An Analysis of a Method of Asymmetrical Veneering for Furniture Elements, Veneered with Bamboo Mats

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The aim of this study was to determine the influence of the application of glue, creating an elastic glue-line, on the deformation of wood-based panels asymmetrically veneered on one side with bamboo. The geometrical stability comparisons included multilayer composites used in the production of sliding doors, medium density fibreboard (MDF) panels, and chipboard used in the production of furniture. Chipboard panels retained their shape and stability after asymmetrical veneering, no matter which direction the veneer was placed in relation to the long edge. MDF boards retained their shape and stability only when they were veneered crosswise. The worst results were attained from composite boards, which bent in every case.

Keywords: Bamboo; Asymmetrical veneering; Deformation; Board

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INTRODUCTION

In an era of open exports and imports of goods from almost every part of the world, there are changing trends in the field of design, furniture decoration, and home decor. One growing trend is the use of bamboo. This material is usually used in garden architecture. However, it is not commonly known that, because of its properties, bamboo is suitable for finishing veneer panels. It is estimated that there are about 1,500 species of bamboo in the world. They all belong to same family of grasses, Gramineae (Poaceae) (Hoser 2006). However, specifying the bamboo species used in industry is almost impossible. This is due to many factors, the most important of which is that at least 60% of bamboo used for the production of veneer comes from the waste of other types of production. Additionally, depending on where the bamboo species are harvested, they have various mechanical and physical properties. For example, one species of bamboo usually comes in about 15 shades that can be distinguished with the naked eye. The most widely used bamboo veneer is a mat made up of many individual stalks of bamboo. The purpose of pre-treating the plant is to segregate it in terms of colour. Only carefully segregated stalks can be laid in a pattern veneer, and complex veneers are used to finish furniture and the panels in sliding doors.

There are currently two methods for asymmetrical veneering on sliding doors made of medium density fibreboard (MDF) decorated with bamboo. The first, the simpler one uses 8 mm thick MDF in which the unseen side is covered with balance paper. The second method is used for gluing specially prepared multilayer composites: balance paper - MDF - balance paper- MDF. The composite prepared in this way is veneered from the board side. Both methods of veneering are complex and require the introduction of additional steps to the standard production process of veneered panels in order to avoid any deformation in the finished product. This is a result of using UF glue, which, after curing, forms a rigid glue-joint.

The producers of these boards would benefit from finding an adhesive characterised by a flexible glue-line, which would allow the use of composite materials with different physical properties. Based on preliminary studies, it was found that a solution to this problem could be to use a polyisocyanate glue-line. The studies showed that the result of glue gelation is a flexible joint. This joint acts as a "vulnerable" connecting layer, making it possible to minimise the warping of furniture elements as a result of seasoning (Oleńska *et al.* 2010).

The aim of this study was to determine the influence of the application of glue, creating an elastic glue-line, on the deformation of wood-based panels asymmetrically veneered on one side with bamboo. The comparisons included multilayer composites used in the production of sliding doors, MDF panels, and chip-board. The results of the studies lead to development of a new production technology of furniture elements.

EXPERIMENTAL

Materials

Experimentation was carried out on three groups of wood-based panels.

Group one

The first group was chipboards having 18 mm thickness; these are popular boards used in furniture production (Figs. 1 and 2).

Fig. 1. Photo of the narrow surface of a wood-based panel veneered on one side

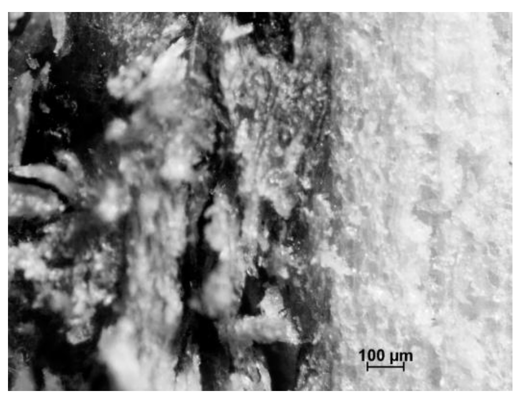


Fig. 2. Microscopic photo of veneered wood-based panel

Group two

The second group was MDF boards, 8 mm thick; these are standard boards used in the production of furniture elements and sliding doors (Figs. 3 and 4).

Fig. 3. Photo of the narrow surface of an MDF board veneered on one side

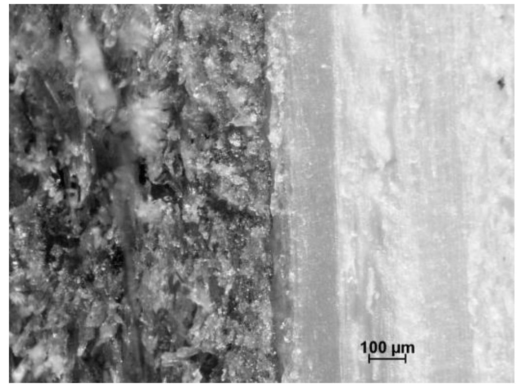


Fig. 4. Microscopic photo of veneered MDF board

Group three

The third group was multilayer composites made of MDF board (board 4 mm - balance paper - board 4 mm - balance paper), which are boards used in the production of sliding doors veneered on one side (Figs. 5 and 6).

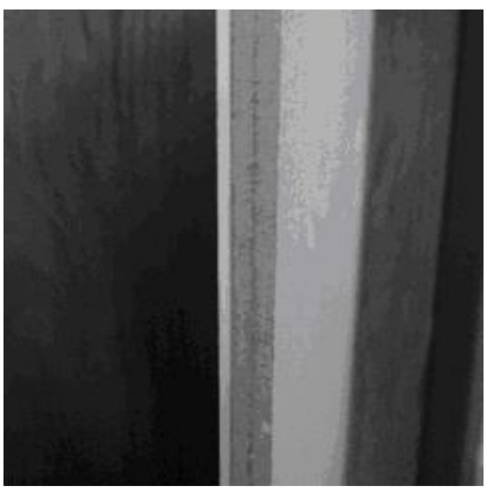


Fig. 5. Photo of the narrow surface of a composite board veneered on one side

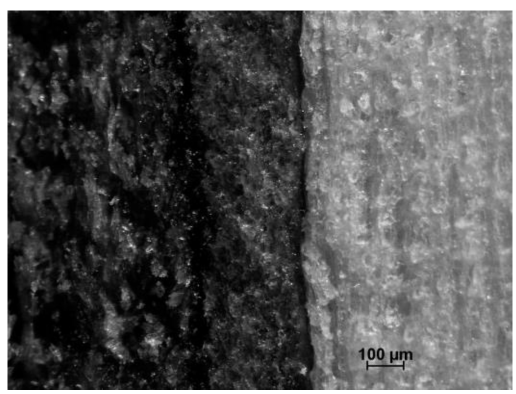


Fig. 6. Microscopic photo of veneered composite

In addition, each group of samples was sorted into two types according to the orientation of the fibres in relation to the long edge of the panel. In one group, the fibres of the bamboo veneer were oriented parallel to the long edge of the panel (samples veneered longitudinally), while in the other group, the veneer fibres were oriented perpendicularly to the long edge of board (samples veneered crosswise). Examples of each type are presented in Figs. 7 and 8.

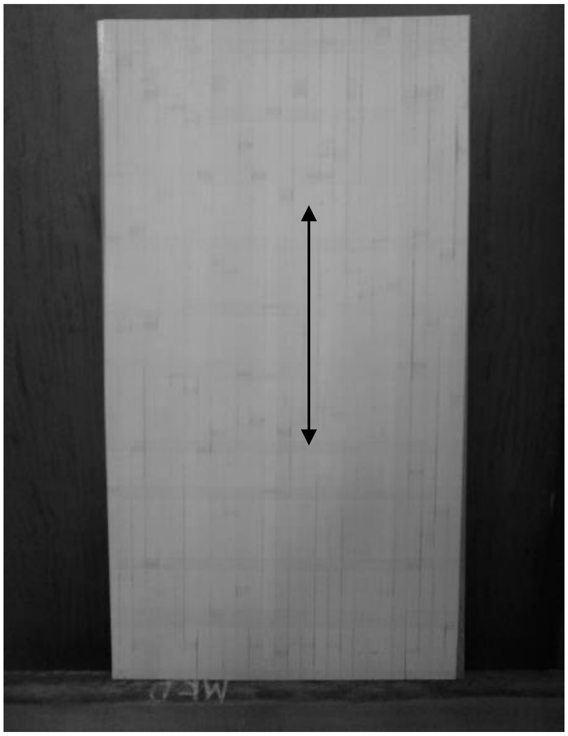


Fig. 7. Board veneered longitudinally

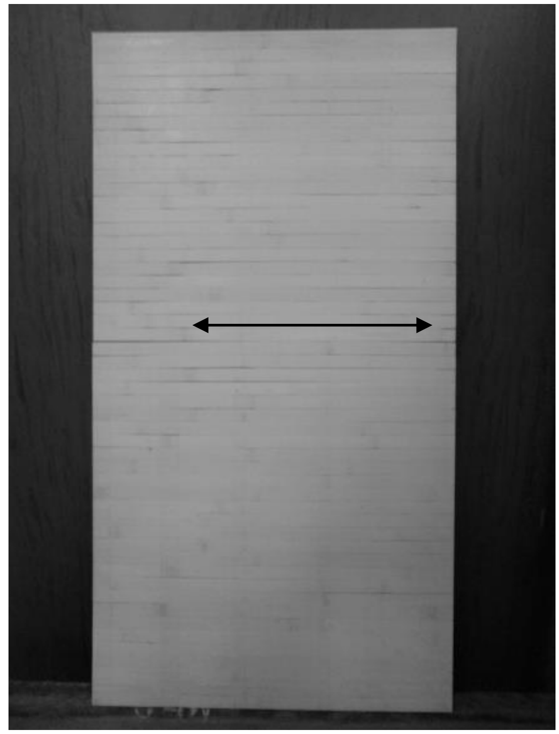


Fig. 8. Board veneered crosswise

All the studied boards were 450 mm wide and 900 mm long. The boards were covered on one side, using parallel fibrous bamboo veneer of natural colour. The veneer is made of flat strips of width about 1.6 mm. Bamboo, despite being classified as an herbaceous plant (because it has no cambium in its structure), has properties that are comparable to many kinds of wood. The properties of bamboo are presented in Table 1 (Pióro 2009), in comparison to the properties of oak (*Quercus robur* L.) (Krzysik 1953), which is one of the most suitable types of wood for furniture. These data prove that bamboo is certainly worth studying to verify the possibility of using it for furniture production.

Table 1. Properties of Oak (*Quercus robur* L.) and Bamboo*

Property	Value for bamboo	Value for oak
Density	750 kg/m^3	710 kg/m^3
Weight density of wet wood	1000 kg/m^3	1080 kg/m^3
Weight density of wood of humidity 9-12%	720 kg/m^3	660 kg/m^3
Brinell hardness	32-40 N/mm^2	60 N/mm^2
Bending strength	176 N/mm^2	92.5 N/mm^2
Shrinkage factor	0.19	0.12

**Phyllostachys pubescens* Mazel ex J. Houz, *Phyllostachys edulis*, *Phyllostachys heterocycla* Mitford, and *Bambusa heterocycla* Carriere

The veneering process was done using parameters: 70 °C, 1.5 MPa, and 150 s. The pressing time was extended at lower temperatures. This was done because of bamboo's high sensitivity to changes in humidity. All of the boards were veneered using the same type of polyisocyanate glue, with a viscosity of 2.5 Pas and density of 1.15 g/cm^3. The easiest method of understanding the reaction process of polyisocyanate glue is to analyse its sub-molecular structure. This includes the internal arrangement of building units and the chemical composition. The adhesive units were formed from a polyisocyanate monomer and a diol-diisocyanate (hexamethylene diisocyanate and 1.4 - butanediol) (Jabłoński *et al*. 2009):

$O=C=N(CH_2)_6-N=C=O$
hexamethylene diisocyanate

$HO-(CH_2)_4-OH$
1.4 - butanediol

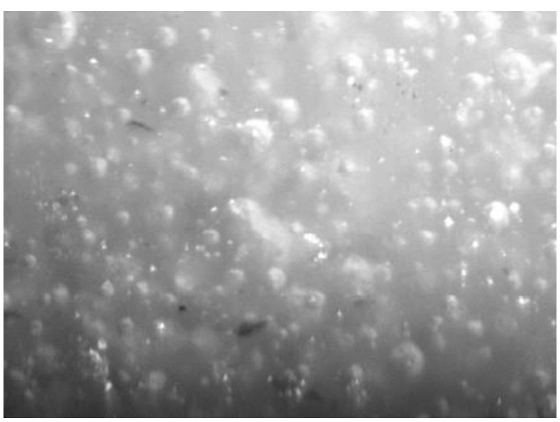
$-[O-(CH_2)_4-O-CO-NH-(CH_2)_6-NH-CO]_n-$
polyurethane

Fig. 9. Chemical reaction of polyurethane formation

Taking into account the chemical structure of the adhesive, it was classified as a polyadduct. Therefore, it arises as a result of the reaction of diisocyanates with glycols according to the formula (Grom *et al.* 1990):

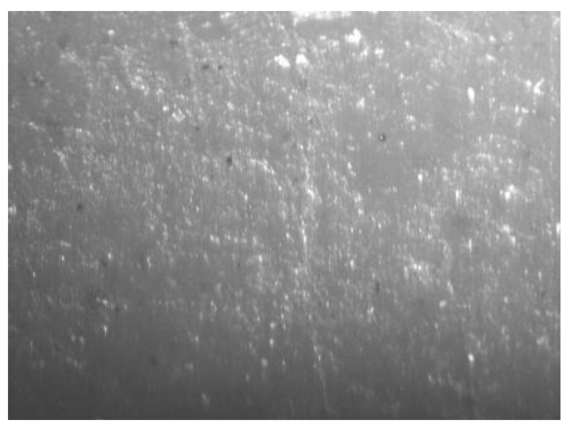
$$nO=C=N-(CH_2)_6-N=C=O+nHO-(CH_2)_4-OH \rightarrow [-NH-(CH_2)_6-NH-C=O]_n \quad (1)$$

Based on the model, it can be concluded that the selected glue does not include formaldehyde compounds. This is an important ecological property of the glue, and was one of the main criteria for choosing it. The other criterion for choosing polyisocyanate glue was its structure after crosslinking. As Figs. 10 and 11 show, the structure of popular industrial glues is rather uniform. Air blisters in PVAC and UF glue-lines have minimal sizes, which can be seen only with the use of a microscope. The size of blisters in the UF glue-line was found to be 136 μm and in PVAC glue-line only 11 μm.



500µm

Fig 10. Microscopic picture of UF glue-line



500µm

Fig 11. Microscopic picture of PVAC glue-line

During cross-linking polyisocyanate glue-line was found to become expanded. The result of this was a large number of air blisters that could be seen without a microscope (Fig. 12), and their size was about 1745 μm.

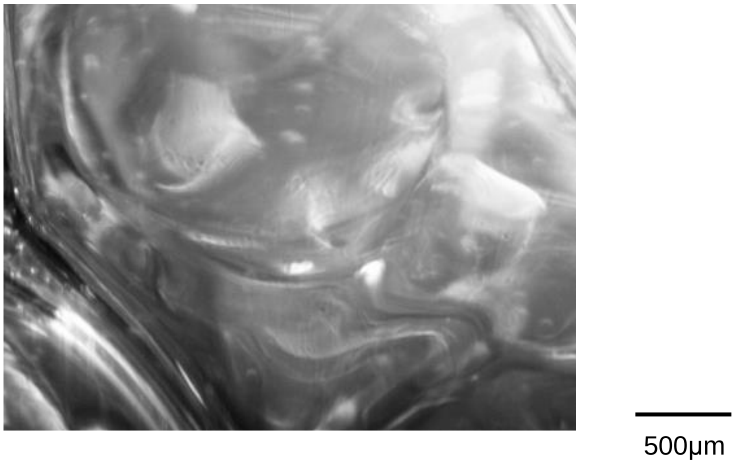


Fig. 12. Microscopic picture of PMDI glue-line

Similar criteria as for the choice of glue were taken to choose a varnish-elasticity of the product, its environment-friendliness, and the gelation. As a result, a thermoplastic varnish was selected whereby gelation takes place through the evaporation of volatile compounds. It should also be noted that the commonly used polyurethane varnish was decided against because polyurethane coatings are much more fragile and less resistant to change in humidity than acrylate ones (Jabłoński *et al.* 2009). This theory was also shown by studies on asymmetrical veneering, which showed that asymmetrical veneered panels that were finished with a polyurethane-based varnish were much more deformed than panels finished with an acrylate varnish (Oleńska *et al.* 2011). In addition, the selected varnish is water-based and odourless (Sitko e*t al.* 2005).

Methods

The basic parameters of the varnish were tested according to the relevant standards. A viscosity study was carried out in accordance with PN-C-81701, method A (1997). The dynamic viscosity, tested using a discharge cup with a conical bottom and a 4 mm diameter hole, was 100 mPas. The paint density was measured according to standard PN-EN ISO 2811-1 and amounted to 1.04 g/cm^3. The chosen method of determining the density allowed the study of products with low and medium viscosities.

The basic parameters of each sample were tested. First, the mean values of the veneer and wood-based panel thickness were measured using the microscopic method. Secondly, the density of the composite was tested using GreCon laboratory equipment. This study was also the base for calculating the porosity values of the veneers for each sample. The last parameter studied was the strength of the glue-line. The measurements were taken according to the European standards that describe the pull-off test (PN-EN ISO 4624:2004). For each panel, three tests were carried out. If the sample was destroyed on the board, this meant that the glue-line was appropriately strong for the combined composite layers. For the results of pull-off test, the following scale was used:

- 0 - All samples were destroyed in the glue-line.
- 1 - Two samples were destroyed in the glue-line and one was destroyed on the board.
- 1.5 - One sample was destroyed in the glue-line and two were destroyed on the board.
- 2 - All samples were destroyed on the board.

The results are presented in Table 2.

Table 2. Properties of the Panels

Description of panel (number, type, veneering direction)	Normative thickness of unveneered board [mm]	Thickness of veneer [mm]	Density of composite [kg/m^3]	Porosity of veneer [%]	Pull-off test
1- Chipboard, longitudinally	18	2.03	600	54.96	2
2- Chipboard, crosswise		2.05	615	55.41	2
3- Chipboard, longitudinally		2.04	620	57.77	2
4- MDF, longitudinally	8	1.97	855	51.01	1
5- MDF, longitudinally		2.07	830	54.85	0
6- MDF, longitudinally		2.04	815	55.74	0
7- MDF, crosswise		1.92	815	50.31	2
8- MDF, longitudinally		1.95	835	51.91	1.5
9- Composite, longitudinally	8.5	1.99	810	55.07	0
10- Composite, longitudinally		2.04	835	50.97	0
11- Composite, crosswise		1.95	810	52.15	0
12- Composite, crosswise		1.98	815	55.70	0
13- Composite, crosswise		1.95	805	55.54	0

The main part of the study, measurements of panel deformation, was carried out on a specially designed stand, the construction of which is shown in Fig. 13.

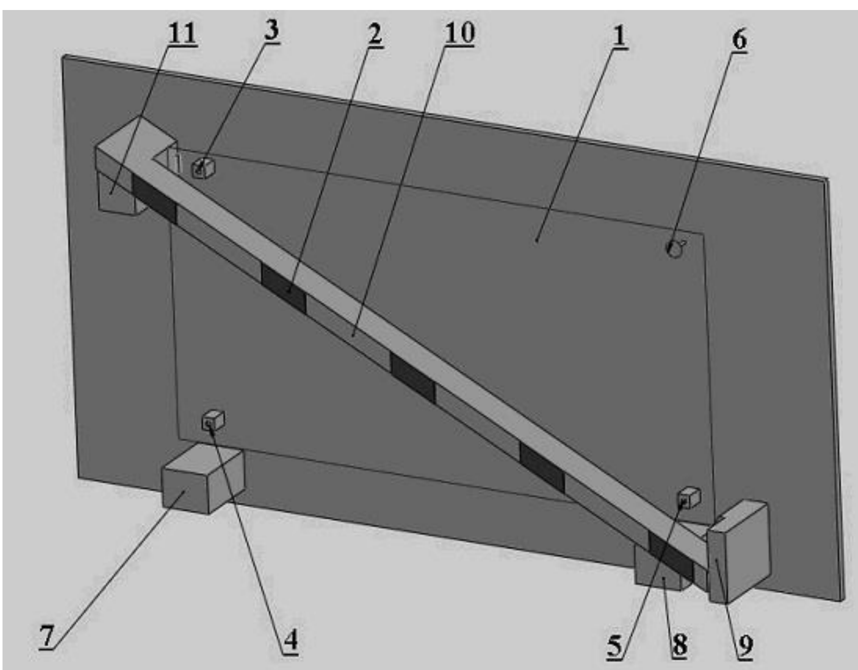


Fig. 13. The scheme of the measurement station (explanation in the text)

The main idea of the stand was to define a reference virtual plane (1). This plane was created with four pegs. Three of them had a constant height of 30 mm (3, 4, 5). The fourth was adjustable (6) and its height was adjusted to the shape of the measured panel. This means that the panel was in contact with all four pegs. The actual shape was axially positioned with the pegs.

During the measurements, the panels were always placed equally in position to each peg using the support of the panel that was previously settled with three fixed blocks (7, 8, 9). The visible surface of the strip (10) formed the reference surface. The strip was placed diagonally with three blocks (8, 9, 11) that positioned the strip in stable place. The distance between the reference virtual plane and reference surface of the strip was constant. This is where the measured board was placed. The geometry was measured in five areas (2), five times in each area (3 mm gap), with a depth gauge. Its precision was 0.01 mm, but the measurement error was 0.02 mm.

Panels were measured in three states:

1. unveneered board prepared for the purifying process
2. board veneered on one side with bamboo, unvarnished
3. board veneered on one side with bamboo, varnished

Before each measurement, the boards were conditioned at 22 ± 2 °C and 65 ± 5% relative humidity for seven days.

RESULTS AND DISCUSSION

The results of measurements for all sample groups are presented in Figs. 14-16.

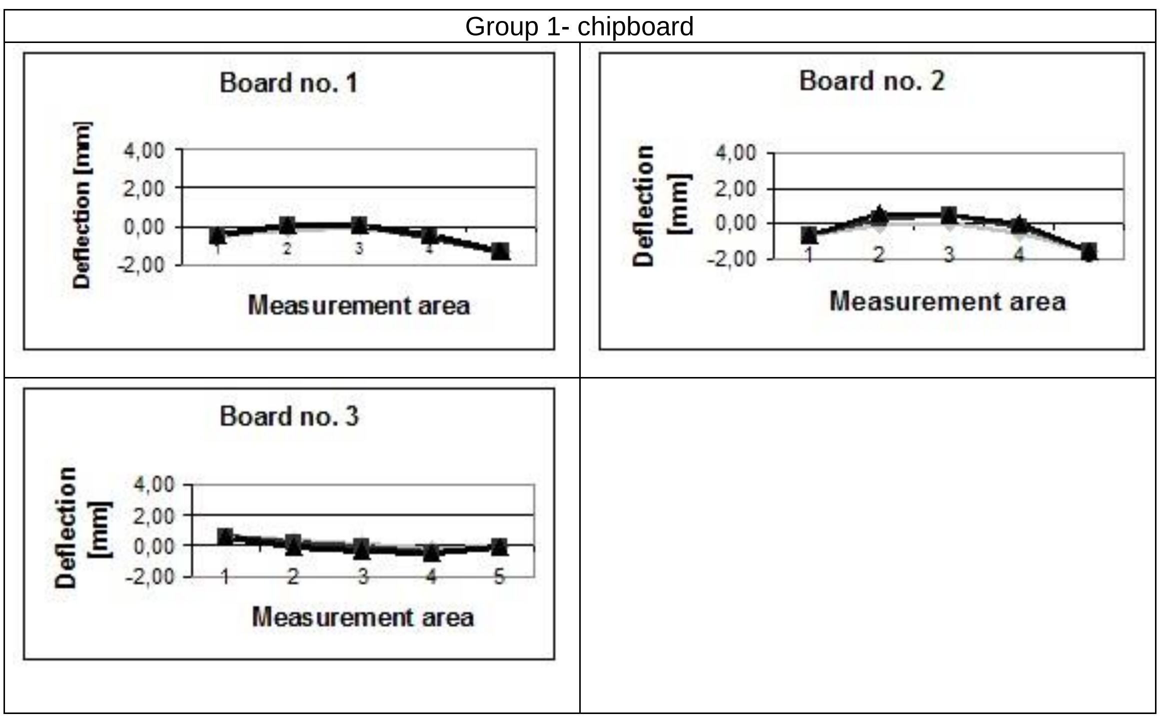


Fig. 14. Group 1 deflection results

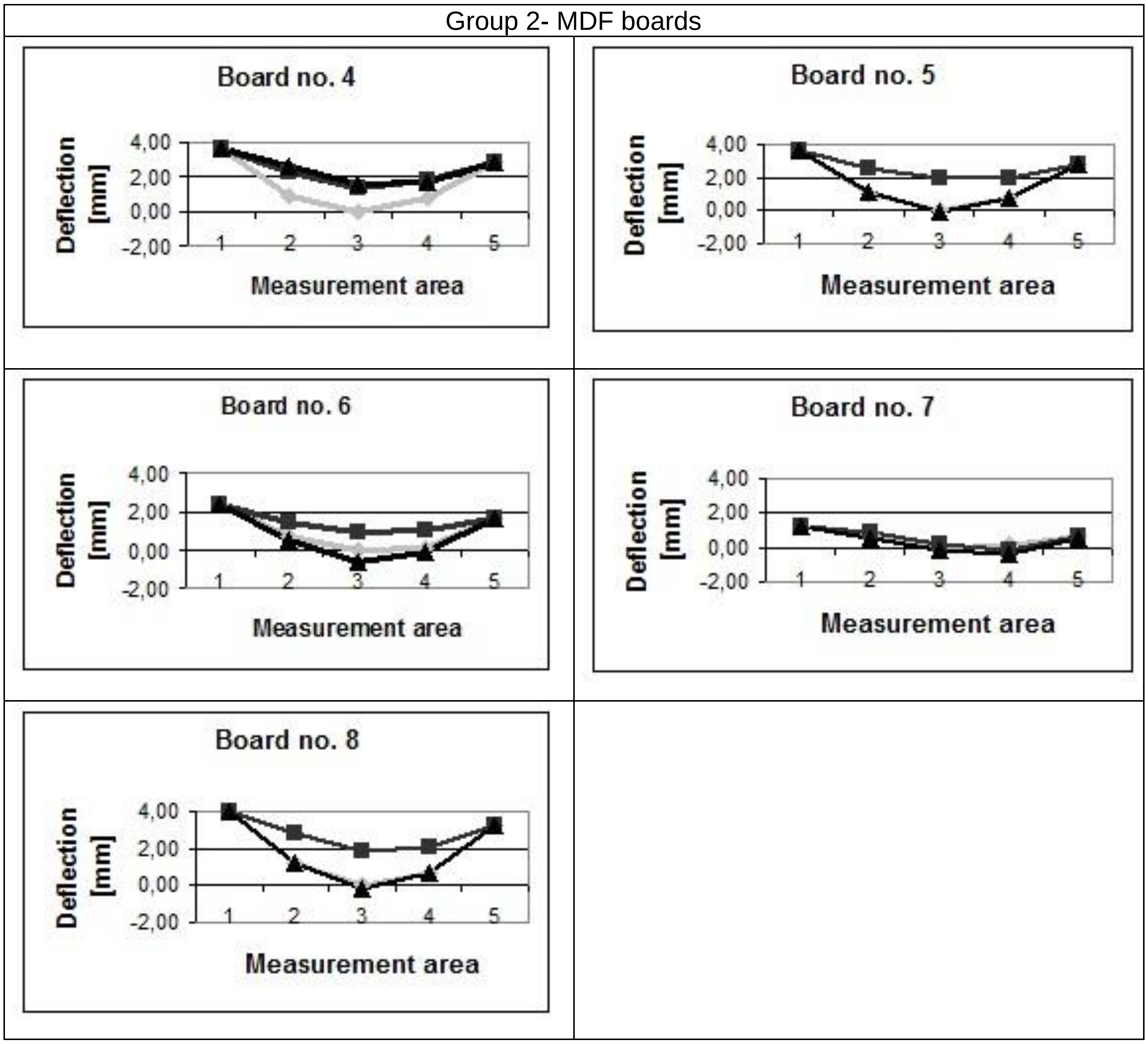
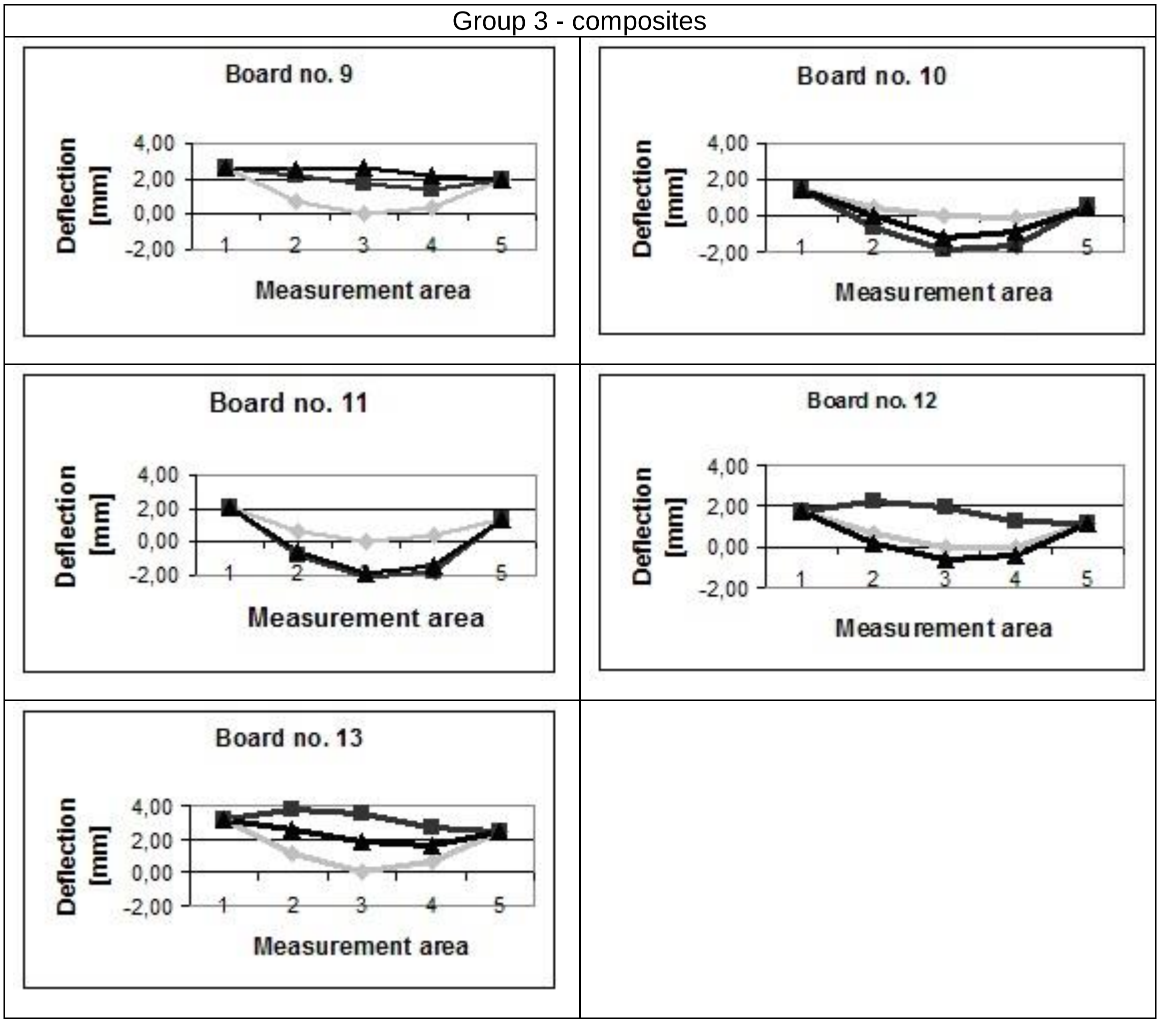


Fig. 15. Group 2 deflection results

After analysing the obtained measurements, it was concluded that the chipboard supplied by the manufacturer was deformed. This is not acceptable in laboratory conditions, although it may be acceptable in industrial production. The deformation measurements of the unveneered wood-based panels were the starting point for the analysis of the veneered and varnished samples. The results showed that wood-based panels 18 mm thick retained their shape after each modification process. Therefore, the properties of veneer used and the direction of the veneer placement did not have any significant influence on the deformation of the boards. It can be said that the elasticity of the polyisocyanate glue-line was good enough for standard industrial furniture elements.

Different results were obtained for the MDF group (the second group in the study). The measurements taken showed that MDF boards did not deform if the veneer was placed crosswise. However, if panels were veneered longitudinally, then the veneering and varnishing processes led to bending in the boards. In any case, the most interesting fact is that the panels warped the most when the weakest glue-line was applied. However, it should be noted that all of the boards (panels 4, 5, 6, and 8) retained their original, concave shape.



♦ unveneered board
■ veneered board, unvarnished
▲ veneered board, varnished

Fig. 16. Group 3 deflection results

The most atypical results were those obtained for the third group: the panels made of composite (board - balance paper - board - balance paper). This production technology requires the overcoming of stresses that are the reason for bending of asymmetrically veneered panels. In any case, the measurements showed that panels made of composite warped the most after being veneered using polyisocyanate glue. Moreover, only panels from the third group failed to preserve their original shape and, after purifying, changed from concave to convex. Furthermore, it should be noted that the glue-line strength was insufficient only in the composite samples. In each case from this group, the sample was broken in the adhesive.

Composite samples warped the most for two reasons: the samples were created from two thick MDF boards (4 mm thick) and because the composite layers were connected using rigid UF glue-joints. It is likely that, during the pressing process, the rigid glue-line deformed, leading to increased adhesive fragility and reducing brittleness resistance to thermal motions of the adhesive interface (Cagle 1977).

CONCLUSIONS

1. Chipboard panels retained their shape and stability after asymmetrical veneering, no matter in which direction the veneer was placed in relation to the long edge. The influence of board thickness was noted.

2. MDF boards retained their shape and stability only when they were veneered crosswise. MDF boards veneered longitudinally deformed to varying degrees. The worst results were achieved for composite boards, which bent in each case.

3. The difference between the reaction of composite and MDF boards is explained by the difference in structure and the thickness of the boards used.

4. Samples made of composites bent the most, and this may support the theory that a sufficiently flexible glue-line is key to minimising stresses existing in veneered composites.

ACKNOWLEDGMENTS

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