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Effect of Zeolite Mineral on the Formulation of a Wood-plastic Composite

UZIEL MEJIA-GONZALEZ[1], DORIAN NEDELCU[2]*, JAVIER CRUZ SALGADO[3], MISAELA FRANCISCO-MARQUEZ[1]

[1] Instituto Politécnico Nacional, Unidad Profesional Interdisciplinaria de Ingeniería y Ciencias Sociales Administrativas, Av Té 950, Col. Granjas México, CP. 08400, México City, México
[2] Babeș-Bolyai University, Faculty of Engineering, 1 Mihail Kogalniceanu Str., 400084, Cluj-Napoca, Romania
[3] Universidad de las Américas Puebla. Departamento de Ingeniería Industrial y Mecánica. Ex hacienda Sta. Catarina Mártir CP 72810, Puebla, México

Abstract: *The present work studies the positive or negative effect of zeolite mineral on the tensile and flexural mechanical behavior of a wood-plastic composite. Eight different blends were developed, the components used were wood flour (WF), polypropylene (PP), zeolite (Z) and maleic anhydride modified polypropylene (MAPP) as coupling agent. The eight blends were made using a counter-rotating twin-screw extruder, while the specimens were produced on a plastic injection molding machine with a 60ton clamping capacity. The standards used to determine the tensile and flexural mechanical properties were ASTM 638 and ASTM 790, respectively. Ten repetitions of each mixture were carried out. In addition, a reference (100% polypropylene) was used to compare the results obtained to determine whether the effect of using the zeolite mineral generated positive or negative results in the compounds obtained. Both studies showed that as the proportion of zeolite increases in the blend, the tensile and flexural properties are affected. However, the mixture (M7) with proportions in its components of, 34.375% WF, 55.875% PP, 6.75 % Z and 3% MAPP, showed an increase in the tensile and flexural mechanical properties, indicating a strong relationship between the components that integrate the wood-plastic composite (WPC), mainly between wood and mineral.*

Keywords*: Wood plastic composite, zeolite, tension properties, flexural properties*

1. Introduction

In the face of competition and globalization, industries require adequate strategies to produce what the market demands and to satisfy consumers; not only that, but they must also seek to reduce waste that can affect the environment, for this reason company develop strategies that not only favor their economy but also the environment. This dynamic has generated positions in society that demand sustainable environmental practices from industries; however, these requirements have gone beyond companies and have become international agendas of governments to recognize and address this problem [1].

The versatility of plastic allows the development of different types of products, replacing some of these, which are manufactured with metal, a situation that was generated with the Second World War, due to the increase in production costs, while plastic molding has been a relatively cheaper option. The products generated by this industry are present in many areas of our daily life, we have them in cell phones, computers, automobiles, medical equipment, packaging, means of handling and transportation of goods, etc. The role they play through multiple products in our daily and economic life is of utmost importance and, consequently, meeting the current demands required by society and markets should be a priority for the industry. It is possible to identify that sustainability in the plastics industry is focused on the development of resins or plastic compounds that are environmentally friendly, as pointed out by [2]. The research and development of new plastic compounds is presented as a great opportunity, not only to meet the needs that exist in the market, but also to generate an environmental differentiator with products that generate positive environmental impacts, through longer or shorter life cycles, depending on the requirement to be met.

**email: dorian.nedelcu@ubbcluj.ro*

In Mexico, the plastics industry represents 2.6 % of the national manufacturing, providing 260 thousand direct jobs and 500 thousand indirect jobs [3], and it contributes to the national gross domestic product (GNP). Packaging is one of the main fields of application of plastic since its characteristics allow to preserve the quality of packaged or stored products [4].

Design thinking [5], concurrent engineering [6], TRIZ methodology [7], design for manufacturing and assembly [8] etc., are some of the methodologies found for the design of new products or services that allow to integrate goals with proposed solutions to customer demand. The manufacturing of composites is an area of study in constant development, since it depends on multiple factors that can affect the expected results. From the point of view of design for manufacturing and assembly, there are several ways in which it is possible to improve the mechanical properties, performance, and life cycle of a product, including the physical redesign of the product, or the selection of the product, or the selection of the material from which it will be made [8].

The WPC concept has been widely used since the 1990s in the United States, but its beginnings are in Italy in 1970 [1]. In [9] work WPC is described as a composite made from a polymer, wood (particulate or pulverized) and additives. For their par in the work of [10] it is mentioned that they are a new generation of composites, which appear as a response to the growing environmental concern, since it is possible to use organic waste and recycled plastics for their elaboration, which allows them to be classified as green composites.t in the work. The same criterion of new generation composites is given by [11, 12]. The behavior of wood-plastic composites depends mainly on the type of natural fiber and complementary additives to be used such as coupling agents, minerals, etc. [13]. From the definitions presented it is possible to say that a WPC is a polymeric composite, formed from natural fibers, a thermoplastic matrix, and functional additives that, due to their characteristics of origin, allow not only the advantages of polymeric composites but also environmental advantages.

As a polymeric composite, a WPC will present mechanical properties that cannot be found in a pristine polymer, these will be defined in most cases by the fillers used in its composition. From the above, the work of [14] show that auxiliary fillers such as zeolite allow improving in certain aspects the mechanical performance of WPCs. This work seeks to continue providing information related to the use of zeolite (mineral) as an auxiliary filler in wood plastic composites for the improvement of the mechanical properties of this type of materials.

2. Materials and methods

2.1. Materials

The materials used for the formulation of the new WPC were commercial pine wood sawdust type with an approximate particle size of 5 mm, purchased from a local sawmill. Polypropylene copolymer (PP) with a density of 0.9 g/cm^3, melting point > 160°C, flow index 5.0 g/10min, Profax brand, purchased from Indelpro. A maleic anhydride modified polypropylene (MAPP) with a density ≥ 0.89 g/cm^3 and a flow index ≥ 80 g/10min, purchased from First Quality Chemicals, was used as coupling agent and the zeolite mineral (Z) was purchased from Grow Depot.

2.2 Preparation of the wood-plastic composite

The natural fiber was transformed from sawdust to wood flour (WF) type presentation, with a particle size < 0.841mm. This process was carried out in a 20HP PULVEX model 400 pulverizer, as shown in Figure 1 and 2.

Figure 1. PULVEX pulverizer model 400

Figure 2. Wood dust, particle size <0.841mm

The WF was dehydrated in a RIOSSA oven at a temperature of 80°C for 8 h. Similarly, PP was dehydrated at a temperature of 60°C for 2 h. Then, the WF, PP, MAPP and Z were then weighed on a Pionner precision balance (Figure 3) with a resolution of 0.01 g. The proportions of each mixture obtained from a design of experiment for mixtures are reported in Table 1. One by one, the materials were placed in a universal mixer, Figure 4, the materials were mixed for 5 min.

Figure 3. Pionner precision balance

Figure 4. Universal mixer

Table 1. Percentage composition of the mixtures

WPC	WF (%)	PP (%)	Zeolite (%)	MAPP (%)
M1	36.00	52.00	9.00	3.00
M2	34.38	60.38	2.25	3.00
M3	36.00	61.00	0.00	3.00
M4	28.88	61.38	6.75	3.00
M5	25.00	63.00	9.00	3.00
M6	33.38	61.38	2.25	3.00
M7	34.38	55.88	6.75	3.00
M8	34.00	63.00	0.00	3.00
M9	0.00	100.00	0.00	0.00

The mixtures were processed in a Leistritz extruder, model ZSE27 MAXX, with double counter-rotating screw, with a length of 905 mm, diameter of 27 mm and 8 heating zones. To establish the initial process conditions of the extruder machine, the melting temperature of the polypropylene was taken as

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a reference according to the manufacturer's data, then the temperatures of the eight heating zones were set as indicated in Table 2.

Table 2. Temperatures for heating zones. Leistritz Ectruder

Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
190°C	195°C	200°C	205°C	205°C	205°C	200°C	200°C

The heating zone 1 corresponds to the melting temperature indicated by the manufacturer, then for the heating zones 2, 3 and 4 there is an increase of 5°C, then, when reaching the temperature of 205°C this remains constant in the zones 4, 5 and 6, finally the temperature drops 5°C in the heating zones 7 and 8 respectively. At the end, the material passes through a die that forms the composite into threads, is shown in Figure 3. In addition to the temperatures of the heating zones, an extrusion speed of 35 RPM was established. The obtained compounds were cooled for 20 min at room temperature. During the extrusion process performed with a counter-rotating twin-screw extruder are shown in Figure 5, the product was packed in bags, (Figure 6).

Figure 5. Wood plastic composite

Figure 6. Extruder mixtures. Eight different types

The compounds obtained were granulated in a Paganni model 200-30 mill, with a 9.5 mm diameter sieving mesh. Next, injection molding of the specimens that were used during the mechanical tests was performed. A plastic injection molding machine of the brand Milacron model MTH55 was used with a clamping capacity of 60 t and 4 heating zones, the injection temperatures were set between 190°C and 200°C, a shot size of 40 mm and a cooling time for the mold of 20 s. A mold with 4 cavities, 2 for tensile specimens and 2 for flexural specimens, was used for the injection process. The injection molding process was performed in a room with a controlled temperature of 25°C. The specimens were measured, prepared, and sorted in accordance with ASTM D638 (Tensile test) and ASTM 790 (Flexural test), Figure 7 represented specimen classification. Between each injection process, a purging stage was carried out to ensure that no impurities were present in the specimens. Ten specimens of each mixture were used for each of the tests that were performed. A total of 180 tests were performed, 90 for the tension test and 90 for the flexural test.

Figure 7. Specimen clasification

2.3. Mechanical tests

Tensile and flexural tests were performed in accordance with ASTM D 638 and ASTM 790, respectively. For the tension test, an Instron universal testing machine was used, with a crosshead speed of 5 mm/min, and for the bending test, Galdabini equipment was used for the three-point bending test with a crosshead speed of 2 mm/min. Both tests were carried out in the physical-mechanical testing laboratory of the Center for Applied Innovation in Competitive Technologies (CIATEC A.C.), Guanajuato, Mexico. Ten replicates were performed for each compound.

2.4. Statistical analysis

Eight different types of mixtures were made, with ten replications each, generating a total of 80 treatments. The mixtures were generated with a design of experiments by extreme vertexes. Using an analysis of variance (ANOVA) and with a p-value of 0.05, the effect of each of the components on the response variables was determined. In addition, an Anderson-Darling normality test was applied to determine if the results obtained from the ANOVA showed normality, and a Levene's test was applied to determine constant variance in the data studied. The ANOVA was performed for the tensile strength results using a full cubic model.

3. Results and discussions

Table 3 is reported the 8 composites that were denominated as: M1, M2, up to M8, each one with different percentages of WF, PP and Z. From the results obtained, it was observed that the contribution of the mineral improves the tension and bending of the mixture, this can be observed when analyzing the increases in the proportion of zeolite. For M3 and M8 the experiment was performed in the absence of the mineral, M2 and M6 2.25% zeolite; M4 and M7 6.75% zeolite; M1 and M5 with 9% zeolite, and relevant data, obtained from them are reported in Figure 8 respectively, M1and M7 mixtures are the most significant results that were obtained from the tensile test.

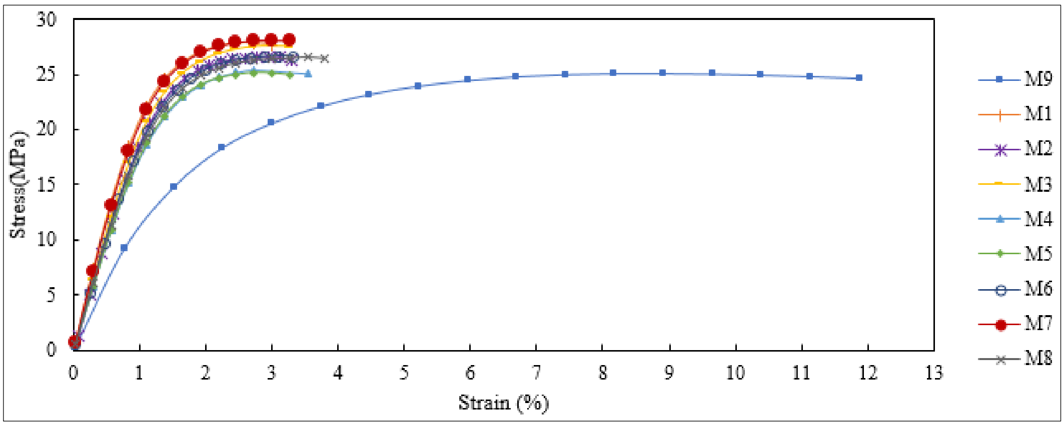

Figure 8. Tensile test, Stress (MPa) – Strain (%)

The M1 composite has 36 % WF, 52 % PP and 9 % Z, while M7 has 34.375% WF, 55.875% PP and 6.75 % Z. Although both composites show good results, M7 showed better performance than M1. When analyzing the results of these two mixtures, it was observed that the increase in the responses obtained in M7 is due to a reduction in the mineral and WF content, which is accompanied by an increase in the amount of PP. Additionally, it can be observed that in the cases where one or more functional fillers were added, a better tensile and flexural strength was obtained compared to the reference sample (M9), which has 100% polypropylene. Table 3 shows a direct relationship between mineral content and WF; the higher the amount of WF, the better the response results. The results have a direct relationship between the amount of mineral and WF content, from the results it can be said that there is a strong interaction between these components in the mixture. Zeolite, being a material with porous characteristics, allows absorbing the moisture produced during the extrusion process, avoiding the generation of fracture zones in the resulting composite, information that coincides with that reported by [14].

Table 3. Mechanical properties of WPC

Mixture	Tension		Flexion	
	Average yield strength (MPa)	Standard deviation σ	σf_M (Mpa)	Standard deviation σ
1	27.86	0.43	43.25	2.60
2	26.56	0.29	43.30	3.04
3	27.54	0.35	46.92	2.06
4	25.50	0.69	41.91	2.23
5	25.06	0.50	44.90	0.85
6	26.59	0.33	44.57	0.96
7	28.10	0.38	48.96	1.42
8	26.48	0.33	43.08	2.36
9	23.64	1.16	37.22	1.95

Table 4 presents the results of the p-values obtained from the ANOVA, where the variable A corresponds to the values of WF, B to those of PP and C to those of Z. It is observed that all interactions (A*B, A*C, B*C, A*B*(-) and A*C*(-)) have a p-value less than $\alpha = 0.05$, so it is said that there is not enough evidence to accept H_0 = All interactions produce the same effect, and it is accepted H_A = At least one of the interactions generates a different effect. For the ANOVA a complete cubic model was applied. The above confirms what was observed during the mechanical analysis, where it was observed that the presence of all the components produced a different result in the response, this also confirms what is known about mix design where all the components depend on each other so that the variation of any of them affects the results of the output variable.

Table 4. P-values, obtained from the ANOVA for tensile strength

Source	P Value
A*B	0.001
A*C	0.003
B*C	0.000
Complete cubic	0.000
A*B*(-)	0.001
A*C*(-)	0.006

By increasing the tensile and flexural properties, a reduction in the elongation capacity of the composite was observed. Figure 9 shows the results for flexural strength for M7 (mix with better mechanical performance) and the reference M9, where it is observed that the M7 mix, having a higher flexural resistance capacity, presents a reduction in its displacement, which is consistent with that reported in the work of [15, 16].

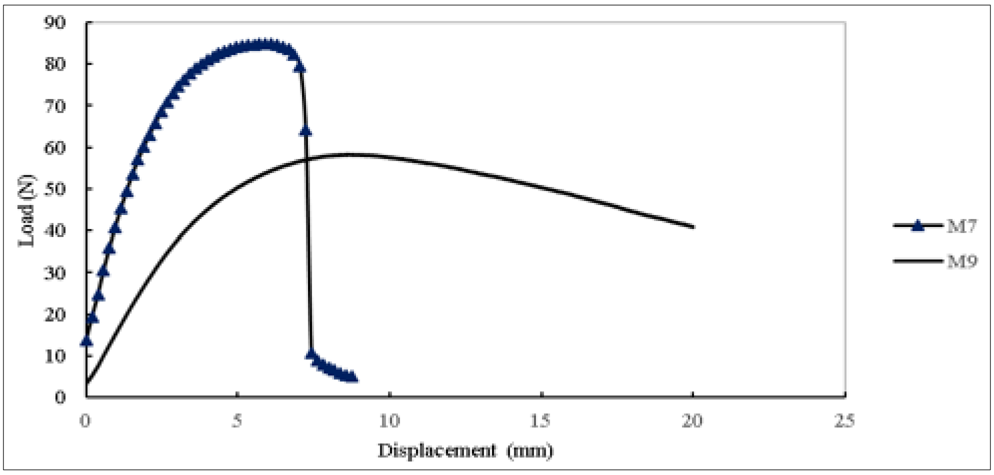

Figure 9. Flexural test, load displacement for mixture 7 and 9

4. Conclusions

The results showed that adding zeolite mineral to a wood-plastic composite allows to obtain an increase in the tensile and flexural strength, however, a reduction in the displacement capacity of each of the developed mixtures was observed, which represents a characteristic property in rigid materials. The tensile and flexural strength improved by increasing the proportions of WF - Z and reducing the amount of PP, while by reducing the amount of WF and increasing the proportion of PP- Z a reduction in the response variables was observed, so it can be concluded that there is a negative relationship between PP and mineral and a positive correlation between wood and mineral. This may be related to the assumption that the mineral, having a porous composition, benefits the absorption of moisture from the wood during the extrusion process of the mixture and consequently avoids the generation of voids in the final composite that are the result of moisture stored in the natural fibers used in wood plastic composites. A mixture (M7) with values of 34.375%, 55.875%, 6.75% and 3% respectively for PM, PP, Z and MAPP, allows obtaining a material with tensile and flexural strength values higher than those of PP.

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