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RESEARCH INTO THE PROPERTIES OF AN INNOVATIVE WOOD-PLASTIC COMPOSITE

Cosmin SPÎRCHEZ
Transilvania University of Brasov, Faculty of Wood Engineering
Str. Universitatii nr. 1, 500068 Brasov, Romania
Tel: 0040 268 415315, Fax: 0040 268 415315, E-mail: cosmin.spirchez@unitbv.ro

Aurel LUNGULEASA
Transilvania University of Brasov, Faculty of Wood Engineering
Str. Universitatii nr. 1, 500068 Brasov, Romania
E-mail: lunga@unitbv.ro

Abstract:
The paper to analyses the characteristics of an innovative type of wood-plastic composite with a low wood content. Using traditional methodologies based on standardized European test methods, the density, strength and modulus of elasticity in static bending were determined. Additionally the impact strength of the composite was analysed by employing the method with two pendulum hammers. Good results were found for their physical and mechanical properties. In conclusion the paper suggests that the analysed product had good properties for specific uses in environments with high humidity.

Key words: *density; impact; modulus of resistance (MOR); wood-plastic composites (WPCs).*

INTRODUCTION

Wood-plastic composites (WPCs) are new composites with multiple uses, utilized especially in high humidity environments or with direct water contact. Wood-plastic composites are nano-composites of the last generation, usually made of a wooden matrix to which plastic is added as a reinforcing filler. The reverse combination wood-plastics is also possible. Usually, WPC_s have a ratio 1:1 wood/plastic and almost insensible to humidity/water. Manufacturers guarantee strongly for these products, affirming that wood-plastic composites are more environmentally friendly and require less maintenance than the alternative use of solid wood treated with preservatives or some rot-resistant species. Moreover, WPC_s have very good physical and mechanical properties, and their price is acceptable, as is visible in Table 1.

Table 1

Physical and mechanical properties for wood plastic composites using wood in combination with glass fibres and thermoplastic resin (Barbu 1999)

Property	**Product A**	**Product B**	**Product C**
Density, kg/m^3	1300	1500	1400
Wood content, %	60	35	-
Fibre glass content, %	-	35	50
Thermoplastic resin content, %	28	23	40
Modulus of resistance (MOR) to bending, MPa	69	103,5	117,3
Modulus of elasticity (MOE) to bending, GPa	1,32	7,9	11,0
Resistance to traction parallel to planes, MPa	69	75,9	69
Expansion after 2 hours, %	7,7	1,3	6,6

WPCs are obtained from virgin or recycled plastic mixed with wood or other natural fibres. In the last 10-15 years, these composites have experienced a great development in terms of research, production and distribution, but mostly in understanding how to obtain certain materials with the desired characteristics. The most common uses of these composites are found in outdoor floorings, but they can also be used for transverse beams, gates, fences, garden and park benches, door and window frames and indoor furniture, mostly in pools, Olympic-size swimming pools, bathrooms and kitchens (Fig.1).


Fig. 1.
Some uses of the wood-plastic composite (www.wpcromania.ro).

At this time, the automotive industry is the largest user of WPCs in Europe with over half of the overall usage. It is also estimated that many European automotive companies will diversify the wood-plastic composites, using flax and hemp natural fibres, which are longer and more resistant than wood fibres. On the other hand, there is another purpose, namely of introducing the composites to the construction and furniture markets.

MATERIALS AND METHODS

The analyzed material is an innovative wood-plastic composite made of 80% plastic, 10% powdered chalk and colorants and 10% woody sawdust. This composite was purchased as panels with an area of 600x600mm and thickness of 12, 15, 18 and 21mm from the manufacturing company Kompozite Holz from Brasov, Romania. These panels have been cut into 20 replicates for each thickness in order to determine the density (50x50mm), for static bending 20 samples of 290x50mm, 350x50mm, 410x50mm and 470x50mm, depending on the thickness of the panels, 10 samples each for water absorption and swelling in thickness and 10 samples of 150x150mm for determination of impact strength.

In order to determine the density of the samples the classical method was used for reporting the mass of the sample relative to its volume (according to the European standard EN 323:1993).

$$\rho = \frac{m}{l \cdot w \cdot t} \; [\frac{kg}{m^3}]$$

where:
m is sample mass, expressed in g;
l - Length of sample, in mm;
w - Width of sample, in mm;
t - Thickness of sample, in mm.

The mass of the samples were determined with an electronic balance, expressed in grams accurate to 3 decimals. The three dimensions of the samples were determined with an electronic calliper accurate to 2 decimals. After calculations were made to determine the density expressed in g/mm^3, the result was converted into the international unit for density, namely kg/m^3. Next, using Excel Microsoft program, the two statistic parameters, arithmetic mean and square deviation, were determined.

Modulus of resistance (MOR) and modulus of elasticity (MOE) in static bending were determined using the methodology stipulated in the SR EN 310:1996. A universal testing machine was used with specific devices for such tests, namely two adjustable bearings on the bottom side to support the sample and a punch to apply force in the case of resistance and two punches for determining the modulus of elasticity in static bending. The distance between bearings was 20 times longer than thickness, as prescribed, and the speed with which the force was applied was 10mm/min.

The equation for determining the resistance was the following:

$$MOR = \frac{3}{2} \cdot \frac{F \cdot l}{w \cdot t^2} \; [N/mm^2]$$

where:
F is ultimate strength, expressed in N;
l - Distance between bearings, in mm;
w - Width of sample, in mm;
t - Thickness of sample, in mm.

The modulus of elasticity (MOE) in static bending is determined using the following equation:

$$MOE = \frac{l^3 \cdot \Delta F}{4 \cdot w \cdot t^3 \cdot \Delta f} [\text{N/mm}^2]$$

where:
ΔF is difference in forces P_2-P_1, the first force being approximately 10% of the ultimate fracture force, and the second one being approximately 40% of breakage load, expressed in N;
Δf is the difference in deformation for the sample, f_2-$f_1$corresponding to the two above forces, expressed in mm.

20 samples were used to determine the resistance and the modulus of elasticity in static bending.
Impact strength was determined by several methods, namely the method with one strike using the Charpy pendulum impact (usually for solid wood), the method with repeated hammer strike (usually for panels) and the method with double pendulums (usually for panels). The working principle of the Charpy pendulum impact machine is shown in Fig. 2, where it can be seen how the pendulum is dropped from a known height from the starting position, hits and breaks the sample found at the bottom, then rises to a known height. This height, along with the initial height, is determined by the angle seen on the angle dial.

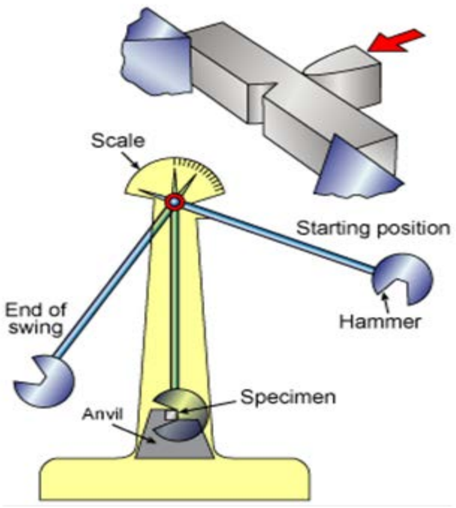

Fig. 2.
Charpy pendulum impact machine (IT 2017).

The double pendulum method is accurate and is specific for wooden and plastic panels, as well as for other composites. This method for determining the impact strength uses two pendulum hammers, but only one kicks to break the sample. The sample is square shaped, measuring 150mm. The machine is mainly composed of two pendulums, each with own dial and dial pointer, a blocking system for the active pendulum hammer, a power brake to stop the movement of the pendulums and the resistance frame (Fig. 3).

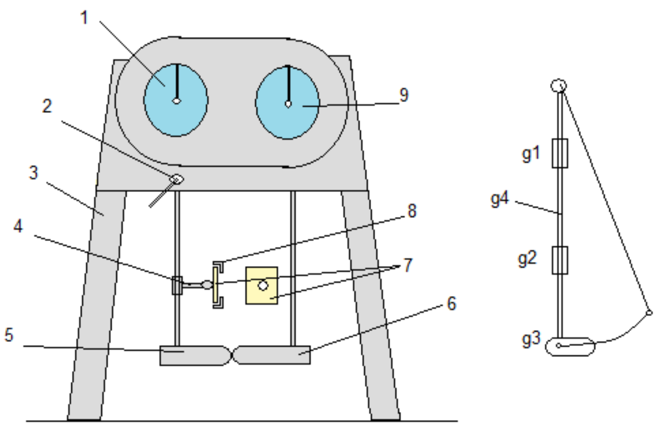

Fig. 3.
Double pendulum impact.

where:
1 is dial of active pendulum hammer;
2 - Handle for blocking the active pendulum hammer;
3 - Resistance frame;
4 - Blowing punch;
5 - Active pendulum hammer;
6 - Passive pendulum hammer;
7 - Wood-plastic composite sample;
8 - Sample frame;
9 - Dial of passive pendulum hammer;
g1 - Mass of first weight, expressed in g;
g2 - Mass of second weight;
g3 - Mass of pendulum;
g4 - Weight of arm.

The punch (4) has an oval shape so it not to rub against the sample and increase impact strength without reason. The active pendulum hammer (5), through its mass (g_3), as well as the other masses (g_2, g_1 and g_4), ensures the energy necessary to hit the sample, as well as fine adjustment. After the punch breaks the sample, the remaining energy of the active hammer is transferred by impact to the passive hammer which acquires an angular movement, shown on its dial.

The mechanical work performed by the active pendulum hammer depends on the mass, distance from the main pivot to the centre of gravity and on the angle from which the movement is initiated, the equation being the following:

$$L1= G\cdot l_c\cdot (1-\cos \alpha)\ [daN\cdot m]$$

where:
G is the sum of the four weights' masses, approximately 17,8daN (hammer 8.2kg; additional weight 7.2kg; axle weight 1.9kg and punch weight 0.5kg, α – the angle from which the active pendulum hammer is launched;
l_c is distance from the main pivot to the centre of gravity of the entire unit (Mitisor 1977), calculated with the following equation (distance from the main pivot 800mm for hammer, 420mm for a additional weight and 600mm for punch):

$$l_c = \frac{\sum_{i=1}^{4} g_i \cdot l_i}{G}$$

For the mechanical work performed by the active hammer to 10daN·m, the angle is 90^0 the distance l_1 should be 8.57cm. The mechanical work spent for breaking the sample is determined as the difference among other mechanical works, respectively:

$$L=L_1- (L_2+L_3)$$

where:
L_1 is the mechanical work performed by the active hammer;
L_2 - the mechanical work of the passive hammer;
L_3 - the mechanical work spent through friction and transfer from one hammer to the other.

The mechanical work spent through friction and collision can be determined by performing a test without a sample, when $L_3=L_1-L_2$. It is recommended that the absorbed energy by piercing the sample should be around 25% of the active hammer's energy. Impact strength (resilience index) is determined as the ratio between the mechanical work spent for breaking the sample and the thickness of the sample, respectively:

$$I = \frac{L_1 - (L_2 + L_3)}{g} \quad [daN \cdot m / cm]$$

A board's impact strength is determined as the arithmetic mean for the 10 pieces, cut from each type of board (each thickness separately).

In order to observe the influence of the water on this wood-plastic composite, some samples were cut into pieces of 50x50mm which were submerged in water for a period of 2 hours and absorption and swelling in thickness of samples were determined by employing standardized European methods (SR EN 317:1996).

RESULTS AND DISCUSSION

When analyzing the exterior appearance of the product, smooth, glossy the surfaces can be observed. The cuts performed with the circular blade are clear, even if the appreciable pore spaces can be observed to increase from the sides towards the panel's inner part. The panels are light and the density reached a mean value of 612.4kg/m^3, with a mean square deviation of 6.6kg/m^3 for the 12mm thickness panel. This value is very low compared to other similar products (Barbu 1999) with densities over 1300kg/m^3. From this point of view, the analysed WPC$_s$ product belongs to the light panel category. The influence of the thickness on the panels' density represents a slight increase, as shown in Fig. 4.

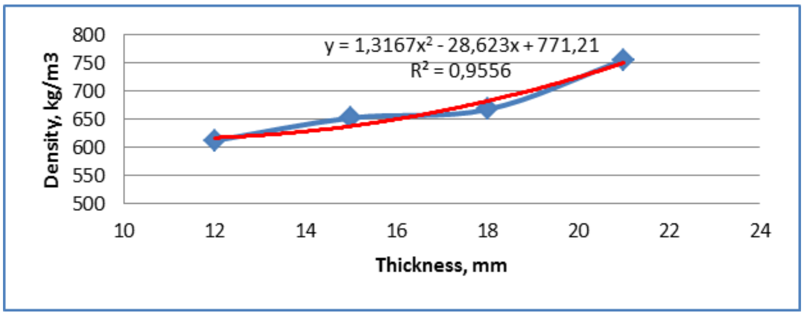

Fig. 4.
The influence of panel thickness on its density.

Modulus of resistance for bending strength obtained from laboratory tests was low, respectively 25.8N/mm^2 (with a standard deviation of 1.5N/mm^2) for a 21mm thickness of WPC$_s$, compared to 70-100N/mm^2 found by other authors (Fang et al. 2013). The low value of the static bending strength results from the lack of some stiffening agents in the structure of the panels, such as fibre glass.

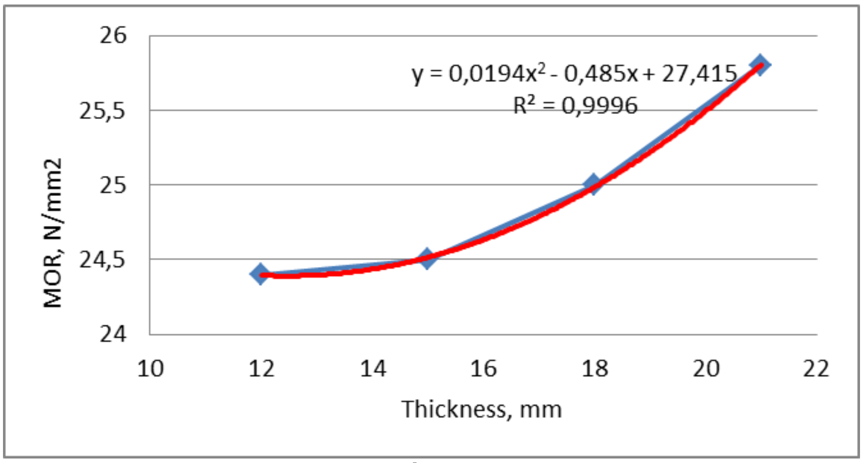

Fig. 5.
Slight influence of thickness on static bending strength.

The influence of thickness on static bending strength was slight (Fig. 5), respectively it increased along with the increase in panel thickness. This increase is due to the increase of panels' density given by the panels' thickness. Modulus of elasticity (MOE) in static bending had low values of 1540-1760N/mm^2, with a slight decrease depending on the panel's thickness (from 1766.5N/mm^2 for 12mm thickness, to 1543.3N/mm^2 for 21mm thickness of panel).

Referring to water absorption and swelling in thickness, there were no significant changes of size and mass of samples. Both water absorption and swelling in thickness having insignificant values of under 0.2%.

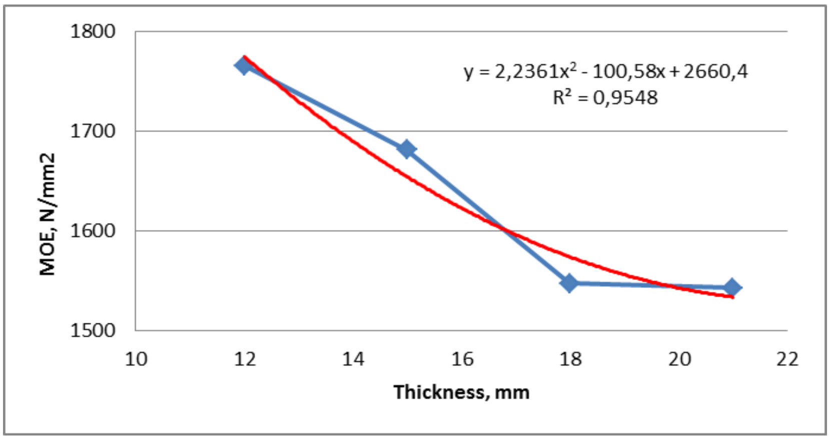

Fig. 6.
Modulus of elasticity related to panel thickness.

Impact strength or the index of resilience of composite panels depends on the mechanical work of the active and passive hammer, on the mechanic work lost through collision and friction and of the thickness of the panel. The lost mechanical work was constantly 4.031daN·m. The index of resilience of the analyzed composite is dependent on the thickness of the panel, having a significant increase from 2.3 to 6.1daN·m/cm (Fig. 7).

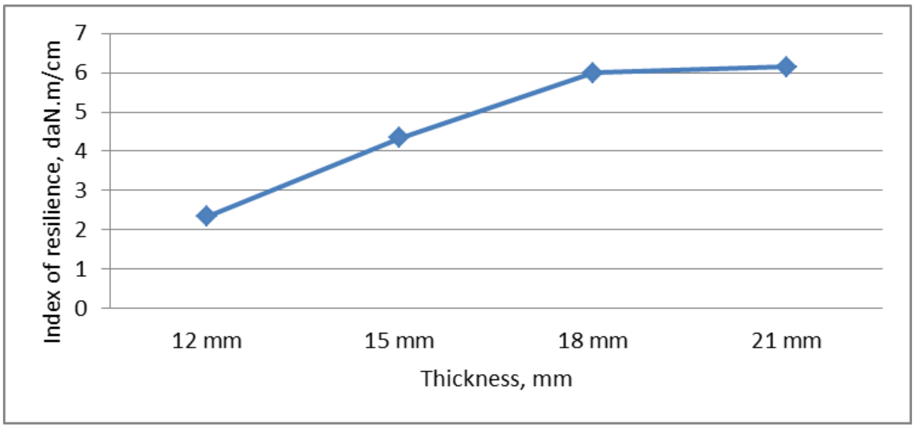

Fig. 7.
Index of resilience related to panel thickness.

In order to make a comparison about index of resilience, there were conducted tests on 10 samples of structured chipboards with thickness of 15mm. The work consumed for breakage was 0.94daN·m and an index of resilience of 0.62daN·m/cm. The values for chipboard comparison are much smaller than of the wood-plastic composite that was analysed in the paper.

CONCLUSIONS

Wood-plastic composite panels with a low content of woody sawdust that have been analyzed in the present paper are porous panels with smooth and glossy surfaces. These composites have proven good resistances and potential to various uses. Impact strength values are very good compared to those of particle boards. Water behaviour is very good, in this case, the panels having the great properties of plastic. In what concerns the area of use, these wood-plastic composite panels can be successfully used in humid environments or in direct contact with water, especially since processing cuts are fine, without pulling out fibres or chips.

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