old Newsprint Fibres.” *Journal of Reinforced Plastics and Composites* 29 (1): 5–11. <https://doi.org/10.1177/0731684408093972>.
 43. ONIŚKO W. 2011. Nowe Generacje Tworzyw Drzewnych i Nowoczesne Technologie. In *Drewnowizja*. Poznań: Instytut Technologii Drewna w Poznaniu. <https://www.drewno.pl/artykuly/7524,nowe-generacje-tworzyw-drzewnych-i-nowoczesne-technologie.html> Accessed: 03 2020.
 44. PARK B. D., KIM Y.-S., RIEDL B. 2001. Effect of Wood-Fibre Characteristics on Medium Density Fibreboard (MDF) Performance. *Journal of the Korean Wood Science and Technology* 29 (3): 27–35.
 45. PKLN-8MAACE. 2011. *Swedwood International Corporate Technical Standard Specification of HDF, Version: 04*.
 46. ROFFAEL E. 2012. Influence of Resin Content and Pulping Temperature on the Formaldehyde Release from Medium Density Fibreboards (MDF). *European Journal of Wood and Wood Products* 70 (5): 651–54. <https://doi.org/10.1007/s00107-012-0614-y>.
 47. SALA C. M. 2020. Wpływ Natrysku Wody Na Przegrzewanie Koberca Włóknistego Płyt HDF, z Dodatkiem Włókien Poużytkowych. *Biuletyn Informacyjny OB-RPPD* 1–2: 45–55. <https://doi.org/doi.org/>.
 48. SALA C. M., ROBLES E. and KOWALUK G. 2020. Influence of Adding Offcuts and Trims with a Recycling Approach on the Properties of High-Density Fibrous Composites. *Polymers* 12 (6). <https://doi.org/10.3390/POLYM12061327>.
 49. SARI B., GOKAY N., AYRILMIS N., BAHAROGLU M. and BARDAK S. 2013. The Influences of Drying Temperature of Wood Particles on the Quality Properties of Particleboard Composite. *Drying Technology*. <https://doi.org/10.1080/07373937.2012.711791>.
 50. SHI J. L. and ZHANG S. Y 2005. Effect of Juvenile Wood on Strength Properties and Dimensional Stability of Black Spruce Medium-Density Fibreboard Panels 59: 1–9. <https://doi.org/10.1515/HF.2005.001>.
 51. THOEMEN H., HASELEIN C. R. and HUMPHERY P. E. 2006. Modeling the Physical Processes Relevant during Hot Pressing of Wood-Based Composites. Part II. Rheology. *Holz als Roh- und Werkstoff* 64 (2): 125–33. <https://doi.org/10.1007/s00107-005-0032-5>.
 52. THOEMEN H., IRLE M. and SERNERK M. 2010. *Wood-Based Panels An Introduction for Specialists*. An Introduction for Specialists, Published by Brunel

- University Press, London, England.
53. TOLVIK CONSULTING 2018. UK Dedicated Biomass Statistics 2017. file://plorl-nt0002/Users_Profiles/salcon/Documents/Doktorat/Bibliografia/Tolvik-UK-Biomass-Statistics-2017-2.pdf., Accessed 03 2020
 54. TRECHSEL H. R., BOMBERG M. T., CARLL C. and WIEDENHOEFT A. C. 2010. Moisture-Related Properties of Wood and the Effects of Moisture on Wood and Wood Products. Moisture Control in Buildings: The Key Factor in Mold Prevention – 2nd Edition, 54-54-26. <https://doi.org/10.1520/mnl11544m>.
 55. WAN H., WANG X. M., BARRY A. and SHEN J. 2014. Recycling Wood Composite Panels: Characterizing Recycled Materials. *BioResources* 9 (4): 7554–65. <https://doi.org/10.15376/biores.9.4.7554-7565>.
 56. WONG E., ZHANG M., WANG Q., HAN G. and KAWAI S. 2000. Formation of the Density Profile and Its Effects on the Properties of Fibreboard. *Journal of Wood Science* 46 (3): 202–9. <https://doi.org/10.1007/BF00776450>.
 57. XING C., DENG J. ZHANG S. Y. 2007. Effect of Thermo-Mechanical Refining on Properties of MDF Made from Black Spruce Bark. *Wood Science and Technology* 41(4): 329–38. <https://doi.org/10.1007/s00226-006-0108-3>.
 58. XING C., WANG S. and PHARR G. M. 2009. Nanoindentation of Juvenile and Mature Loblolly Pine (*Pinus Taeda L.* *Wood Science and Technology* 43 (615). <https://doi.org/10.1007/s00226-009-0266-1>.
 59. XU J., WIDYORINI R. and YAMAUCHI H. 2006. Development of Binderless Fibreboard from Kenaf Core. <https://doi.org/10.1007/s10086-005-0770-3>.

Streszczenie: *Wpływ ciśnienia defibracji oraz temperatury suszenia włókien na właściwości płyt pilśniowych suchoformowanych wysokiej gęstości z dodatkiem włókien poużytkowych*
Celem badań było określenie wpływu ciśnienia defibracji oraz temperatury suszenia włókien na właściwości mechaniczne i fizyczne ultra cienkich płyt (2.5 mm) włóknistych wysokiej gęstości (HDF), wytwarzanych z 5% dodatkiem włókien poużytkowych (rHDF). W pierwszej części wyprodukowano włókna przy zmiennym ciśnieniu defibracji 0.65 MPa (V1), 0.90 MPa (V2), 1.00 MPa (V3) and 1.06 MPa (V4). W drugiej części zastosowano różne nastawy temperatury suszenia włókien: 100°C (V00), 111°C (V11), 122°C (V22) and 133°C (V33). Wyniki wskazały, że ciśnienie defibracji jest istotnym czynnikiem i wpływa na wszystkie właściwości HDF. Zbyt niskie ciśnienie rozwłókniania negatywnie wpływa na właściwości mechaniczne i fizyczne HDF oraz FC (wysoki poziom). W przypadku wpływu temperatury suszenia włókien na właściwości HDF - nie stwierdzono prostej korelacji. Stwierdzono liniową ujemną korelację wytrzymałości na zginanie statyczne - spadek o 10% porównując V00 do V33, IB - spadek o 23% porównując V00 do V22 i SS - również spadek o 23% porównując V00 do V33.

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