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FURNITURE DESIGN WITH PRINCIPLES OF SUSTAINABLE DESIGN BY USING PAPER PULP

Alena SOBOTKOVÁ
Ing. - Mendel University in Brno, Faculty of Forestry and Wood Technology
Zemědělská 1, 613 00 Brno, CZECH REPUBLIC
Tel: +420 721 511 147, E-mail: xsobotk6@mendelu.cz

Milan ŠIMEK
PhD. - Mendel University in Brno, Faculty of Forestry and Wood Technology
Zemědělská 1, 613 00 Brno, CZECH REPUBLIC
Tel: +420 777 878 207, E-mail: milan.simek@mendelu.cz

Marius-Catalin BARBU
Transilvania University of Brasov, Faculty of Wood Engineering
Prof. Dr.- FH Salzburg, Campus Kuchl, Markt 136a, A-5431 Kuchl, AUSTRIA
Tel.: +43-50-2211-2102, E-mail: marius.barbu@fh-salzburg.ac.at

Abstract:

This paper presents manufacture and testing of paper boards made from recycled paper pulp. The aim was to create material for creating paper boards which could be used in furniture design with various shapes. The used types of pulp were deinked pulp (DIP) and old corrugated cardboards (OCC). Several test pieces – paper boards were made with different combinations of materials and its mechanical and physical properties were tested. The used glue for each material was urea formaldehyde glue and starch in combination with glucose.

The tests which were done were determination of density and density profile (EN 323:2005), moisture content (EN 322:2005), modulus of elasticity in bending and bending strength (EN 310:1993), thickness swelling and water absorption (EN317:2005), internal bond (EN 319:2005) and screw withdrawal resistance (EN 320:2011). The aim was to create material for creating boards which could be used in furniture design with various shapes.

The result of this paper shows possible material combinations which could be used for furniture parts. Paper boards will be used for table top of side table in following steps.

Key words: *paper; pulp; furniture; sustainability; board; recycling.*

INTRODUCTION

Our environment is being polluted with waste material more and more each year. Especially packaging material is causing a lot of waste which ends up in the landfills. Designers are creating new furniture every year and the market is overloaded with different furniture pieces. People are always looking for new products only because of fashionable reason very often which also contributes to a lot of waste products and furniture. That is why designers should look for alternatives in furniture production. In this paper the focus is given to paper which can serve as a substitute for some furniture parts or even the whole furniture pieces.

Paper has one of the biggest amounts of waste per person every year. Theoretically paper can be recycled many times, but its fibres are getting smaller each time and therefore they are losing its strength. Furniture which is made traditionally leaves often a lot of waste which is not possible to reuse. During the design process it is important to think about the most efficient use of material as possible (Koo *et.al* 2017).

The focus in this work is given to paper pulp which could be used in furniture design. Pulp is fibrous cellulose based material which results from several different manufacturing processes. 90 % of pulp is made from wood, the rest out of other plants. The pulp industry is great example of sustainable development. It is self-sustaining industry (Sixta 2006).

Pulp can be made from recycled papers such as old corrugated cardboards (OCC) or old magazines and newspapers (DIP = deinked pulp). Deinked pulp is made from old magazines, newspapers or office paper. During the pulping process it is necessary to remove all chemicals from paper, such as glue, pigments and printing inks. This process changes the structure of the paper and lowers the strength of cellulose fibres (Dukarska *et al.* 2018).

Even though the paper is recycled in paper industry, there is still a lot of wastepaper which is not used. Although consideration of use of paper together with wood industry, the result is different. The use of paper in board manufacturing industry should be easier to implement (Nicewicz *et. al* 2006).

This study is investigating the possible use of paper pulp for boards which could be combined with wood structures. The focus was also given to a sustainable and natural glues in comparison with industrially used glues such as urea-formaldehyde resin.

OBJECTIVE

The main objective of our research is to reuse paper pulp in furniture design industry. The use of paper pulp boards should be for table top of side table. The main idea is to use recycled material for furniture design because of the need of sustainable development in furniture industry.

MATERIAL, METHOD, EQUIPMENT

The used paper pulp was deinked pulp (DIP), old corrugated cardboards (OCC) and thermomechanical pulp (TMP). Although this material was not considered for further testing, because its consistency was not suitable for the boards. During the pressing the boards exploded because of high moisture content which was around 60 %. Because of the size of fibres and its wooden structure, the water couldn't get out of the material and it caused the explosion. All the testing pieces where made from deinked pulp old corrugated cardboards which was the original idea – to use recycled material.

For testing the boards, the single opening press (Höfer HLOP 280) was used. The first test samples were done in the dimensions of 20 x 20cm. The thickness of the board was 20mm. The density of the boards was 0,75g/m3. First trials were done without any additives and with different temperatures. The testing started with 60°C, continued with 120°C and ended with 180°C. The pressing time depends on the thickness of the board. In case of 7mm thick board the pressing time was 5 minutes. In case of 20mm board the pressing time was 15 minutes. The samples were made in combination of DIP with starch glue and glucose, the same also for OCC and they were compared to board made from DIP and OCC mixed with urea formaldehyde glue which is used in wood-based panel industry. The thickness of the board was also 20mm and the density was 0,75g/cm^3.

Another testing was done with the 7mm boards made also from DIP and OCC. The frame used for pressing had dimensions of 32 x 32cm. The boards were made with urea-formaldehyde glue. After that there was a trial of 7mm boards made with starch glue and glucose. Unfortunately, the thickness didn't allow the moisture to come out of the board and the boards exploded while pressing as well. That is why there are only results of testing the 7mm boards made from UF glue.

In the end 20mm boards with urea formaldehyde glue were manufactured with dimensions of 50 x 50cm. They were made both from DIP and OCC.

From the boards mentioned above, eighty testing samples were cut and tested. The testing was done by the universal testing device Zwick/Roell Z 250. The testing samples were made according to European standards with dimensions 50 x 50mm and several tests of its mechanical properties were done after that – determination of density and density profile (EN 323:2005), moisture content (EN 322:2005), thickness swelling and water absorption (EN317:2005), internal bond (EN 319:2005) and screw withdrawal resistance (EN 320:2011). For testing of modulus of elasticity in bending and bending strength (EN 310:1993) the test samples had dimensions according the standard for each thickness. The width was 50mm and the length are always 20 times thickness of the board plus 50mm.

Fig. 1.
Paper Boards:
***a – Paper boards DIP and OCC with starch glue; b – Testing samples OCC, DIP (*180°C, 120°C, 60°C).**

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a. *b.*

Fig. 2.
UF Paper Board:
***a – Paper boards DIP with UF glue 7mm thick; b – T*esting of swelling in thickness.**

RESULTS AND DISCUSSION

In this chapter there are the results for each paper board combination. The results of this project are different paper boards which can be used for furniture. The testing paper boards were made from DIP and OCC with thickness of 7 and 20mm. Both materials were mixed with starch glue and urea formaldehyde glue. Eighty testing samples were made and for each test three samples were used. The testing was done according to European standards.

The following graphs are showing density profile of each paper boards. The project started with testing mixed paper pulp only with water and without any additives. Also, the temperature while pressing was lower – 120°C and 180°C after that. In the first graph (Fig. 3), it is seen that the testing samples without any additives had the lowest density which was around 450kg/m^3. Other samples in the first graph were made with starch glue. Their density was much higher in comparison with the first trials of 120°C and 180°C without any glue. The average value was 700kg/m^3.

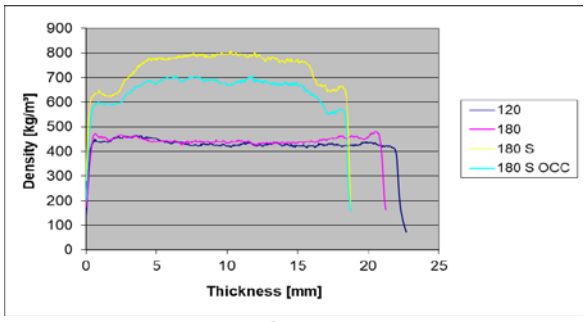

Fig. 3.
Density profile of 20mm starch boards.

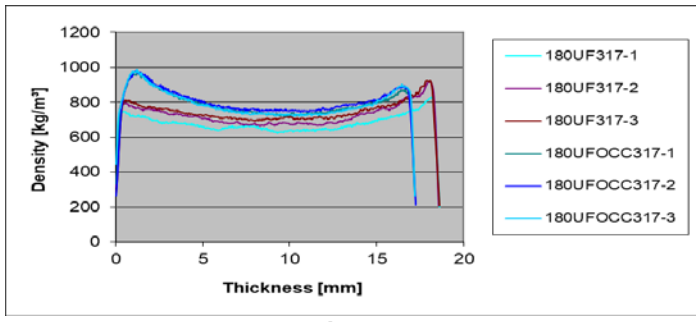

Fig. 4.
Density profile of 20mm UF boards.

Following graph (Fig. 4) is showing the density profile of paper boards from DIP and OCC with urea formaldehyde glue. The average value was 800kg/m^3.

The last graph is showing the density of urea formaldehyde boards with 7mm thickness. The average value was around 1000kg/m^3.

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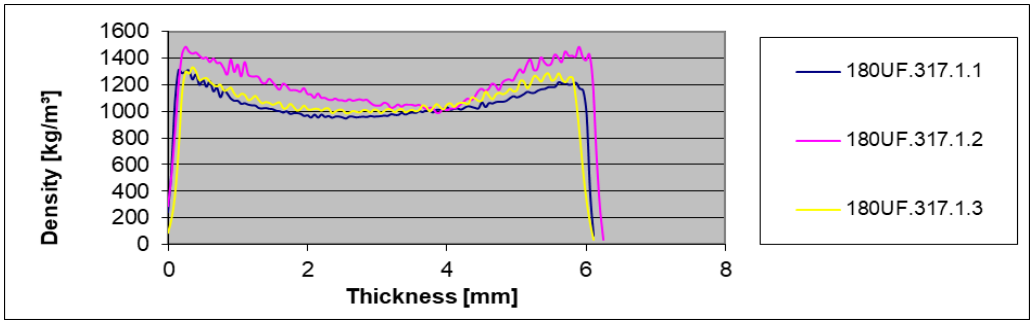

Fig. 5.
Density profile of 7mm UF board.

Table 1

Comparison of testing the mechanical properties for DIP and OCC boards with 7 mm and 20 mm thickness using UF and starch glue

TESTING METHOD	***Internal Bond EN 319***	***Screw withdrawal EN 320***	***Density profile EN 323***	***Swelling in thickness EN 317***	***Bending strength EN 310***	***Modulus of elasticity EN 310***
material/thickness/units	***[N/mm²]***	***[N]***	***[kg/m3]***	***[%]***	***[N/mm²]***	***[N/mm²]***
120 DIP 20 mm	*0,01*	*182,26*	*422,30*	*31,12*	-	-
180 DIP 20 mm	*0,01*	*127,08*	*439,76*	*27,90*	-	-
180 S DIP 20 mm	*0,37*	*1031,93*	*730,59*	*22,52*	-	-
180 UF DIP 20 mm	*0,39*	***1899,97***	*841,96*	*29,50*	*6,13*	*1189,07*
180 S OCC 20 mm	*0,33*	*953,35*	*641,16*	***19,97***	-	-
180 UF OCC 20 mm	***0,51***	*1277,94*	*659,10*	*21,03*	*5,89*	*750,83*
EGGER MDF ST E1 >19 - 30 mm	*>0,55*	*>1080*	*600 - 800*	*<10*	*>18*	*>2100*
180 S DIP 7 mm	-	-	-	-	-	-
180 UF DIP 7 mm	*0,41*	*542,95*	***1078,67***	*52,93*	***14,29***	***3019,93***
EGGER MDF ST E1 >6 - 9 mm	*>0,65*	-	*600 - 800*	*<17*	*>23*	*>2700*

In this research there were manufactured paper boards from two different materials (DIP and OCC). Two types of different glue were used (starch and urea formaldehyde) and the thickness of paper boards was 7 and 20mm. Eighty testing samples were prepared according to European standards and their mechanical and physical properties were tested. For each testing method three samples were used.

In the table above (Table 1) can be seen that the samples made without any additives (glue) and with lower temperature at first had much lower values than the samples made with glue. The density of DIP sample pressed with 120°C was around 400kg/m^3 while the samples pressed with one of the mentioned glues varies from 700kg/m^3 to 1000kg/m^3. That is why the following samples were made with either starch glue or urea formaldehyde glue.

The values for the 7mm board from DIP and UF glue were quite good in comparison with other samples. Its results can be compared with industrially manufactured fibreboards. The comparison was made with EGGER MDF ST E1 >6 - 9mm. The density of the board is 1078,67kg/m^3. The internal bond was 0,41N/mm^2. Thanks to its high density the bending strength was 14,29N/mm^2 and the modulus of elasticity was 3019,93N/mm^2. Swelling in thickness in this case was around 52,93% which was higher in comparisons

with other samples. Screw withdrawal resistance was the lowest in comparison with other samples made with glue – 542,95N. The 20mm boards had higher resistance because of their thickness.

As it was mentioned before, the 7mm thick board with starch glue was not working because of the moisture content of the paper pulp. The moisture content was around 60%. Because of the small thickness of 7mm, the steam could not easily get out of the board while pressing which led to explosion of the board. That is why there are only results of DIP board with UF glue and 7mm thickness.

In case of 20mm boards made from DIP and OCC with the two types of glue, the results were quite similar. Bending strength could be done only for the UF glue for this paper but there will be more testing samples done as part of the project. The highest value of screw withdrawal resistance had DIP board with UF glue where the resistance was 1899,97N. Average density was 841,96kg/m^3. The lowest swelling in thickness had the OCC samples with starch glue – 19,97%. Highest result of internal bond which was 0,51N/mm^2 had sample from OCC UF glue. This result was closest to the EGGER MDF ST E1 >19 - 30mm which should be higher than 0,55N/mm^2. Bending strength of DIP and OCC was 6,13N/mm^2 in case of DIP and 5,89N/mm^2 in case of OCC. DIP sample with UF glue had higher modulus of elasticity than UF OCC sample – 1189,07N/mm^2. OCC sample with UF glue had modulus of elasticity 750,83N/mm^2. The highest value had 7mm UF samples.

The results are not complete because of some troubles during pressing the boards and lack of provided material. Other boards will be done as following part of the project. Although these results still give a good idea about the strength of the paper boards and the best option. The most significant results show the 7mm thick board made from deinked pulp and urea-formaldehyde glue. The second material would be old corrugated cardboard boards with starch glue and the 20mm thickness.

CONCLUSIONS

The results obtained from this project are different paper boards which can be used as a table top for furniture, in this case for side table. There were manufactured boards from deinked pulp and old corrugated cardboards with 7mm and 20mm thickness. The used glue was urea-formaldehyde resin and starch together with glucose.

With consideration of the results, the best option would be the use of UF glue in either 7mm thickness or 20mm, which would be better for a top of table. Because of the short time of research, it was hard to make all the combinations on time. That is why the project will continue and there will be done other tests as well.

The result of this project will be furniture piece according the previous research. The idea is to design and manufacture side table. Inspiration for the project comes from the Canadian company Dear Human and their paper pulp furniture (Dear Human 2016).

a. **b.**

Fig. 6.
Paper pulp furniture:
a – Dear Human paper pulp Tea tables (Dear Human 2016); b – Dear Human Paper Rock table (Dear Human 2017).

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