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MATERIALS ENGINEERING

Study of the mechanical properties of a composite material from polypropylene matrix with guadua fibers and ceramic powder

INGENIERÍA DE MATERIALES

Estudio de propiedades mecánicas de un material compuesto de matriz de polipropileno con fibra de guadua y polvo de cerámica

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Abstract

The use of natural fibers as a reinforcement in Compound Materials (CM) has been grew up in recent years. In this case, it is a CM with matrix of recycled polypropylene (PP), coming from lids of different packaging using in products of daily consume, for the reinforcement, natural *Angustifolia Guadua* fibers and tenacious ceramic powder was chosen. The Guadua fiber was obtained under drying and immunized conditions, according to the process of "Guadua Factoria Company". The drying is made to reduce the moisture on the *Guadua* and for prevent formation of fungi and lichens, the process allows a correct adhesion with the matrix too. The powder of tenacious ceramic is also a recycled material; it was obtained from ceramic floors that were pulverized before insertion into the CM. The proportions used to manufacture the MC specimens were a group of 100% PP and other groups with different proportions of materials, in that groups, PP matrix was remained in 60%, and the reinforcement materials were combined in the following proportions, one with 30% *Guadua* fiber and 10% ceramic powder, other with 33% *Guadua* fiber and 7% ceramic powder and the last one with 35% *Guadua* fiber and 5% ceramic powder. Once the CM specimens were obtained, mechanical tensile tests, according to the norm ASTM 638D for polymers, were performed, flexion tests, according to the norm ASTM 790D for reinforced plastics, were carried out too. Results obtained were analyzed using Analysis of Variance ANOVA, finding as more important result, that the PP tensile elastic modulus increased by 53.49% when 35% of *Guadua* and 5% of ceramic were added.

Keywords: *alternative materials, cellulosic fibers, plastics, recycling.*

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Resumen

El uso de fibras de origen natural como refuerzo en Materiales Compuestos (MC), ha venido tomando fuerza en los últimos años. En este caso se tiene un MC con matriz de polipropileno (PP) reciclado, proveniente de tapas de diferentes envases de productos de consumo diario. Para el refuerzo se eligió usar fibra natural de *Guadua Angustifolia* y polvo de cerámica tenaz. La fibra de *Guadua* se obtuvo en condiciones de secado e inmunizado con el fin de reducir su humedad y evitar la aparición de hongos y líquenes. El polvo de cerámica tenaz también es un material reciclado, obtenido de pisos de cerámica que se trituraron y pulverizaron previo a la inserción al MC. Las proporciones usadas para fabricar las probetas del MC fueron: una con 100% de PP y otras con diferente composición del MC, donde la matriz de PP se mantuvo con el 60%, y se combinaron los materiales de refuerzo, para obtener los siguientes grupos de especímenes, uno con 30% fibra y 10% cerámica, otro con 33% fibra y 7% cerámica y un último con 35% fibra y 5% cerámica. Una vez obtenidas las probetas del MC, se realizaron los ensayos mecánicos, de tensión según la norma ASTM 638D para polímeros, y de flexión con la norma ASTM 970D para plásticos reforzados. Se analizaron los resultados obtenidos, mediante análisis de varianza (ANOVA), usando un nivel de significancia de $\alpha = 0.05$ y un enfoque de valor P para la verificación de la hipótesis nula. El análisis estadístico se realizó mediante el software Minitab 18, encontrando como resultado más importante, que el módulo de elasticidad a tensión del PP aumentó en un 53,49%, al adicionarle *Guadua* en un 35% y cerámica en un 5%.

Palabras clave: *fibras celulósicas, materiales alternativos, plásticos, reciclaje.*

1. Introduction

A CM is a structure formed by systems in two or more phases to microscopic scale, its properties are designed for be better to the properties of the original constituents acting by itself. One of its phases is continuous and no stiff, it is the weak phase and is named matrix. The other one is discontinuous, stiffer and strong, it is called reinforce [(1)]. The investigation of new compounds with characteristics bettering is advancing with fast [(2)], and the efforts to reduce environmental contamination are undeniable [(3)], because of this, the investigation about compound materials, using recycled supplies is necessary [(4)(5)]. For this, properties of constituents should be known, and if the CM is better, an application should be proposed, showing benefits in structural uses and sustainability.

The studies of compound materials using PP (see Table 1) has been developed since a couple of years, but its, employing PP mixed with natural fibers and ceramics are few [(6)]. In the next lines, investigations carried out with this kind of mixes are described, its will be a reference for the results in this study. The comparisons should be conservators, taking account the variety of Guadua that was employing in the present investigation (see Table 2).

Hurtado et al.[(7)], added nano-clays to PP in concentrations of 3%, 5% and 7%, using an extruder of twin screw. The mechanical properties of the new material increased in the next way, 4% in tensile strength, 40% in flexural strength, 59% in elastic modulus and 57% in flexural modulus, these results shown that the effect of adding particles of ceramics or nano-clays, is beneficial.

Other study of compound material with polymeric matrix in PP, which obtain good results, was carried out by Caicedo et.al [(8)]. They use cedar fibers, doing test specimens by injection, obtaining an increase of 20.3% in tensile strength, and 46.2% in flexure strength. This study shows that natural fibers produce a better mechanical behavior of PP, and that both, extrusion, and injection process are good choice for the making of test specimens.

Furthermore, Passatore et al. [(9)], observed favorable results in the analysis of Young´s modulus, mixing PP with Piassava in proportions of 20, 40 and 60%. The modulus rises in 90% in comparation to PP mixed with $CaCO_3$, test specimens were manufactured by injection. The study shows the mix with organic fibers produces better mechanical properties in comparation to mixes with inorganic particles.

Germannya et al. [10] mixed PP with alumina particles in proportions of 1, 3 and 5%, finding that the mix in 1% was better in mechanical properties such as tenacity and elongation modulus, while mix with 5% was better in thermal performance. Same results in mechanical properties were obtained by Ordoñez-Benavides [11], who mixed PP with ZSM-5 Zeolites, showing an improved in the elasticity modulus of 14%. These studies keep the evidence of better mechanical properties, mixing PP with minerals.

Rosales et al.[12] did mixes of PP with lactic acid and montmorillonite, they deduced that montmorillonite increased the Young´s modulus. Pilaguano et al.[13], mixed PP with powder of bamboo in amounts of 5, 10 and 15% and 0.2 and 5% of nano-clays, manufacturing test specimens by extrusion and injection. Improvements in elasticity and flexure modulus were observed, but with bad results in resistance to the impact and tensile. These results are important because mixes of PP with organic and inorganic materials favors properties as elasticity modulus but reduces other properties as tensile strength.

On the other hand, Jaramillo et al [14] made a compound with PP and fibers of pineapple, in which an increase of 22% in tensile strength, 60% in Young´s modulus, 19% in flexure resistance, and 50% in flexure modulus was obtained. A comparation between these results and the findings in investigations of mixes with natural fibers and minerals, shows that tensile strength is affected mainly by the addition of inorganic constituents.

In this investigation, mechanical properties of a CM of PP reinforced with fibers of *Angustifolia Guadua* and powder of ceramic were studied, the aim is to advance in the knowledge of CM coming from recycled supplies that could be propose as structural material in applications of furniture or shelves.

2. Methodology

In this work, PP was selected, because it material is considered safe for human health [15], then, PP is used in food package [16]. *Angustifolia Guadua* fiber is an item what has similar mechanical characteristics to the steel [17]. Powder of ceramic has good thermo-mechanics properties [18]. In Tables 1 and 2, mechanical properties of Guadua and Polypropylene are presented [19][20] respectively. Tests of tensile and flexure, under ASTM 638D [21] and ASTM 790D [22] standards were carried out, using experimental methodology, and results were analyzed by ANOVA [23] with Minitab 18 as support.

Materials in this project was totally recycled, PP was obtained from lids of different plastic containers, it was washed, dried, and cut manually. The Guadua was provided by Guadua Factoria Company located in Duitama city. It comes in little fibers with a length of 2 to 3 mm, and a diameter of 1 mm approximately. The fibers are waste of a saw. The Guadua is native of the Quindío region, is onion biotype and it comes with a drying and immunizing treatment to avoid lichens. This Guadua is not delignified, what is common for create CM with natural fibers and plastic resins, aimed good adhesion between the constituents. The process was not realized to verify good adhesion of PP and Guadua fibers in extrusion method. Finally, crushed ceramic came from the waste of a construction zone. It was sifted to a size of 150 μm.

Materials were mixed and extruded to a temperature of 260 °C. For each test specimen, 400 grams of mixture were used, Table 3 shows proportions and nomenclature used for the groups of test specimens. In each case, 8 test specimens were extruded.

Table 1. *Properties of Polypropylene.*

Plastic Abbreviation	Thermal Properties				Mechanical Properties		Density	Shrinkage
	Tm	Tg	Td	Cte.	Stress strain	Compression Stress		
	°C	°C	°C	ppm/°C	MPa	MPa	g/cm^3	%
PP	168-175	-20	107-121	81-100	31.02- 41.36	37.92- 55.15	0.900 – 0.910	1 – 3

Source: Polipropileno s. f. [19]

Table 2. *Properties of Angustifolia Guadua*

Mechanical Properties	Average (MPa)	S. D (MPa)	C. V (%)
Traction parallel to the fiber			
Maximum Stress	132	24.1	1 8%
Elasticity Modulus	17468	3655	21 %
Traction perpendicular to the fiber			
Radial Maximum Stress	1.1	0.3	22 %
Tangential Maximum Stress	1.8	0.4	21 %
Compression parallel to fiber			
Maximum Stress	48	3	5 %
Stress in the proportional limit	36	2	6 %
Elasticity Modulus	1913	1625	9 %
Compression perpendicular to fiber			
Radial Maximum Stress	5	0.6	12 %
Tangential Maximum Stress	6.8	0.9	21 %

S. D= Standard Deviation. C.V. = Coefficient of Variance. Source: Lopez y Correal [20]

Table 3. *Nomenclature of test specimens.*

Nomenclature	% PP	% Guadua	% Ceramic
PP 100	100	0	0
PPGC 3505	60	35	5
PPGC 3307	60	33	7
PPGC 3010	60	30	10

Source: Own elaboration

The extrusion process was carried out with an extruder manufactured for the project. It has a capacity of 3 g/min and is powered to 110V. It has a DC motor of 12 V and 60 rpm, has a temperature control PID control in an Arduino board. Heating zone has 7 resistances of 40 W each one, and temperature was measured by a K sensor. The extruder can be seen in Figures 1 and 2, and in Figure 3, molds can be seen too. The constituents were added slowly to the extruder, test specimens of PP only took 7 – 10 minutes in fill the mold, while the other specimens took 10 – 15 minutes. It should be near to room temperature for be removed from the molds.

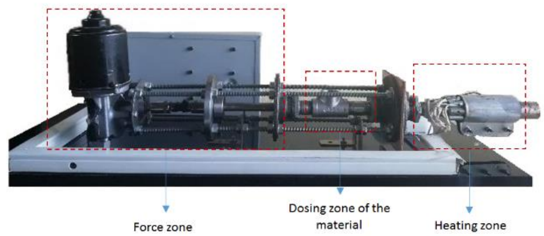


Figure 1. *Rear view of the plastic extruder. Source: Own elaboration*

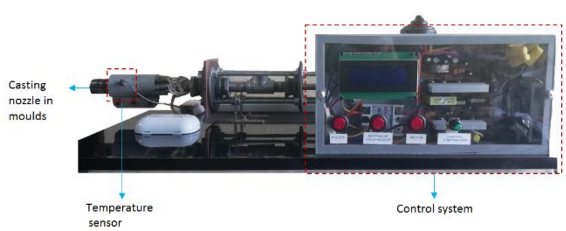


Figure 2. *Front view of the plastic extruder. Source: Own elaboration*

Figure 3. *Molds. Source: Own elaboration*

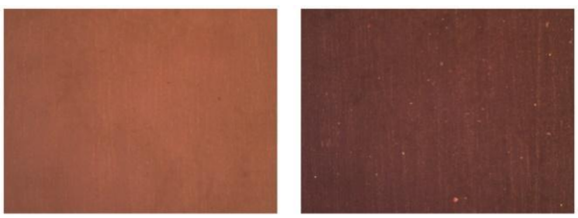
For the mechanical tests, 8 specimens for each combination were extruded, it means that 32 test specimens for tensile tests were obtained, and in the same way, 32 test specimens for the flexure tests were extruded. Figure 4 shows tensile test specimens, and Figure 5 shows flexure test specimens.

Figure 4. *Tensile test specimens. Source: Own elaboration*

Figure 5. *Flexure test specimens. Source: Own elaboration*

The Figure 6 shows a photography in which the mixture of PP and *Guadua* can be seen, and in the Figure 7 two photographs can be observed. In Figure 7a particles of ceramic cannot be seen, while in Figure 7b, the particles its show as glowing dots of orange and yellow hue. The photographs were taken with a Pace Technologies brand inverted microscope, model IM-5000, which has a trinocular tube with inclination of 45°, a magnification of 1x50 were used.

Figure 6. *Dispersion of the Guadua fibers in the CM.*
Source: Own elaboration



a) b)

Figure 7. *Photograph taken with a Pace Technologies microscope* ***(a)*** *Sample PP100* ***(b)*** *Sample PPGC3505.*
Source: Own elaboration

The tests of tensile and flexure were carried out in the mechanical testing laboratory located in the south headquarters of the Antonio Nariño university in Bogotá city. A universal machine model HT-2102, serial 2129, brand HUNGTA were used. The randomization of the tests was done in a very simple way, the 32 tensile specimens were put into a plastic bag in where were eaten and taken one by one for each test. For the flexure testing, the same process was used. The data of each test were charged in the calculus sheet of the software Minitab 18, and a one-way ANOVA were performed. A significance level of $\alpha = 0.05$ were used, and the verification of the null hypothesis were done by P value. Make sense to mention that null hypothesis was "all means are the same", assuming that there is not difference between the configurations of CM.

3. Results

Tensile elasticity modulus: In the Table 4, values of tensile elasticity modulus (TEM) and its standard deviation can be seen

Table 4. *Tensile elasticity modulus.*

Combination	Tensile elasticity modulus (MPa)
PP1000	369.8 ± 112.5
PPGC3505	567 ± 62.9
PPGC3307	565 ± 91
PPGC3010	474.5 ± 83.6

Source: Own elaboration

Data shows a rise of 53.49% in TEM for the combination PPGC3505 with respect to pure polypropylene, it is in agreement with results of Hurtado et al. [(7)], Who obtained improvements of TEM in 57%, adding nano-clays to the pure polypropylene, in the same proportions of this work. For the other combinations, rises of 52.79% y 28.31%, in samples PPGC3307 and PPGC3010 respectively, were attained. The last combination in mention has the less improvement in TEM, it could be because with more quantity of clay, the effect of interaction between materials added is higher.

Figure 8 and results of the analysis in the software shows that nule hypothesis can be descarted, then, the favorable effect of the componenets over the elasticity modulus is confirmed. In Tables 5, 6 and 7, response of ANOVA by Minitab 18 software is displayed, there is found that P value is less than error acepted and the information of the factor and complete ANOVA is presented.

Table 5. *One way ANOVA: 100%. 35%. 33%. 30%.*

Nule Hypothesis	All means are equals
Alternative Hypothesis	Not all means are equals
Significance level	α = 0.05

Method. Variances equals are assumed for the analysis. Source: Own elaboration

Table 6. *Information of the factor*

Factor	Levels	Values
Factor	4	100%. 35%. 33%. 30%

Source: Own elaboration

Table 7. *Analysis of Variance*

Source	GL	SC Adjust.	MC Adjust.	F Value	P Value
Factor	3	209506	69835	8.77	0.000
Error	28	223073	7967		
Total	31	432580			

Source: Own elaboration

Figure 9 is a plot of normal probability, it shows percentage vs residuals, point fitted to the straight line indicate that normal distribution and constant variance assumptions are valid and results of ANOVA are reliable. Ultimate tensile stress: In Table 8 values of breaking stress, with its standard deviation, can be seen, and Figure 10 shows stress strain curves obtained from data of the universal machine.

Table 8. *Ultimate tensile stress.*

Combination	Ultimate tensile stress (MPa)
PP100	10.75 ± 4.62
PPGC3505	8.25 ± 2.37
PPGC3307	5.25± 2.49
PPGC3010	5.75 ± 2.37

Source: Own elaboration

The ultimate tensile stress data shows that the MC did not overcome values of **PP100**, even it fall in 23.2% for **PPGC3505**, 46.5% for **PPGC3010** and 51.1% for **PPGC3307**. This results has the same tendence that results of Pilaguano et al. [13], reduction in tensile resistance may be due to that in high deformations, adherence forces between particles and matrix lost, producing breaking in less stress, in this case, the interaction between factors (percentage of additives) is more evident, because data shows a lift after of a down, forming a concave curve upwards, as is showed in Figure 11.

In this case, like in the elasticity modulus, P value was zero in the software, what indicate that breaking tensile is affected by variations in the material.

Flexural elasticity modulus: Table 9 shows flexural elasticity modulus (FEM) and its standard deviation.

Table 9. *Flexural elasticity modulus.*

Combination	Flexural elasticity modulus (MPa)
PP100	2.17 ± 0.50
PPGC3505	2.96 ± 0.67
PPGC3307	2.55 ± 0.94
PPGC3010	2.75 ± 0.67

Source: Own elaboration

Data are not clear for the FEM and it is confirmed by the P value of 0.171 which is higher of significance level defined for the tests, because of this is evident that added materials not affect the FEM of the PP. This contradict studies realized by Hurtado et al. [7], it could be for the addition of Guadua, what will produce changes in adhesion forces between materials.

Ultimate flexural stress: Table 10 shows values of ultimate flexural stress (UFS) and its respective standard deviation.

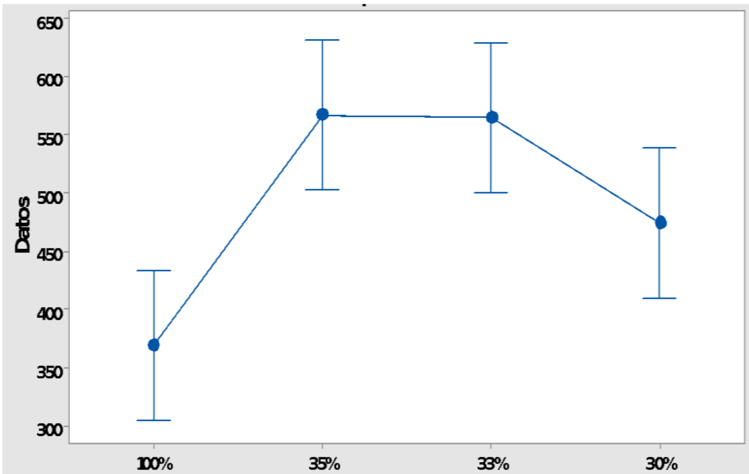


Figure 8. *Means and intervals for tensile elasticity modulus. Source: own elaboration*

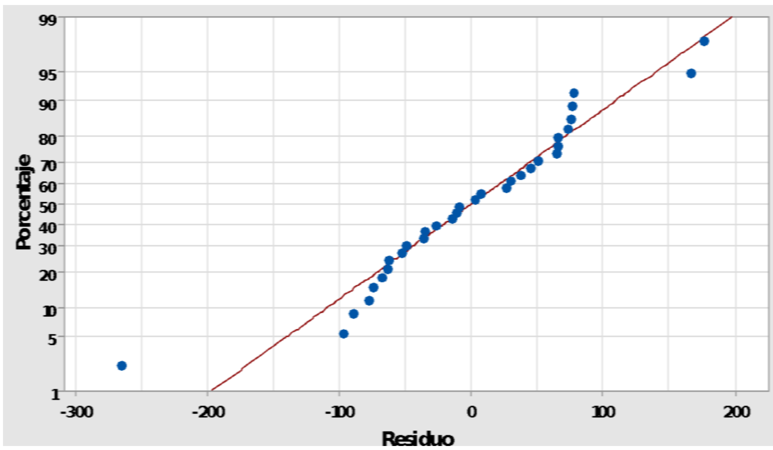


Figure 9. *Plot of normal probability for the tensile elasticity modulus. Source: own elaboration*

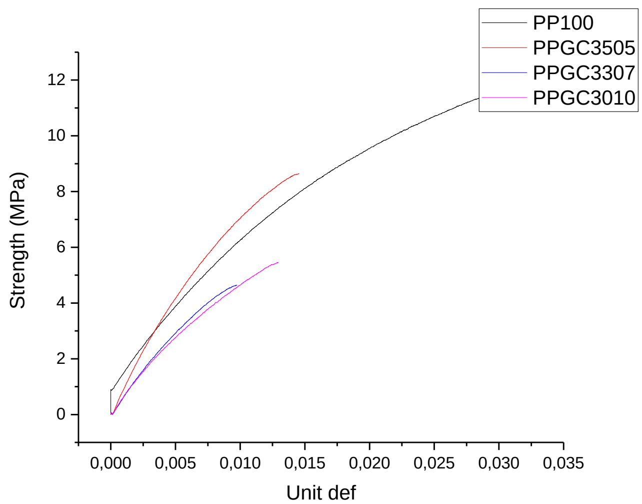


Figure 10. *Curves of stress vs unitary deformation for all the combinations. Source: own elaboration*

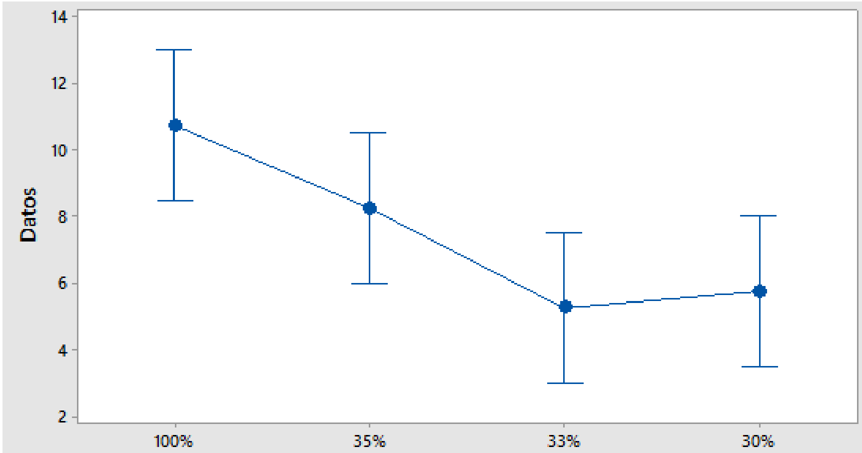


Figure 11. *Plot of means and intervals for the ultimate tensile stress. Source: own elaboration*

Table 10. *Ultimate flexural stress.*

Combination	Ultimate flexural stress (MPa)
PP100	28.68 ± 8.67
PPGC3505	21.61 ± 6.39
PPGC3307	19.72 ± 8.71
PPGC3010	28.50 ± 6.61

Source: Own elaboration

In UFS like in FEM data has not tendece define, it is confirmed by the analysis in Minitab, in which is oBserved that P value is higher that α, what make impossible dischart the nule hypothesis, it means that does not exist a significant difference between means of the groups, then there is no difference in the UFS of the PP100 and the compound materials. Tables 11, 12 and 13 shows the analysis in Minitab 18 by ANOVA, in this, P value with respect to the significance level α can be seen and the rest of information of the ANOVA.

Table 11. *One way ANOVA: 100%. 35%. 33%. 30%.*

Nule Hypothesis	All means are equals
Alternative Hypothesis	Not all means are equals ales
Significance level	α = 0.05

Method. Variances equals are assumed for the analysis.
Source: Own elaboration

Table 12. *Information of the factor.*

Factor	Levels	Values
Factor	4	100%. 35%. 33%. 30%

Source: Own elaboration

Table 13. *Analysis of variance.*

Source	GL	SC Adjust.	MC Adjust.	F Value	P Value
Factor	3	516.4	172.13	2.92	0.051
Error	28	1648.9	58.89		
Total	31	2165.3			

Source: Own elaboration

5. Conclusions

An improvement of 53.49% in the tensile elasticity modulus of the PP was obtained when Guadua in 35% and clay in 5% was added, the other combinations show important rises too, this suggest that the material can be proposed as reinforcement in applications of low load and low tolerance or high adjust requirements. In the statistical analysis of flexural tests is evidenced that there is no significative improvement in the flexural ultimate stress and flexural elasticity modulus, it should be taking account in the moment of propose a possible application. In the ultimate flexural stress, combination of PPGC3010 reach the same values of PP100, it is the compound with the higher quantity of clay and less quantity of Guadua, this suggests that a variation of these materials in higher proportions could make better the ultimate flexural stress.

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7. References

(1) Daniel IM, Ishai O. Engineering mechanics of composite materials Volumen 13. 2nd ed. New York: Oxford University Press; 2006. 411 p.

(2) Newell J. Ciencia de materiales - aplicaciones en ingeniería. 1a ed. Alfaomega Grupo Editor; 2011. 368 p.

(3) Gil Barroso JR, Camacho AM. Introducción al conocimiento de los materiales y a sus aplicaciones. Editorial UNED; 2010. 718 p.

(4) Ahlgren WL. The Dual-Fuel Strategy: An Energy Transition Plan. Proc IEEE. 2012;100(11):3001–52. https://doi.org/10.1109/JPROC.2012.2192469.

(5) Bolden J, Abu-lebdeh T, Fini E. Utilization of recycled and waste materials in various construction applications. 2013;9(1):14-24. https://doi.org/10.3844/ajessp.2013.14.24.

(6) Alves-Fidelis ME, Castro-Pereira TV, Martins-Gomes O, De Andrade F, Toledo-Filho RD. The effect of fiber morphology on the tensile strength of natural fibers. Journal of Materials Research and Technology. 2013;2(2):149-157. https://doi.org/10.1016/j.jmrt.2013.02.003.

(7) Hurtado SGG, Revelo JC, Pruna CF, Barragán VHG. Obtención y Caracterización de Compuestos de Polipropileno Reforzado con Nanoarcillas Mediante Extrusión e Inyección. Rev Politécnica. 2015;35(3):43. Available from: https://revistapolitecnica.epn.edu.ec/ojs2/index.php/revista_politecnica2/article/view/397.

(8) Caicedo C, Vásquez Arce A, Crespo LM, De la Cruz H, Ossa ÓH. Material compuesto de matriz polipropileno (PP) y fibra de cedro: influencia del compatibilizante PP-g-MA. Inf Téc. 2015;79(2):118. https://doi.org/10.23850/22565035.156.

(9) Passatore CR, Leão AL, Rosa D dos S. Compuestos de polipropileno reforzado con fibra de piasava. In: XIV SLAP/XII CIP 2014. Porto de Galinhas, Brasil: Associação Brasileira de Polímeros - ABPol; 2014.

(10) Silva GD, Almeida YM, Sanguinetti RAF, Yadava YP. Efeitos da adição de partículas de alumina em compósitos de polipropileno. In: 12° Congresso Brasileiro de Polímeros (12°CBPol) [Internet]. São Carlos: Associação Brasileira de Polímeros - ABPol; 2013. p. 1–4. Available from: http://e-democracia.com.br/cbpol/anais/2013/pdf/6FCN.pdf

(11) Ordoñez-Benavides GJ. Evaluación de las propiedades térmicas y mecánicas del polipropileno reforzado con zeolitas tipo ZSM-5. [Master’s Thesis]. Medellín: Instituto Tecnológico Metropolitano; 2016. Available from:

https://repositorio.itm.edu.co/handle/20.500.12622/502

(12) Rosales C, Sabino M, Perera R, Rojas H, Romero N. Estudio de mezclas de poli (ácido láctico) con polipropileno y nanocompuestos con montmorillonita. Rev Latinoam Metal Mater. 2014;34(1):158-71.

(13) Pilaguano-Guanochanga JG, Vizueta-Caisatoa PJ. Caracterización de compuestos de polipropileno reforzados con polvo de Bambú y nanoarcillas obtenidos mediante extrusión e inyección [Bacherlor's Thesis]. Quito: Escuela Politécnica Nacional; 2017. Available from: http://bibdigital.epn.edu.ec/handle/15000/17383

(14) Jaramillo N, Hoyos D, Santa JF. Compuesto de fibra de hoja de piña fabricados mediante moldeo por compresion por capas. Ing Compet. 2016;18(2):151-62. https://doi.org/10.25100/iyc.v18i2.2163

(15) McDonald GR, Hudson AL, Dunn SMJ, You H, Baker GB, Whittal RM, et al. Bioactive contaminants leach from disposable laboratory plasticware. Science. 2008;322(5903):917. https://doi.org/10.1126/science.1162395

(16) Greenpeace. ¿Cómo llega el plástico a los océanos y qué sucede entonces? - ES [Internet]. Greenpeace España. 2015 [citado mayo 25 de 2020]. Available from: https://es.greenpeace.org/es/trabajamos-en/consumismo/plasticos/como-llega-el-plastico-a-los-oceanos-y-que-sucede-entonces/

(17) Minke G. Manual de construcción con Bambú. 1a ed. Cali, Colombia: Merlin S.E. SAS; 2010. 154 p.

(18) Malagón E. Materiales cerámicos: propiedades, aplicaciones y elaboración. UNAM; 2005. 168 p

(19) PQI de Occidente. Polipropileno [Internet]. 2013 [cited 2020 may 25]. Disponible en: http://www.plasquim.net/polipropileno.html

(20) López LF, Correal JF. Estudio exploratorio de los laminados de bambú Guadua angustifolia como material estructural. Maderas Cienc Tecnol. 2009;11(3):171-82. http://dx.doi.org/10.4067/S0718-221X2009000300001.

(21) ASTM D-638 Standard Test Method for Flexural Properties Of Unreinforced And Reinforced Plastics And Electrical nsulating Materials. West Conshohocken: ASTM International.; 2001.

(22) ASTM D-790 Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. West Conshohocken: ASTM International; 2010.

(23) Douglas C. Montgomery. Diseño y análisis de experimentos. segunda. Mexico: Limusa, S.A. de C.V.; 2004. 692 p.