Flexural Properties of Blockboard Reinforced with Glass Fiber and Various Types of Fabrics

Mihai Ispas, Camelia Cosereanu, Octavia Zeleniuc,* and Mihaela Porojan

Flexural properties were evaluated of blockboard with spruce (*Picea abies* Mill) core and faces made of 2.5-mm fromager (*Ceiba pentandra*) veneer and 3-mm high-density fiberboard (HDF). For these two types of structures, fiber glass, jute, gauze, and cotton fabrics, were separately bonded under the face layers to improve the strength performance. Flexural properties, modulus of rupture (MOR), and modulus of elasticity (MOE) were determined under laboratory conditions. Improved values were found for MOR and MOE tested in the parallel to core grain direction compared to those perpendicular-to-grain. They were 32% to 49% (MOR) and 39% to 95% (MOE) improvements in case of veneer faces and 142% to 161% (MOR) and 134% to 245% (MOE) improvements in case of HDF faces. The best results of MOR and MOE were obtained for glass fiber used as insertion material, the higher ones being reached for specimens tested in the parallel direction to grain, which were 56.1 N/mm^2 (MOR) and 6704 N/mm^2 (MOE) for HDF faces. Generally, the improvements were more evident on the blockboard structures with veneer faces oriented perpendicular-to-core grain (30% for MOR and 18% MOE) and for HDF faces with parallel core grain orientation (16% for MOR and 6% MOE).

Keywords: Blockboard; Spruce core; Fromager veneer; HDF; Fabrics; Fiber glass; MOR; MOE

Contact information: Department of Wood Processing and Wooden Products Design, Transilvania University of Brasov, Faculty of Wood Engineering, B-dul Eroilor 29, 500036, Brasov, Romania;
**Corresponding author: zoctavia@unitbv.ro*

INTRODUCTION

Blockboard is an engineered wood product that is widely used in furniture making, where resistance to bending is required. Thus, it is preferred over plywood for long shelves or top tables. It is lightweight, exhibits high resistance to warping or twisting, is durable, and it is also suitable for interior design, such as wall panels, partitions, doors, or flooring.

In Europe, the total production of blockboard amounted to 268,000 m^3 in 2004. The main blockboard producers are Germany, Italy, Poland, and Czech Republic (Bio-based News 2005). Romania became the leader in Europe with a blockboard production of 145,000 m^3 in 2017, because of the investments made by Schweighofer Group**.**

Blockboard consists of a central layer (core) made up of solid wood strips that may contain defects undesirable for the face of the finished panels (Laufenberg *et al.* 2006). Otherwise, two faces from different wood-based composites, such as veneers, medium-density fiberboard (MDF), high-density fiberboard (HDF), or plywood, complete their sandwich structure, which is more stable and has a good resistance to warping. Adjacent veneers are oriented perpendicular to the core wood grains' orientation. The thickness of the outer layers ranges from 2 mm to 3.5 mm and are applied on the core with an adhesive under high pressure. The core is usually made from low-grade logs and low-quality wood, small length timber, or timber wastes, which can increase the yield of the raw material used. Therefore, making a blockboard core represents a significant opportunity for increasing the use of unused materials (Bowyer and Stokke 1982).

Several studies have investigated the physical and mechanical properties of the blockboard made from various wood species and wood-based materials for the faces and core (Tang *et al.* 2001; Laufenberg *et al.* 2006; Gayda 2016; Teixeira and Firme de Melo 2017; Pinati *et al.* 2018; Nelis *et al.* 2019). Others studied the influence of adhesive type and content (Zanuttini and Cremonini 2002) and the type of joint (Teixeira and Firme de Melo 2017; Nazerian *et al.* 2018) on the mechanical properties of the blockboard. Non-destructive testing to detect defects in the blockboard structure (Wu *et al.* 2009; Yang and Qi 2011), laboratory decay, termite resistance evaluation (Kartal and Ayrilmis 2005), formaldehyde emission (Böhm *et al.* 2012), and fire performance (Laufenberg *et al.* 2006) tests have been also performed by researchers.

Regarding the mechanical properties, it was found that short core blocks up to approximately 20 cm could be used for blockboard manufacturing to obtain a good panel performance (Bowyer and Stokke 1982). No difference in static bending was observed for experimental panels made with core strips with and without glue on the edges (Zanuttini and Cremonini 2002). The bending strength performance increases when short slats are end-to-end mitered jointed or half-jointed instead of butt-jointed (Nazerian *et al.* 2018). Densities of the blockboard panels made from different cores (*Paulownia*, *Picea abies*, *Pinus oocarpa*, *Castilla ulei*, and *Acrocarpus fraxinifolius*) have influenced the values of bending strength and modulus of elasticity. The lighter core materials presented lower modulus of rupture (MOR), modulus of elasticity (MOE), and screw withdrawal resistance compared to pine (Pinati *et al.* 2018; Nelis *et al.* 2019). Additionally, it was shown that MOR and MOE tested in parallel core grain orientation recorded considerably higher values than those of perpendicular core grain orientation (Tang *et al.* 2001; Teixeira and Firme de Melo 2017; Haseli *et al.* 2018).

In the blockboard production the key items are represented by the cost of the core material and also by the strength properties when compared to plywood. To overcome this, one way is to use locally available low-grade wood material resources for the core (Nazerian *et al.* 2018) and make a suitable dispersion of defects in all areas of the panel (Colak *et al.* 2007). The other way is to reduce the negative effect of the defects, such as knots or cracks, which decrease the strength of the panel, is by combining the low quality cores with more resistant faces, such as MDF (Haseli *et al.* 2018) or HDF.

Today, the blockboard producers are confronted with the problem of raw material availability and prices. Therefore, they should maximize yield from low-grade and scrap wood and keep the cost at a low level required by the market, sometimes these affect the mechanical performance of the blockboard.

The present research investigates the flexural properties (MOR and MOE) of the blockboard reinforced with four types of inserts under the bounded face layers. Blockboard made of spruce core covered with HDF and veneer were used as reference. The properties of experimental blockboard structures were compared with those of reference panels.

EXPERIMENTAL

The outcome of the experimental set-up was flexural strength of the proposed structures without modification of the panel's appearance and to maintain their weight and thickness within acceptable limits. The inputs considered as constant parameters were the raw materials for the core and face layers, the panel dimensions, and the technological process. The experiment was performed in the laboratory conditions and the proposed structures (with insertion materials) were compared to the reference panels (without insertion materials) manufactured also in laboratory conditions.

Materials

All raw materials for the experimental panels' manufacturing were provided by the Romanian manufacturer Holzindustrie Schweighofer Group (HSG) (Comanesti, Romania) and consisted of 15-mm-thick spruce (*Picea abies* L.) assembled cores and two types of face layers (HDF 3-mm-thick and fromager veneer 2.5-mm-thick). Urea-formaldehyde adhesive (UF) (S.C. Viromet S.A., Victoria, Romania) was used for gluing the face layers to the core. As indicated by the manufacturer, urea formaldehyde resin (82.5%) was mixed with rye flour (11.5%) and ammonium chloride (6% dry mass based on the weight of dry resin) and applied at 200 g/m^2 to 250 g/m^2, as shown in Table 2.

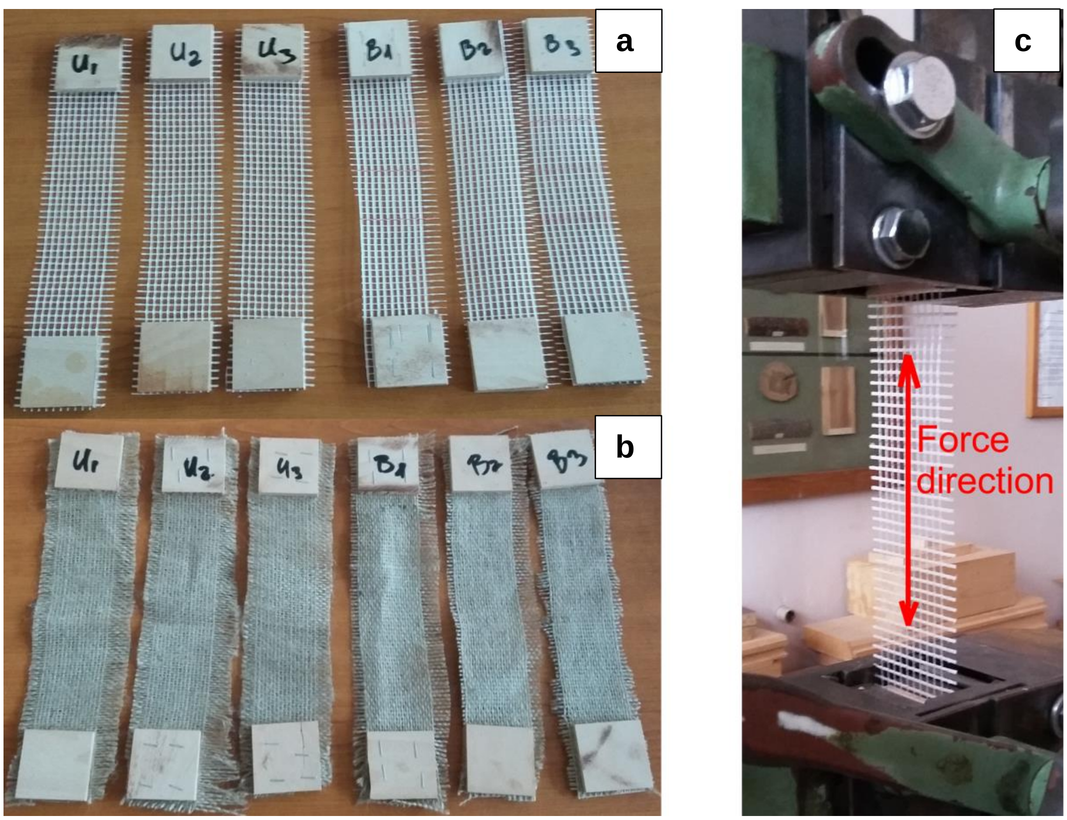

Fig. 1. Specimens prepared for the tensile strength test; a) glass fiber; b) jute fabric, and c) performance of the tensile test at the universal testing machine

The strips of the core were edge-glued side-by-side with a polyvinyl acetate resin at the manufacturer's location. Assembled cores and face layers were provided by HSG at the size of 500 mm × 500 mm (length × width). Glass fiber ISOMAT 712 (GF) (160 g/m^2 weight, acquired from Izotech Services, Bucharest, Romania) and fabrics, such as gauze (G) (48 g/m^2 weight, manufactured by Europoptex, Craiova, Romania), jute (J) (330 g/m^2 weight manufactured by Textila, Iasi, Romania), and cotton (C) (155 g/m^2 weight, manufactured by Sabaev, Bucharest, Romania) were used as insertion materials that were applied with UF under the faces. Prior panel manufacturing, three samples of 50 mm (W) (Figs. 1a and 1b) from each insert type were subjected to the tensile strength test (Fig. 1c) according to ISO 13934-1 (2013). The samples B1 through B3 were oriented with weft (transverse yarns inserted over-and-under the warp) along the force direction, and U1 through U3 samples were oriented with warp (longitudinal yarns) along the force direction. The results are shown in Table 1.

Table 1. Tensile Strength of the Insertion Materials Used for the Experimental Blockboard Structures

Material	Force Direction on:	Breaking Force (N)*
Glass fiber	Weft	1673 (42.6)
	Warp	290 (9.6)
Gauze fabric	Weft	55 (4.3)
	Warp	47 (3.3)
Jute fabric	Weft	430 (7.1)
	Warp	457 (7.4)
Cotton fabric	Weft	185 (6.5)
	Warp	165 (2.6)

* Values in parenthesis represent the standard deviations

Table 2. Design of the Experimental Blockboards

Code No.	UF Resin Content (g/m^2)	Mean Density* (kg/m^3)	Components
R-V	250	412 (15.8)	-Spruce core -Fromager veneer
R-HDF	250	567 (24.0)	-Spruce core -HDF
GF-V	400	442 (12.0)	- Spruce core - GF - Fromager veneer
GF-HDF	400	614 (26.0)	- Spruce core - GF - HDF
G-V	500	446 (14.6)	- Spruce core - G fabric - Fromager veneer
G-HDF	500	583 (11.5)	- Spruce core - G fabric - HDF
J-V	500	453 (8.6)	- Spruce core - J fabric - Fromager veneer
J-HDF	500	584 (12.3)	- Spruce core - J fabric

			- HDF
C-V	500	500 (17.3)	- Spruce core - C fabric - Fromager veneer
C-HDF	500	605 (17.6)	- Spruce core - C - HDF
* Values in the parenthesis are standard deviations; GF: glass fiber; G: gauze; J: jute; C: cotton			

Blockboard manufacturing

Ten types of blockboard structures were manufactured in the laboratory conditions (Table 2). Samples without inserts were used as reference for comparing the bending test results. First, the UF adhesive mixture was uniformly applied with a palette knife onto one side of the core. A sheet of HDF or veneer (oriented perpendicular to the core grain direction) was then applied. The operation was repeated for the other side of the core, and the sandwich obtained was hot-pressed at 6.5 MPa and 105 °C for 9 min (the pressing parameters were based on the HSG manufacturer recommendations). After hot-pressing, all panels were conditioned at room conditions (20 °C and 35% air relative humidity) for 72 h. For reinforcing materials applied between the core and face layers, the UF adhesive was applied both on the core and faces, so that the amount of adhesive increased, as shown in Table 2. The code of blockboard structures, their components, and mean density values are presented in Table 2. Figure 2 shows the design of the blockboard structures.

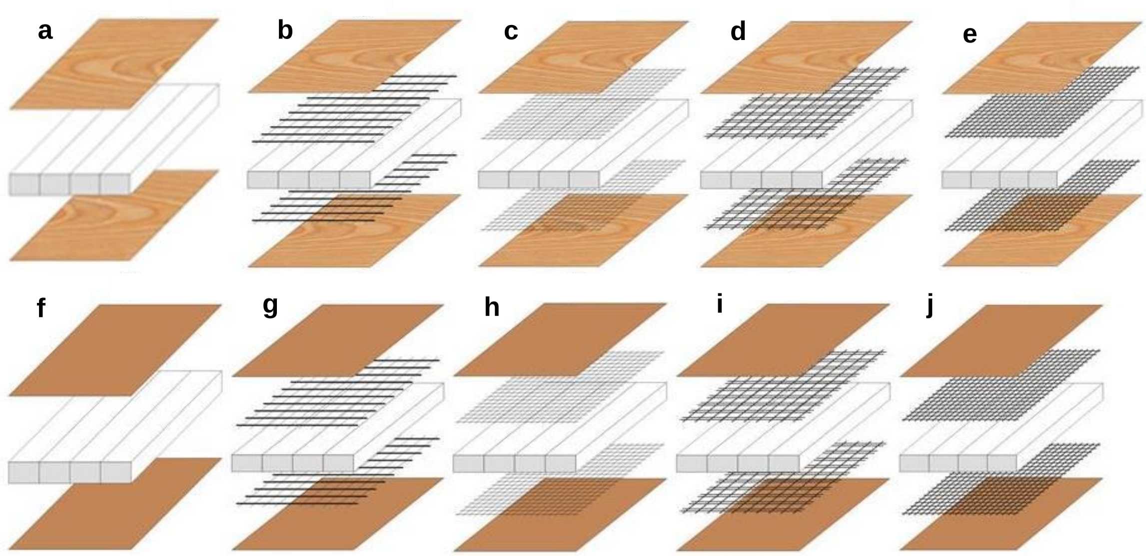

Fig. 2. Design of the manufactured blockboard structures: a) R-V; b) GF-V; c) G-V; d) J-V; e) C-V; f) R-HDF; g) GF-HDF; h) G-HDF; i) J-HDF, and j) C-HDF

Methods

Static bending properties (MOR and MOE) were tested according to EN 310 (1993). Sampling was taken from each experimental panel according to EN 326-1 (1994). Six specimens from each blockboard panel were cut and tested, three of them were parallel (Fig. 3a), and the other three perpendicular to the core grain orientation (Fig. 3b).

Three panels of each structure were used, so the bending tests (MOR and MOE) were conducted on nine specimens of each type.

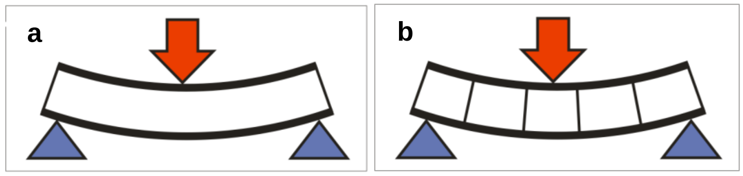

Fig. 3. Testing method: a) parallel and b) perpendicular to the core grain orientation

Prior to mechanical testing, the specimens with dimensions of 492 mm × 50 mm × 19 mm were conditioned for 14 days at the temperature of 20 °C ± 2 °C and 65% ± 2% relative humidity to reach the equilibrium moisture content of 12%. The universal testing machine (IBX 600; IMAL, San Damaso, Italy) was used for testing the samples. The cross-head speed of the equipment was adjusted so that the failure occurred within an average of 60 s ± 10 s.

RESULTS AND DISCUSSION

The results of flexural tests are presented in Fig. 4 for MOR and in Fig. 5 for MOE, both in parallel (//) (a, b) and perpendicular (⊥) (c, d) direction. In red are indicated the values for reference samples.

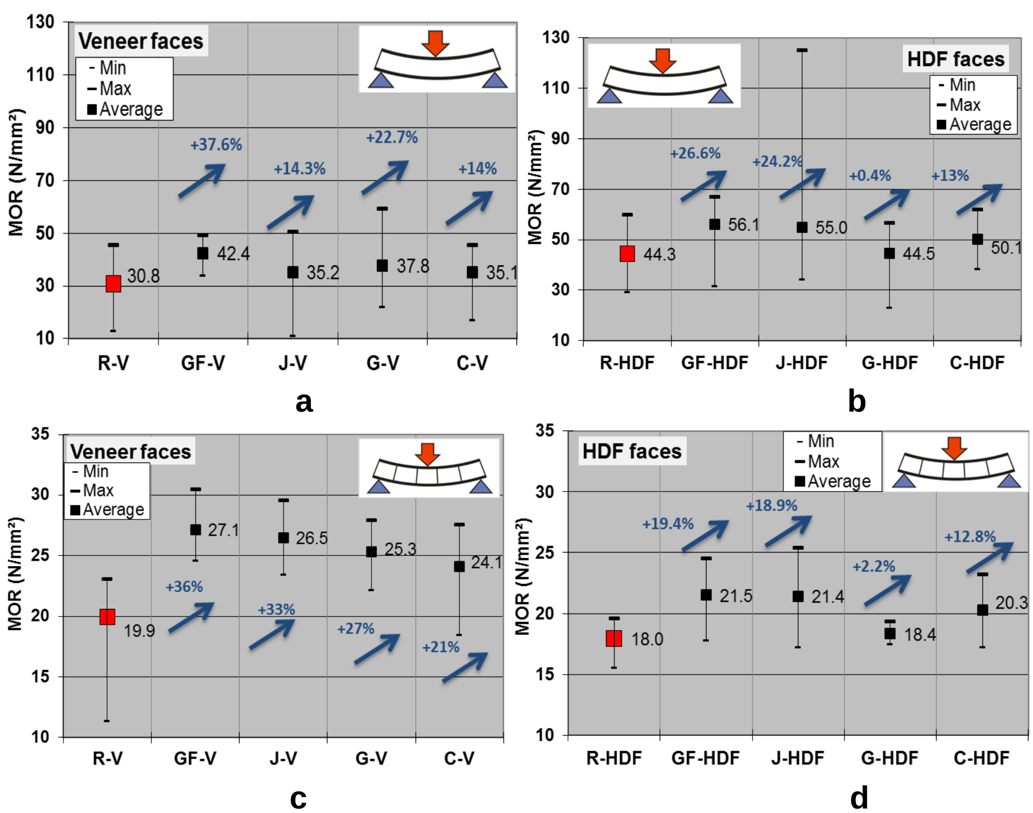

Fig. 4. MOR values: a) MOR // and veneer faces, b) MOR// and HDF faces, c) MOR⊥ and veneer faces, and d) MOR⊥ and HDF faces

The highest increase of MOR was reached by all structures reinforced with GF, followed by J. The lowest values were registered by structures reinforced with C and G fabrics. All inserts proved to be more efficient in improving bending properties when compared to both references R-V and R-HDF. This was more obvious for blockboards with veneer faces than those with HDF faces, for which MOR values parallel-to-core grains (MOR//) were 14% to 37.6% higher than R-V (Fig. 4a), whilst for HDF layers they were 0.4% to 26.6% higher than R-HDF (Fig. 4b). The same trend was noticed for MOR values perpendicular-to-core grain direction (MOR⊥) (Figs. 4c and 4d). For veneer faces, MOR⊥ values were 21% to 36% higher than R-V (Fig. 4c), while for HDF faces they were 2.2% to 19.4% higher than R-HDF (Fig. 4d).

The MOE values demonstrated similar trends and performance to those for MOR. Generally, MOE// values were higher than MOE⊥ and increased for almost all structures when compared to the references (Fig. 5). The MOR// values were 1.32 to 1.49 times higher than MOR⊥ for blockboard with veneer faces and 2.42 to 2.61 times higher for blockboard with HDF faces. The results obtained were in agreement with other studies (Laufenberg *et al.* 2006; Teixeira *et al.* 2017; Haseli *et al.* 2018; Nazerian *et al.* 2018). Generally, the standard deviations of the results were higher for MOR than for MOE (Figs. 4 and 5). This was explained by the influence of the core strips' defects on each specimen. Figure 6 represents the core formation (Fig. 6a) with longitudinal strips, and also their blue marking on the ends prior to blockboard manufacturing. Marks indicated the row of strips that had small lengths jointed end to end and helped the authors avoid these areas as much as possible during sampling for the bending tests.

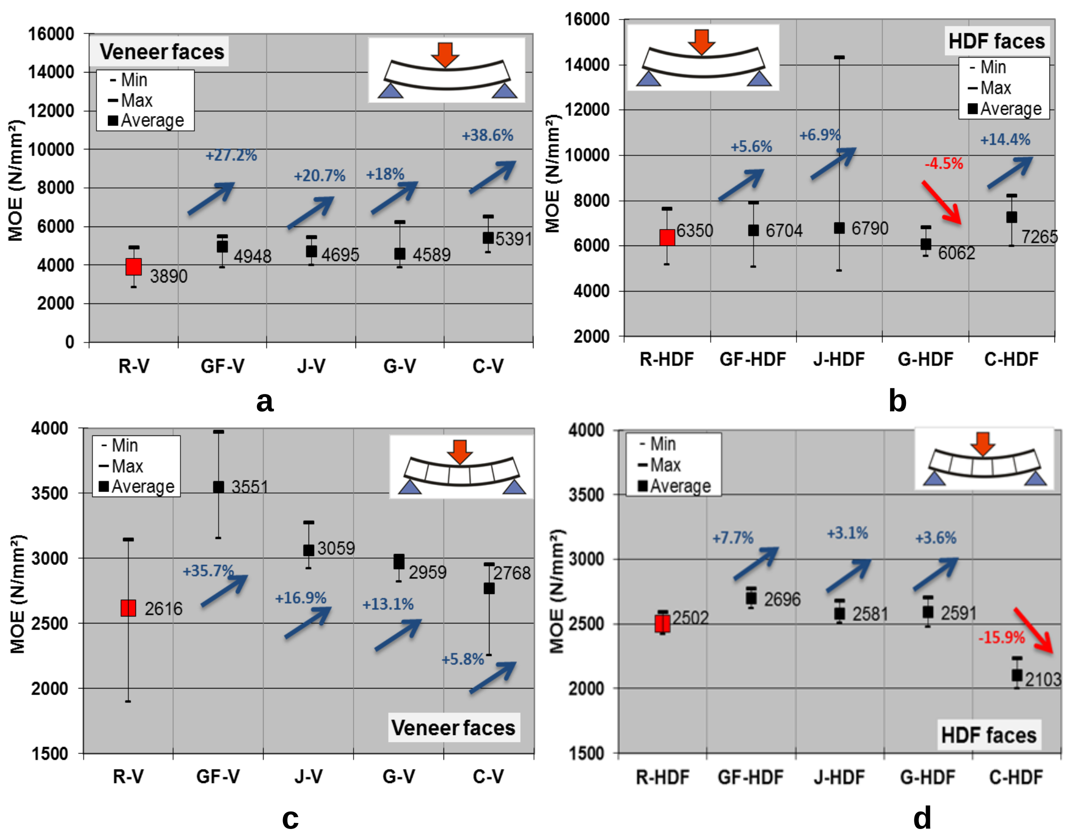

Fig. 5. MOE values: a) MOE// and veneer faces, b) MOE// and HDF faces, c) MOR⊥ and veneer faces, and d) MOR⊥ and HDF faces

Based on the obtained results, insertion materials reacted differently, but all of them improved the bending performance of the blockboard structures. The tensile breaking force of the insertion materials (Table 1) could be an important factor in their selecting for improving the bending performance. The higher force obtained for GF and J fabric confirmed their positive effect recorded for MOR and MOE both in parallel and perpendicular directions.

The density influenced positively the strength (MOR and MOE) in parallel direction, when compared to blockboard with HDF faces with veneer faces. Other researchers (Pinati *et al.* 2018; Nelis *et al.* 2019) also observed a similar trend in density.

a b

Fig. 6. Blockboard's spruce core; a) the core area with strips jointed end to end and b) marked rows where strips with small lengths are jointed end to end

The breaking of samples after bending tests is shown in Fig. 7.

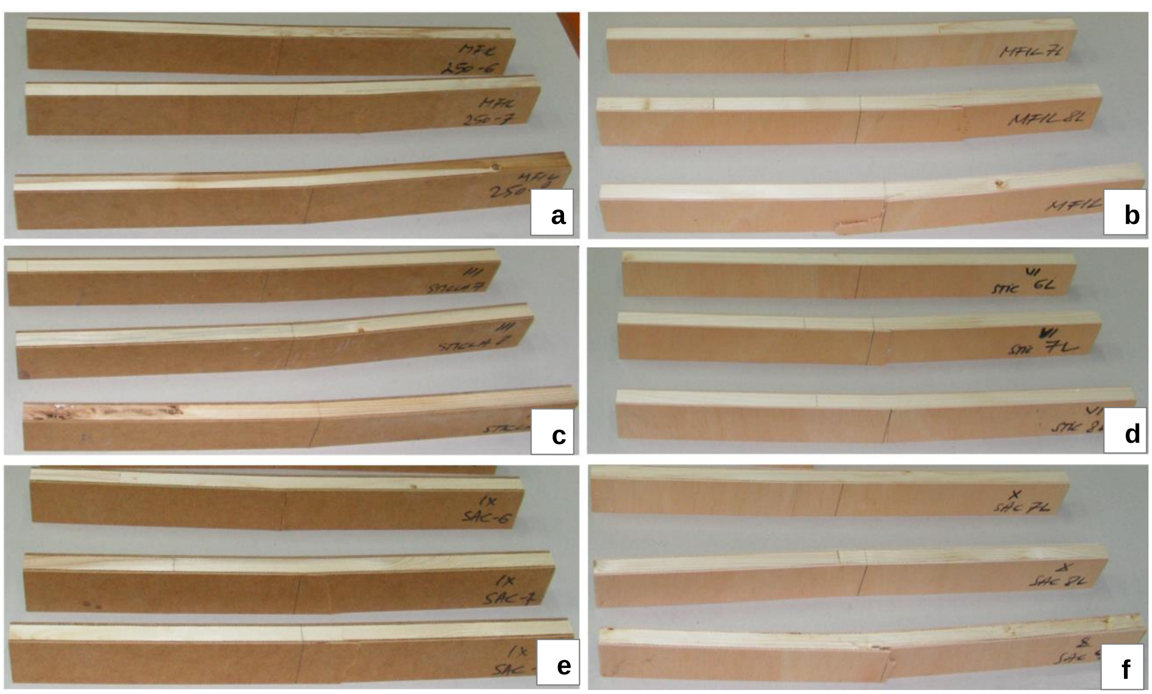

Fig. 7. Failure modes of specimens during bending test parallel to the core grain orientation: a) R-HDF, b) R-V, c) GF-HDF, d) GF-V, e) J-HDF, and f) J-V

For the blockboard with HDF faces, in which high MOR// values were registered (56.1 N/mm^2) (Fig. 7 a, 7c, and 7e), the failure started with bottom face tension. The specimens presented a slight deflection, and only a few cracks developed on faces that did not spread on the core. In contrast, for blockboard with veneer faces (Fig. 7b, 7d, and 7f), after tension in the bottom faces that had perpendicular grain orientation, the cracks started on the face and were further expanded to the core. This was especially true for the reference samples and those with jute insertion, in which bending strength was below 35 N/mm^2.

In specimens with perpendicular core grain orientation, failure occurred within the core and a sudden rupture was produced (Fig. 8).

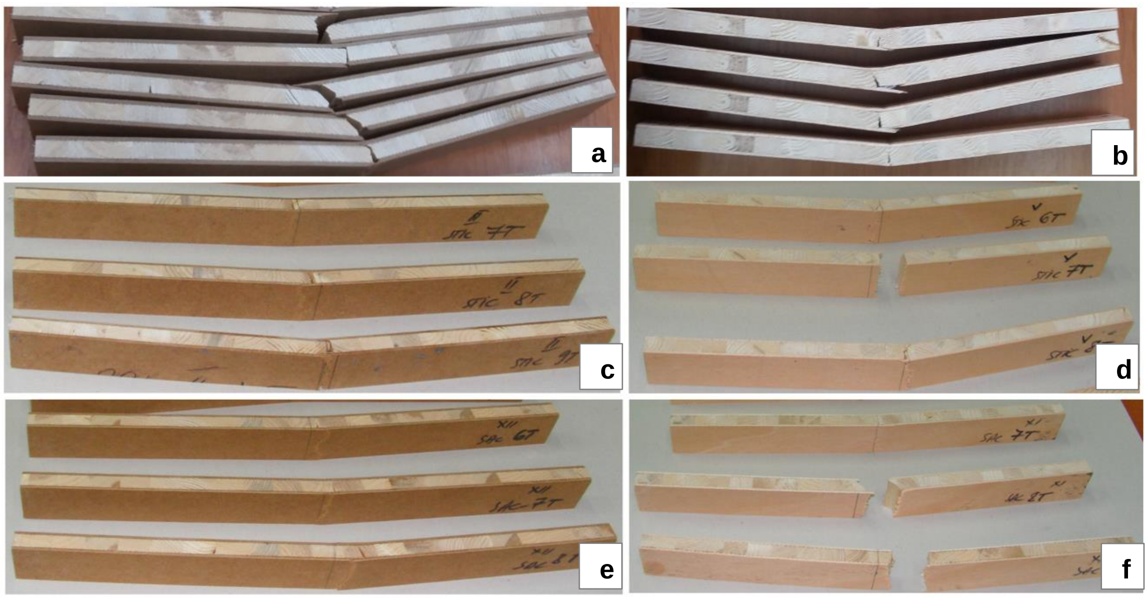

Fig. 8. Failure modes of specimens during bending test perpendicular to the core grain orientation: a) R-HDF, b) R-V, c) GF-HDF, d) GF-V, e) J-HDF, and f) J-V

Figure 8a, 8c, and 8e shows that both glass fiber and jute fabric insertions (GF-HDF and J-HDF) improved the behavior to failure compared to the reference sample (R-HDF). The veneered structures with insertions that exhibited a high increase of MOE (with 35.7% for glass fiber and with 16.9% for jute) (Fig. 8d and 8f) indicated higher stiffness and consequently cracks occurred suddenly during bending.

Even if the structures with gauze inserts and veneer faces (GV) exhibit bending strengths higher than reference (R-V) it is not recommended for their use in practice for the large panels sizes, due to the difficulty of arranging them on the core surfaces. According to the results obtained in the present research, the insertion materials brought benefits to flexural properties that were more evident for glass fiber and jute.

CONCLUSIONS

1. The strength performance either in parallel- or perpendicular-to-core grain orientation of blockboard was improved by adding insertion layers below the outer faces.

2. The best performing structures in terms of bending strength were those with glass fiber inserts, which also have the technological advantage of a relatively easy handling.
3. The insertion materials positively influenced the strengths for both types of blockboard. It was more obvious for veneer faces in perpendicular direction (MOR⊥), and for HDF faces in parallel directions (MOR//).
4. The results also showed that MOR// values were 1.32 to 1.49 times higher than MOR⊥ for blockboard with veneer faces and 2.42 to 2.61 times higher for blockboard with HDF faces.

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