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NEW ECOLOGICAL COMPOSITE MATERIALS FOR THE UPHOLSTERED FURNITURE INDUSTRY

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Abstract: *The paper presents a description of composite materials with an emphasis on natural fiber composite materials. It reviews industries such as car making and civil engineering which make up the largest consumers of these materials and it presents some of their specific applications. The authors research the use of natural fiber composite materials in furniture making and present the results of mechanical and water resistance testing of two blends of hemp fibers and natural based matrices.*
Key words: *natural fiber composites, hemp, ecological matrix.*

1. INTRODUCTION

1.1 The need to replace wood in the upholstered furniture industry

Composite materials have numerous applications and are used in many fields of which aeronautics, car making and civil engineering are some of the largest [4]. They come in a wide range of material combinations, but they are mostly composed of the following constituents: a reinforcing material, such as fibers or particles, and a binding agent.

The reinforcing agent can be particles or fibers. Ground glass, carbon, rubber and rock are some of the most common particles used, while glass, aramid, basalt and carbon are often used as fibers.

The binding agent, called the matrix, is an important part of the composite since it holds the reinforcing material together. Composites are classified based on their matrix in: polymer matrix composites, metal matrix composites and ceramic matrix composites.

The final material's properties are somewhere in between its constituents and may feature anisotropy due to the reinforcing agent's form and direction. For example, most fiber reinforced composites have great strength and stiffness along the fibers' direction, but perform worse normal to this direction.

With the passing of time most industries have been faced with more and more constraints:

- to lower the price of their products;
- to increase production capacity and to decrease production time;
- to find "greener" alternatives to the artificial raw materials commonly employed.

Due to these reasons many manufacturers have started looking towards plants as sources of raw materials. Most of them are easily cultivated, grow fast contrary to the formation of natural resources such as oil or coal and some of them have good mechanical and chemical properties.

The upholstered furniture industry, as a sub-branch of the furniture industry, is a large consumer of wood, chipboard, plywood and other wood-based boards, polyurethane, non-woven materials, fabrics, leather and leather substitutes. Natural resources are limited. The partial replacement of wood and wood-based products in the structure of an upholstered product with composite materials with matrices of thermoplastic materials such as polypropylene and/or adhesives together with natural fibers as a reinforcing material contributes to the conservation of existing forest resources, to the reduction of pollution and the greenhouse effect, to the development of a more competitive upholstery industry and to the creation of new jobs. Under current conditions, 6 cubic meters of raw wood from the forest are required for one cubic meter of wood processed for use in the upholstery industry.

The interest and necessity of replacing some wooden items in the structure of upholstered furniture, without affecting the external appearance of the product and its functional requirements, was presented in more detail in [1].

The main disadvantage of thermoset composites (carbon and glass fiber and epoxy resin matrices) is that they cannot be recycled. In contrast, thermoplastic composites, which use natural fibers as a reinforcing material can be recycled at the end of their life cycle [6].

1.2 Furniture parts made of thermoplastic composite materials

The collaboration of the authors as part of research projects with a company that produces upholstered furniture (Taparo S.A. of Targu Lapus, Romania) was completed with several products made of composite material obtained from hemp and polypropylene.

A relevant example is the redesign of a sofa side from the wooden version (figure 1) to composite version (figure 2). The main advantage of this first application is the reduction of the number of items from 21 to 2. This is because the composite parts can be formed into complex shapes, while the original materials cannot. There is a weight decrease from 3.95 kg to 1.65 kg [1, 2, 3].

Fig. 1. Wooden sofa side [2]

Fig. 2. Composite sofa side [1]

Other applications followed such as the redesigning of parts for sofas, armchairs and chairs, in order to be made from thermoplastic composite material (Figures 3 and 4).

Fig. 3. Chair made from the composite material

Fig. 4. Armchairs made from the composite material

2. MATERIAL DEVELOPMENT

2.1 Material samples

The natural world has a large number of sources for fibers which can be processed and used in composites.

Some of the plants which are cultivated most often for fibers include cotton, hemp, flax, jute, willow and sisal [7]. These have a fast growing rate and produce good quality fibers. Some have great mechanical properties, which can be seen in table 2.

They can be separated to different degrees from the rest of the plant material and used as long fibers or cut to a specific length. They can be woven in random directions or spun in fiber bundles and woven according to a pattern. The matrix consists of a thermoplastic material often, which is intertwined with plant fibers, or it can be a liquid resin that is coated onto the already woven material.

The main problem with the commonly encountered fiber composites is that they use artificial matrices. These are oil derived products such as thermoplastic and thermosetting resins and can impact the environment by using a non-renewable resource, making recycling difficult in the case of thermosetting resins and furthermore being non-biodegradable. The current trend is to try and replace the man-made resins with natural or plant derived materials.

Table 1

Mechanical properties of often used natural and artificial fibers [5, 7, 8]

Fiber	Density	Elongation	Tensile strength	Young Modulus
Hemp	0.86		250	11
Cotton	1.5-1.6	7.0-8.0	287-597	5.5-12.6
Jute	1.3	1.5-1.8	393-773	26.5
Flax	1.5	2.7-3.2	345-1035	27.6
Sisal	1.45	3.0-7.0	468-640	9.4-22
Glass-E	2.5	2.5	2000-3500	70.0
Glass-S	2.5	2.8	4570	86.0
Aramid (avg.)	1.4	3.3-3.7	3000-3150	63-67
Carbon (avg.)	1.0-1.3	1.4-1.8	4000	230-240

The authors were actively involved in the development of natural fiber composites in order to use them in manufacturing the structure of upholstered furniture articles. To provide ecological and recycling advantages, the authors are looking to switch to plant-derived binders. Two suitable materials were identified from a cost and supply perspective: a starch-based component and a lignin-based component. Samples using each matrix were consolidated and subjected to tensile testing.

Two types of natural fiber composite materials were prepared and specimens were taken for tensile and flexural testing. Both materials contain 66% hemp by weight, with the first one having a 34% starch-based matrix and the second one a 34% lignin-based matrix. The materials were thermoformed into sheets with an approximate thickness of 7 mm. Samples were cut from both sheets according to the standards (figures 5 and 6).

Fig. 5. Starch-based binder: the samples before testing

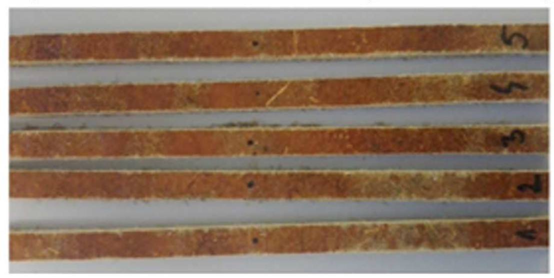

Fig. 6. Lignin-based binder: the samples before testing

2.2 Tensile testing

A Zwick Roell Z150 testing machine was used to perform the tensile tests. The samples and test methods were performed according to the standard D3039: Test Method for Tensile Properties of Polymer Matrix Composite Materials.

Tensile testing results for the first material, the one with the starch-based binder are given in table 2, and the results for the second one in table 3.

Table 2

Tensile testing of the hemp and starch-based binder composite

Sample no.	Thickness [mm]	Breaking force [N]	Tensile strength [MPa]	Elongation at breaking point [%]
1	7.1	1070	15.07	2.8
2	7.5	881	11.83	2
3	6.5	941	14.59	2
4	6.8	1190	17.63	2.1
5	6.6	1300	19.70	2.1
Avg.	**6.9**		**15.76**	**2.20**
St. dev.	**0.40**		**3.01**	**0.34**

Table 3

Tensile testing of the hemp and lignin-based binder composite

Sample no.	Thickness [mm]	Breaking force [N]	Tensile strength [MPa]	Elongation at breaking point [%]
1	7.5	127	1.69	1.6
2	7.6	127	1.67	1.7
3	6.7	183	2.73	2.2
4	6.6	147	2.23	1.9
5	6.8	139	2.04	1.4
Avg.	**7.0**		**2.07**	**1.76**
St. dev.	**0.47**		**0.44**	**0.30**

2.3 Material samples and flexural testing

The same two hemp fiber composites were bend tested along with a particle board for comparison reasons. Flexural testing is a good representation of the average loading scenarios encountered in real products and is a combination of tensile and compressive forces. The sample size for the first material, the one with the starch-based binder, is given below in figure 7 and the results in table 4.

Fig. 7. Starch-based binder: the samples before and after testing

Table 4

Flexural testing of the hemp and starch-based binder composite

Sample no.	Thickness [mm]	Deformation at breaking point [mm]	Flexural strength [MPa]	Flexural modulus [GPa]
1	7.5	4.40	21.76	1.480
2	7.5	4.40	14.83	1.226
3	7.6	4.00	26.80	1.980
4	7.2	4.50	32.58	2.381
Avg.	**7.5**	**4.33**	**23.99**	**1.767**
St. dev.	**0.17**	**0.22**	**7.54**	**0.516**

The results for hemp and lignin-based binder composites are given below in the table 5.

Table 5

Flexural testing of the hemp and lignin-based binder composites

Sample no.	Thickness [mm]	Deformation at breaking point [mm]	Flexural strength [MPa]	Flexural modulus [GPa]
1	5.9	3.60	14.73	1.942
2	6.2	3.80	13.01	1.634
3	5.8	4.00	16.33	2.012
4	5.6	4.20	11.00	1.594
Avg.	**5.9**	**3.90**	**13.77**	**1.796**
St. dev.	**0.23**	**0.26**	**2.29**	**0.212**

2.4 Comparison of the tensile and flexural results

Figure 8 shows that the starch-based binder is clearly much stronger than the lignin-based binder and the particle board has properties between the two hemp composites. The hemp and starch-based material are the clear winners being on average 3.24 times stronger than the much more often used particle board.

Before testing, the lignin-based binder was expected to outperform the starch-based one because hemp also contains a significant quantity of lignin and the binding should be better between materials of the same kind. The authors speculate that lignin performed poorer than starch because it didn’t penetrate the hemp cloth deep enough. However, the fact that a natural binder and hemp composite outperformed particle board by a large margin is once again proof that natural fiber composites can be employed successfully in many applications with clear advantages compared to wood and other engineered wood products.

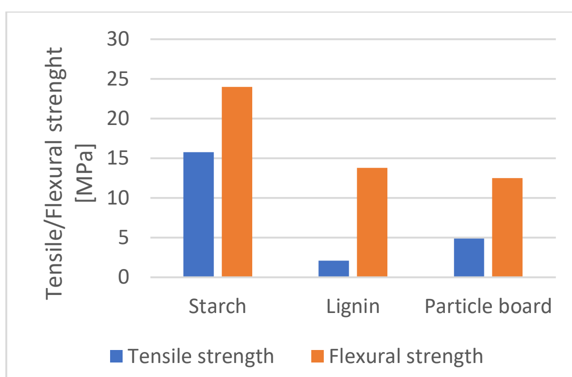

Fig. 8. Average tensile and flexural strength of the two hemp composites and the particle board

3. WATER RESISTANCE OF NATURAL BINDER HEMP COMPOSITES

The authors tested the water resistance of the two material formulations containing hemp and either a starch-based matrix or a lignin-based matrix. Water resistance remains an issue to be improved and was confirmed by the testing done. The samples were 30 by 30 mm wide and approximately 7 mm thick and were weighed in their dry state and then immersed in 100 ml of water for 60 hours (Figure 9 and 10).

Table 6 shows the obtained results, where M.C.HE.L-0.6.3.-06 is the 66% hemp and 34% starch-based binder composite and M.C.HE.L-0.6.3.-21 is the 66% and 34% lignin-based binder composite. The results clearly show that the lignin-based binder absorbed much more water than the starch-based one, thus making the latter one a much better choice for use in furniture.

Table 6

Water absorption of the tested composites

No.	Sample name	Initial mass [g]	Final mass [g]	Absorbed water after 60 hours [g]	Percentage of absorbed water [%]	Average percentage [%]
1	M.C.HE.A-0.6.3.-21	6.467	20.572	14.106	218	191
2	M.C.HE.A-0.6.3.-21	7.124	18.693	11.569	162	
3	M.C.HE.A-0.6.3.-21	7.029	20.500	13.471	192	
4	M.C.HE.L-0.6.3.-06	4.607	10.995	6.388	139	160
5	M.C.HE.L-0.6.3.-06	4.366	11.126	6.760	155	
6	M.C.HE.L-0.6.3.-06	4.270	12.177	7.907	185	

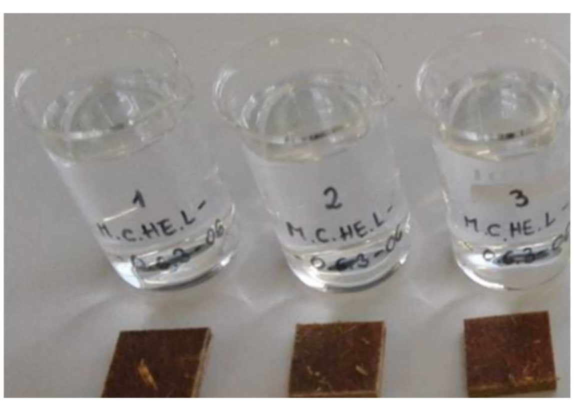

Fig. 9. The starch-based binder samples before water immersion

Fig. 10. The lignin-based binder samples after 60 hours of immersion

4. CONCLUSIONS

The field of composite materials is in a continuous evolution. Even though natural fiber composites have been used for some time, they are becoming more and more important because of the decreasing natural supplies and environmental concerns regarding energy consumption, toxic compound emissions and waste management.

The authors have been involved in designing and manufacturing furniture and other items made of hemp and polypropylene fibers in their involvement in composite development at Taparo SA. However, concerns have been raised regarding the availability of polypropylene fibers used as a matrix, their recycling and the possibility of pollution if they end up as waste. This is why there is growing interest in researching and improving natural, non-oil derived binders, such as starch- or lignin-based ones.

The paper presents two composite materials made of 66% hemp fibers and 34% by weight either starch- or lignin-based binder, their mechanical properties and water resistance characteristics. Even though it was expected that the lignin-based binder would yield higher strength because of its resemblance to the chemical structure of the hemp fibers, this was not the case and starch was the best choice featuring a tensile strength many times greater than its competitor.

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Noi materiale compozite ecologice pentru industria mobilierului tapitat

Lucrarea prezintă o descriere a materialelor compozite cu accent pe materialele compozite din fibre naturale. Aceasta trece în revistă industrii precum cea auto și inginerie civilă, care alcătuiesc cei mai mari consumatori ale acestor materiale și prezintă câteva dintre aplicațiile lor specifice. Autorii cercetează utilizarea materialelor compozite din fibre naturale în fabricarea mobilierului și prezintă rezultatele testelor mecanice și de rezistență la apă a două amestecuri de fibre de cânepă și matrici de origine naturală.

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