

PRODUCTION OF FURNITURE ELEMENTS WITH PARTICLEBOARD CUTTING WASTE CORE

Dimitar Angelski, Krasimira Atanasova, Vanesa Angelova

University of Forestry, Sofia, Bulgaria

E-mail: d.angelski@ltu.bg, k_atanasova@ltu.bg, angelova438@gmail.com

ABSTRACT

The scarcity of natural resources and the generation of waste without adequate disposal are worldwide concerns related to the linear production model. The present study is part of a research project to create a technology for the utilization of laminated particleboard cutting waste in furniture element production. A layer of waste details was laminated on both sides with High Pressure Laminate (HPL) with a thickness of 0.8 mm. Polyvinyl acetate adhesive was used for lamination. The influence of the lamination process conditions and the arrangement scheme of the core details on the appearance, bending strength, and processing features in the subsequent technological phases of the manufacturing process has been established.

Key words: waste utilization, laminated particleboard, lamination, HPL.

INTRODUCTION

The scarcity of natural resources and the generation of waste without adequate disposal are a worldwide concern related to the linear production model (de Carvalho Araújo *et al.* 2019). According to data from the European Environment Agency, industrial processes and products, as well as the management of waste, were responsible for 12.42% of greenhouse gas emissions in 2019 (<https://www.europarl.europa.eu/>). A study by European Federation of Furniture Manufacturers (UEA) reveals that 80% to 90% of the furniture waste is incinerated or sent to landfill, with only 10 % recycled (UEA as cited in Forrest *et al.* 2017). Low recycling rates might depend on the fact that furniture is treated as "bulky waste" (Decision C. 2019/1004/EC, Decision C. 2019/1885/EC), is not sorted from other municipal waste appropriately, and that there is a lack of suitable recycling services (Vanacore *et al.* 2021). A publication by Wiprächtiger *et al.* (2022) shows that waste prevention is better from an environmental point of view than recycling or recovery. Daian *et al.* (2009) propose a potentially profitable wood waste recycling-oriented business model based on the on-site processing of wood waste into high-value products.

Furniture waste in the EU typically consists of a variety of elements such as wood particleboards, medium-density fibreboard, metal and aluminium, plastic and different textiles (Vanacore *et al.* 2021). According to a publication by Daian *et al.* (2009), an average of 8% of engineered wood products is wasted in the form of offcuts.

The characteristic of small-scale furniture enterprises in Bulgaria is the presence of warehouses that contain a lot of waste from cut laminated boards with different colours, textures, and sizes, which cannot be put into production. These warehouses reduce the effective production area and complicate the production process. The waste itself represents an unrealized financial resource since the funds invested in it are practically irrecoverable (Takacs *et al.* 2020). At the same time, in recent years, there has been a trend of increasing shortages of materials for furniture production (<https://ec.europa.eu/eurostat/>) and a significant extension of delivery times.

A complex solution to the mentioned problems is the creation and implementation of technologies for plate waste utilization. The correct choice and rational use of such technologies

are prerequisites for the utilization of usable structural elements with relatively low cost, carbon, and water footprint.

Currently, existing technologies refer to the recovery of waste with widths from 20 to 50-60 mm. The waste strips are used to form composite plates that are calibrated and laminated on both sides. The strips can be joined to each other by glueing along a straight edge using polyvinyl acetate (PVA) adhesive. Usually, the joining along the edges is carried out on specialized presses with two-way applied pressure: along the edges and in a direction perpendicular to the plate plane (Kavalov and Angelski 2014).

The technologies described in this way are not applicable to laminated chipboards due to their characteristic surfaces. In order to achieve good adhesion strength between the plate laminated surface and the cladding layer, polyurethane adhesives (PU) must be used. PU adhesives are primarily produced from non-renewable resources and have high carbon footprint levels (Fonseca *et al.* 2023). The materials from which the waste pieces remain are from different lots, so they cannot be assumed to be of the same thickness. Measuring and dividing the pieces by thickness would take a lot of time. For this reason, it is necessary to level the waste parts by thickness, which, given their small dimensions, is non-technological (additional time and energy are spent).

In this regard, the aim of the present study is to determine the influence of the arrangement scheme of the details in the core and the lamination conditions of furniture elements on their appearance, bending strength, and processing conditions in the next technological phases.

METHODOLOGY

Waste pieces of laminated chipboard with different colours, textures, and sizes were used for the core of the furniture elements. The parts were 18 mm thick. Some of their surfaces were scratched or partially damaged. They were cut into details of equal width ($B = 23 \text{ mm}$) and lengths according to the adopted arrangement scheme (Figure 1).



Figure 1: Cut-out details for the furniture element core

The details were stacked side by side, with their laminated sides facing each other without being glued together (Figure 2) and laminated. This approach allowed us to unify the dimensions of the blanks needed to form the core element. The main size is the width of the details "B"

(Figure 2A), which is determined by subtracting the thicknesses of the cladding sheets from the desired final product thickness.



Figure 2: Schematics of core detail arrangement. A – orientation of the details, B – initial scheme of the detail arrangement

High-Pressure Laminate (HPL) with a thickness of 0.8 mm was used as the laminating material. According to a study by the European Panel Federation (EPF), the carbon footprint of HPL is about 1.2 kg CO₂ eq.m⁻² (Helmi 2024).

Polyvinyl acetate (PVA) dispersion adhesive JOWACOL 103.05 was chosen for lamination. The adhesive characteristics are presented in Table 1.

The lamination was carried out on a laboratory hydraulic press with manual loading at a heating plate temperature of 50 °C and a pressing time of 4 min.

An adhesive amount of 150 g.m⁻² was applied to the cladding sheets.

The experiments were carried out at a hydraulic pressure of 100 bar, which corresponds to a plate pressure of 0.12 MPa, with 45% loading on the press. According to research by Angeliski and Atanasova (2023), this value ensures sufficient quality adhesion of the cladding layers to the substrate.

Table 1: Properties of JOWACOL103.05 adhesive (<https://www.hranipex.lt/>)

Property	Value	Units
Quantity applied	150 – 200	g.m ⁻²
Open assembly time	5 – 8	min
Pressure	> 0.5	N.m ⁻²
Minimum pressing time at a temperature of 20 °C	30	Min
Minimum pressing time at a temperature of 50 °C	4	Min
Minimum pressing time at a temperature of 90 °C	1.5	Min
Viscosity Brookfield	approx. 12000	mPas
Solid content	approx. 50	%
Density at 20 °C	approx. 1.08	g.cm ⁻³
VOC – Volatile Organic Compounds	0.08	%

Two series of specimens were prepared – with the orientation of the core details parallel to the furniture element length (longitudinal orientation of the details, Figure 3A) and with the orientation of the core details perpendicular to the finished unit length (transverse orientation of the details, Figure 3B). The finished units are cut into specimens with a width of 50 mm and a length of 550 mm, according to EN 310:1993, as well as parts with a width of 36 mm and 18 mm, at the same length (Figure 3).

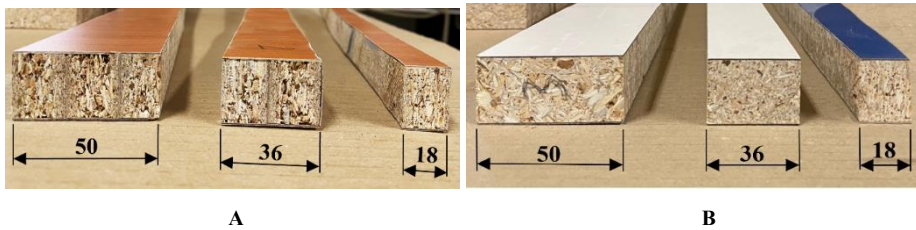


Figure 3: Specimens. A – longitudinal orientation of the core details; B – transverse orientation of core details

For comparison, 550 x 50 mm specimens were cut from 25 mm thick factory-laminated particleboard and 550 x 25 mm specimens were cut from 18 mm thick laminated particleboard. The measurements for these specimens are called baseline.

The resulting plate elements were conditioned for 24 hours at 22°C and 60 ± 2 % R.H.

Appearance, bending strength, and manufacturability of the lamination and second machining phases of the obtained elements were evaluated.

The appearance was assessed organoleptically.

The bending strength f_m [$N \cdot mm^{-2}$] was tested according to EN 310:1993.

For the research, a Universal testing machine with computer control WDW – 50E, manufactured by the company HST, China, 2022, was used. The measurements were carried out at a load application speed of 10 $mm \cdot min^{-1}$.

The experimental data were processed statistically by the testing machine software (MaxTest, USA).

RESULTS AND DISCUSSION

After conditioning, the laminated elements had a good appearance. The cladding sheets were glued evenly, with no peeling or running of adhesive. Marking of core details was observed on two pieces, one of which was on one of their sides. The marking was barely noticeable at a certain angle.

The marking can be explained by the different particleboard densities in thickness (density profile of particleboards), which make uneven penetration of the adhesive possible, as well as high pressing pressure values.

A warping of the elements was found (Figure 4) with curvature perpendicular to the longitudinally oriented core details. This means that it is not recommended to make elements with a core of longitudinally oriented parts and a width greater than 500 mm.

To prevent the elements from being warped, no matter what the unit width is, it is enough to add a transversely oriented detail in the core.

Displacement of the core details in length was found, which made it difficult to form the overall dimensions of the elements. Rotation was also observed, which produced holes in the core (Figure 4).



Figure 4: Defects of the specimens: ↓ – the element warping; * – holes, as a result of rotation of the core details

When forming the final dimensions of the elements, due to the rotation of the core details, the parallelism between the laminated surfaces and the cutting planes was broken, as a result of which sections of the laminated surfaces were observed along the edges of the elements (Figure 5). This can lead to reduced adhesion when edging with ethylene vinyl acetate adhesives.



Figure 5: Defects when cutting an element with longitudinally oriented details in the core

The results of the bending strength tests are presented in Table 2.

Table 2: Bending strength of factory laminated particleboard specimens (f_{m_b}), of a laminated element with a longitudinal orientation of the core details (f_{m_l}) and a laminated element with a transverse orientation of the details in the core (f_{m_t}), at specimen widths of 18 and 50 mm (average values)

Bending strength f_m [$N \cdot mm^{-2}$]	f_{m_b}	f_{m_l}	f_{m_t}	$f_{m_l} - f_{m_b}$ [%]	$f_{m_t} - f_{m_b}$ [%]
Specimen width [mm]					
18	7.90	14.2		80	
50	14.65	19.58	8.28	34	-43

The results show that HPL lamination increased the bending strength of the specimens by 80%. It can also be seen that the bending strength of an element with a longitudinal orientation of the core details was greater than the base bending strength by 34%. When the details in the core of the element were oriented transversely, the bending strength was 43% less.

In order to achieve a comparable or greater bending strength than the basic one, it is necessary to develop combined schemes for arranging the details in the core. Given the

displacement of the details in the core lengthwise, it is rational to experiment with limiting this displacement by means of perpendicularly oriented details at both ends.

Table 3 presents the results of bending strength tests for specimens of different widths from elements with differently oriented details in the core (Figure 3).

Table 3: Bending strength for specimens of different widths from elements with longitudinal and transverse core detail orientation (average values)

Specimen width [mm]	18	36	50	100
Bending strength f_m [N.mm⁻²]				
f_{m_l} (Figure 3A)	14.2	20.3	19.58	
f_{m_t} (Figure 3B)		6.1	8.28	6.7

According to the presented results, it can be recommended that in the arrangement scheme of the details in the core, the longitudinally oriented details are grouped in pairs.

Values of the bending strength of specimens with transversely oriented details in the core were found to be lower than the base ones. It cannot be claimed that the length of the transversely oriented details affects the bending strength.

Figures 6 – 7 present the studied detail's stress-strain relationships.

The comparison between the graphs presented in Figures 6 and 7 shows a different failure mechanism for the factory-laminated particleboard and the elements with longitudinal or transverse orientations of the core details. In the case of factory-laminated plates, with an increase in the loading force, the deformation gradually increases until the part breaks. In the core details with longitudinal orientation, for the majority of specimens, jump-like changes in the curves have been observed. The first change corresponds to peeling off the top HPL pressure-facing layer. Cases were also found where the unit had broken without the coating peeling off, or the seam under pressure was destroyed successively on both sides of the pressure beam (Figure 8A).

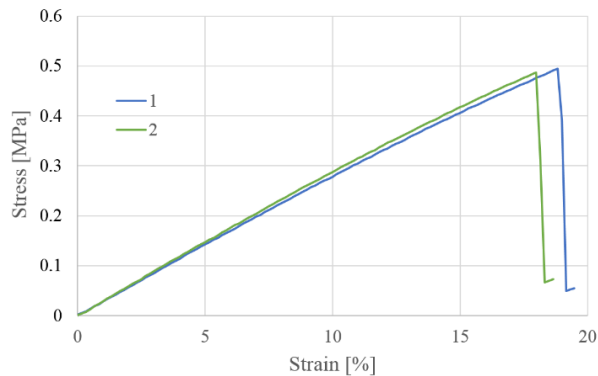


Figure 6: Stress-strain relationships (in percent of thickness) of 25 mm thick factory-laminated particleboard specimens. Width of the specimens is 50 mm

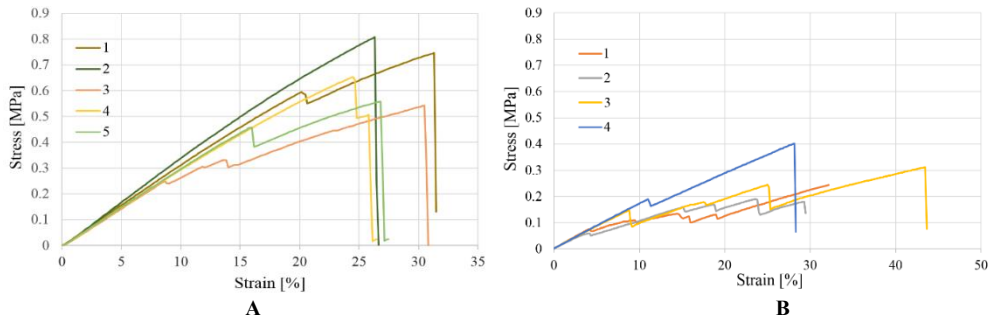


Figure 7: Stress-strain relationships (in percent of thickness) of 50 mm wide specimens.
A – longitudinal orientation of the details in the core; B – transverse orientation of the details in the core

The stress-strain relationships of the specimens with a transverse orientation of the details in the core, presented in Figure 7B, are characterized by a smooth increase in the deformation as a result of an increase in the stress and non-periodic drops, which correspond to displacement of the details from the core, which is the reason for the destruction of the adhesive bond (Figure 8B).



Figure 8: Damaging of specimens under bending stress. A – longitudinal orientation of the core details;
B – transverse orientation of the core details

The analysis of the destruction of the adhesive seam shows sufficiently high adhesion strength due to the presence of parts of wood particles on the surface of the detached cladding sheets.

CONCLUSION

The presented study investigates the influence of the lamination process conditions and the arrangement scheme of the core details on the appearance, bending strength, and conditions in the subsequent phases of the technological processing of laminated furniture elements. The core details were obtained from particleboard cutting waste. HPL with a thickness of 0.8 mm and PVA adhesive for hot bonding were used for lamination. The lamination was carried out at a heating plate temperature of 50 °C, a plate pressure of 0.12 MPa, and a pressing time of 4 min. The adhesive was applied to the cladding sheets at a quantity of 150 g.m⁻². The details in the core were arranged with their laminated surfaces side by side without being glued to each other.

It was found necessary to use a combined scheme of arrangement of the details in the core, which includes longitudinally and transversely oriented details.

It may be recommended to limit the length displacement of the details by placing perpendicularly oriented details at both ends of the fill layer and grouping the longitudinally oriented details in pairs.

The pressing conditions were suitable except for the pressing pressure, which needed to be reduced.

The results of the study can serve as a basis for research to create a technology for the production of three-layer furniture elements by double-sided lamination of a core composed of cutting particleboard plate waste.

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CONTENTS

EXAMINATION OF THE DEGREE OF SHRINKAGE AND SWELLING OF THE DOUGLAS FIR CELL WALL.....	7
Nikolay Bardarov, Martina Todorova, Vladislav Todorov, Viktor Mollov	
INFORMATION MODELLING OF SUSTAINABLE BIOENERGY AND BIOFUEL PRODUCTION.....	18
Boriana Deliyaska, Adelina Ivanova, Nikolay Nikolov, Radostina Popova-Terziyska	
INFLUENCE OF SOME TECHNOLOGICAL FACTORS OVER VIBRATION SPEED WHEN MILLING WHITE PINE DETAILS ON A UNIVERSAL WOOD SHAPER	28
Georgi Kovatchev, Valentin Atanasov	
MACHINES FOR PRIMARY LOG CUTTING: PART I – A STUDY ON SOME OPERATIONAL INDICATORS	36
Valentin Atanasov	
IMPACT OF FEED RATE ON ROUGHNESS OF THE CUT SURFACE AND ENERGY CONSUMPTION DURING CUTTING DRY BEECH WOOD WITH A CIRCULAR SAW	45
Anastasija Temelkova, Zoran Trposki	
EVALUATION OF THE MACHINED SURFACE QUALITY OF SCOTS PINE (<i>PINUS SYLVESTRIS</i> L.) WOOD SPECIMENS, DEPENDING ON THE CUTTING MODE OF A CNC MACHINE	53
Aleksandar Doichinov, Pavlin Vitchev	
PROCESSING SAWLOGS INTO PARQUET BLANKS	63
Ana Marija Stamenkoska, Branko Rabadziski, Goran Zlateski, Zoran Trposki, Anastasija Temelkova, Vladimir Koljozov	
INFLUENCE OF THE COMPONENTS OF THE WINDOW ON THERMAL CONDUCTIVITY	71
Elena Jevtoska, Gjorgi Gruevski	
A REVIEW OF SOME FACTORS AFFECTING THE ACCURACY OF MEASURING THE GEOMETRIC CHARACTERISTICS OF MORTISE AND TENON JOINTS	79
Nikola Mihajlovski, Gjorgi Gruevski	
CHANGES IN THE SURFACE PROPERTIES OF WOOD DURING BROWN ROT.....	85
Marko Petrič, Miha Humar, Andreja Žagar	
PRODUCTION OF FURNITURE ELEMENTS WITH PARTICLEBOARD CUTTING WASTE CORE.....	96
Dimitar Angelski, Krasimira Atanasova, Vanesa Angelova	

6 CONTENTS

EFFECT OF AGING ON THE AESTHETIC AND DECORATIVE FEATURES OF THE INNOVATIVE SALIXDUO PRODUCT FINISHED WITH ACRYLIC AND POLYURETHANE LACQUERS	105
Barbara Lis, Tomasz Krystofiak, Mikołaj Sumionka, Leszek Danecki, Bogusława Waliszewska	
FRAGMENTATION IN MACEDONIAN TRADITIONAL ARCHITECTURE IN RELATION TO THE WOOD AS A STRUCTURAL ELEMENT	112
Branko Temelkovski	
SPECIFICITIES OF BRAND DESIGN IN HIGHER EDUCATION.....	122
Silvina Ilieva, Kristin Ozanian	
ADVANCING FABRIC MATERIAL DIGITALIZATION THROUGH PHOTOMETRIC STEREO RECONSTRUCTION	131
Atanas Hristozov	
SCIENTIFIC JOURNAL „INNOVATIONS IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN“	139