USING DESIGN OF EXPERIMENTS TO DETERMINE MECHANICAL PROPERTIES OF WOOD PLASTIC COMPOSITES

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Abstract— **Composites are of paramount importance in several fields, because of mechanical properties compared to their weight ratio are higher than matrix. One of these composites are wood plastic composites (WPCs) which are being developed for many applications, like construction, automotive, furniture and others. The use of WPCs with sustainable resources is an awareness that is growing in the world, and have advantages such as recyclable, low cost, sustainable, high strength, and others. Some factors have effect on mechanical properties like particle size, coupling agent, and weight ratio.**

The aim of this study was to investigate mechanical response of WPCs based in pecan shell and pine wood using statistical design to estimate mechanical properties of WPCs using High density polyethylene and Polybond 3009. In the study, parts were manufactured using injection molding. The characterization was based on the ASTM D638 and ASTM D790-03 standard to estimate tensile and Flexural strength. The results obtained indicate that each of the factors above have effect on the mechanical properties.

Key words—**mechanical properties, composites, statistical design, tensile test.**

Introduction

Composite materials are of paramount importance in several fields, since their mechanical properties compared to their weight ratio are higher than matrix phase. Composites are used in several applications. They are based on a matrix and dispersed phases. One of these composites are wood plastic composites (WPCs) which are being developed for several applications, for instance construction, automotive, furniture and others. The use of WPCs with sustainable resources is an awareness that is growing in the world (Ortega et al., 2018). In Europe, the government is imposing requirements of the minimum 85% of recycling the car weight content since 2015, including plastics composites (Komornicki et al., 2017). Some of the advantages of WPCs are the composition based on thermoplastics as recyclable, low cost, sustainable, high strength, and others. Ortega et al., (2018) described that recycling can add value to a composite and will make it a greener material. As mentioned above, the WPCs are based on thermoplastics, and the fillers (dispersed phase) such as wood flour or fiber from different types of sources, like oak, jute, flax, sisal, cotton, among others. Some factors that can improve mechanical properties are the fiber type, particle size, coupling agent, weight ratio, among others. WPCs have been studied by several authors, and most of these works reports WPCs characterization, and predicting properties by using micromechanical models and general experimentation. Other studies use statistical design for optimization. However, few works have been done to analyzed parameters interaction in the mechanical properties of the composites. In these studies, parts have been manufactured using different processes, for instance injection molding, extrusion molding and compression molding. The characterization has been made by using the ASTM D638 standard or ISO 527 to estimate tensile strength and Young's elastic modulus.

This study will provide an insight of the effect of the factors mentioned above, including fiber type, particle size and weight on the mechanical properties of the WPCs based in high density polyethylene (HDPE) applying statistical design. These factors need to be analyzed more in depth to understand how each of them affect the response of tensile and flexural strength.

The objective of the research was to determine the effect of the pine wood and pecan shell in the tensile response of the composite using high density polyethylene (HDPE). This report provides the data for, pecan shell and pine wood that were analyzed. The experimentation was based in a split plot design. The parameters used were to respond two hypotheses. The design was based in two fibers the pecan shell and pine wood of three mesh sizes 60 and 80. Weight ratios of 30 y 40%.

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Experimental Methods and Materials

In this section, a methodology is presented of the proposed approach in various steps, which mainly describes the testing of the two-hypothesis considered.

Hypothesis 1: Mechanical properties of wood plastic composites can be improved by using pecan shell and pine wood as filler.
Null Hypothesis Ho: Hs=Hw=Hdpe
Alternative Ha: Hs≠Hw≠Hdpe
Where Hpe polyethylene, Hs Pecan shell and Hw wood flour

Hypothesis 2: Particle size has significant effect in the tensile properties of WPCs.
Ho: Hm60=Hm80
Ha: Hm60≠Hm80
Where 60 and 80 are mesh sizes.

The first part of the experimentation consisted on the preparation of the experimental design to produce samples that can be tested for tensile and flexural strength. The samples should be manufactured based on specific standards that will provide reliable data from each test.

Statistical Design

The production of samples was based on a split plot design considering HDPE with two factors: wood and pecan shell, two mesh sizes 60 and 80 and two weight contents 30% and 40% , Table 1 shows the runs of the split plot design. The table was generated using Minitab. The weight factor was selected were based in several works from (Mijiyawa, Demagna, Bohuslav, & Erchiqui, 2015), (Stark & Berger, 1997), (Essabir et al. 2015) amon others. The particle size was selected based on the review of particle size paper such as (Stark & Berger, 1997) and (Cruz-Salgado & Dominguez-Dominguez, 2015) where bigger particle had high strengh response.

StdOrder	RunOrder	Blocks	Fiber	Content %	MAPE%	HDPE	Fiber Size
3	1	1	w	40	3.5	56.5	80
5	2	1	s	30	3.5	66.5	80
4	3	1	w	30	3.5	66.5	80
1	4	1	w	30	3.5	66.5	40
7	5	1	s	40	3.5	56.5	60
2	6	1	w	40	3.5	56.5	40
6	7	1	s	40	3.5	56.5	80
8	8	1	s	30	3.5	66.5	60

Table 1 Table of experimental design (w: pine; s: pecan shell)

Mill flour process

The process preparation started with the milling process using a commercial mill from Meadows Mill Inc. Model 250E-5780-12. Shell was milled in the mill machine using 1/16 in. screen as initial step. The wood flour was from commercial company the American wood Company using 60 and 80 mesh. Matrix was HDPE from ExxonMobil part number HD6733, and Poly bond 3009. The flour from pecan shell was processed using a commercial sieve machine from Tech-Lab model TL6008.rom The value of 3.5% of MAPE (Polybond 3009) was considered from several papers were the average value was selected among 2 to 5% and this was the final value. Sieve screen of 20, 60 and 80 mesh were used. The samples were produced in a two-step process which used a twin extruder to mix the polymer, coupling agent and the flour. Both flours were dried for 24 hrs. at 50 °C prior to injection molding process.

Injection Molding

The extrusion machine was a 15cc twin co-rotating screws by Xplore model DSM 15 cc capacity. The samples were molded in a single piston injection molding unit. The injection molding machine was a Xplore DSM 12 cc heating chamber, model Micro 12 cc IMM figure 5.2 with the following parameters:

-Set up mold temperature according to material specification and from previous process data, it was at 45°C
- Molding temperature at 190°C

The data of materials is shown in table 2.

Property	Pecan shell	Pine wood	HDPE
Tensile at yield	112n(rupture)	57.9MPa	26.7 MPa
Elastic Modulus	NA	8.9 GPa	0.75 GPa
Poisson Ratio	NA	0.38	0.46
Density(g/cm^3)	0.46	0.44	0.98

Table 2 Materials mechanical properties

Mechanical testing

All samples were stored in a zip plastic bag with proper identification of run number and material combination. The mechanical testing of tensile and flexural strength was made using the universal tester Instron machine model 5882 with Blu hill software for the data collection in CVS format. The machine was set up at 1mm/min speed head. Using the load data, tensile strength calculation was based on the general equation:

$$\sigma = \frac{F}{A} \quad (1)$$

Where σ= tensile stress, F= Force and A= Area of the section
The area was estimated from measuring the cross section of the sample Type V (dog bone shape) in the testing cross section area see figure 1.

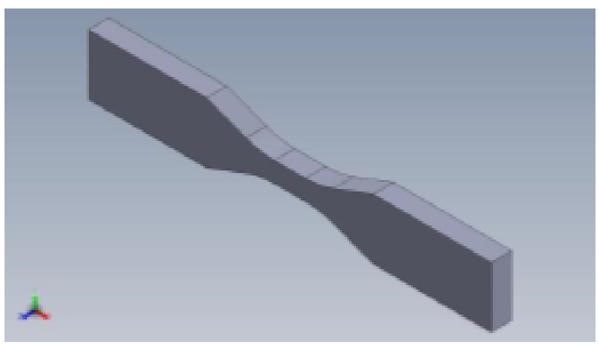

Figure 1. SolidWorks model based on ASTM 638-14 type V

The tensile testing was performed using ASTM 638-14 and the flexural testing was performed using the ASTM D790-03o determine. According to the standards a require minimum of 5 samples per run is needed to determine the tensile and flexural strength.

Results and Discussion

All samples were tested for tensile and flexural strength. Table 3 shows the Anova analysis results for tensile and flexural strength where shows the P values of pine wood and pecan shell with 60 and 80 mesh at two levels of % weight. Based in the results all factors are significant since P<.05. The values of P are very small which indicates a strong correlation in all factors. Also, the results indicate that interaction of factors is significant meaning that fiber vs. weight and particle size has different tensile and flexural strength. The samples row which are the fiber type had a significant effect on the response since pine wood data has higher values see figure 3. As results the interaction which P<0.05 also denotes that particle size for both fibers have significant effect on both strengths. Figure 2 chart shows the effect of the fiber type in the response, where the pine wood(w) have the highest tensile values compares to pecan shell (s). These results are similar in the analysis by (Neagu, Gamstedt, & Berthold, 2006) and others on different wood fiber had significant different mechanical properties.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	6312.667	8	789.0834	384.6743	4.08E-66	2.042986
Columns	402.5262	1	402.5262	196.2295	2.47E-24	3.946876
Interaction	310.4226	8	38.80283	18.91619	2.35E-16	2.042986
Within	184.6173	90	2.051303			
Total	7210.233	107				

Table 3 Anova Analysis of tensile and flexural strength.

However, the data of pecan Shell is not higher than HDPE values. This condition could be linked to a low interface strength between pecan shell and HDPE. Also, from (Maldas, Kokta, & Nizios, 1992) degradation may have occurred that caused poor bonding due the injection molding temperature. Never the less on pine samples shows that bonding mechanism may be stronger in the composite which the results are reflected in the tensile and flexural response.

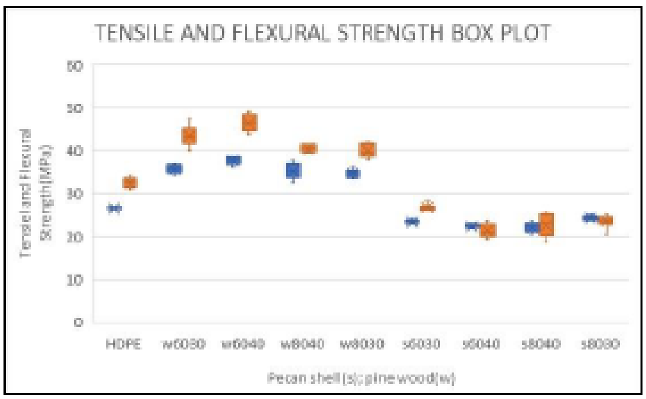

Figure 2. Comparison of strengths in response for pecan Shell(s) and Pine Wood(w)

From figure 3 the results of effect on both strength for the pine Wood are significant since at 40% weight response is higher for both particle size. These results have disagreement with (Cruz-Salgado & Dominguez-Dominguez, 2015) and (Mijiyawa et al. 2015) where they indicates that at 30% weigth value the strenght is higher.
In the other hand bigger particle size (mesh 60) shows a slightly higher value for both responses (tensile and flexural). This data is in some extent in agreement with results by (Stark & Berger, 1997) where maximum tensile was observe about .2 mm particle size.

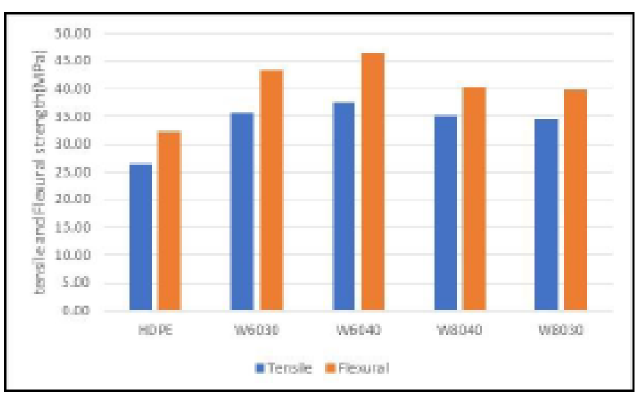

Figure 3. Effect of weight and particle size on pine wood

It is observed in figure 4 that fiber has a significant impact on both tensile and flexural strength values for the pecan shell. Additionally, the results of pecan Shell are in agreement to some extent with (Maldas, Kokta, & Nizios, 1992) for 30% weight in the strength response for both tensile and flexural which is higher. Also, the particle size effect has similar response as observed in the pine wood, bigger size has higher response in the strength(Stark & Berger, 1997). On table 4 the summary of both tensile and flexural strength and is observed that overall fiber type has significant effect on both responses of tensile and flexural strength. This implies that fiber has the higher impact.

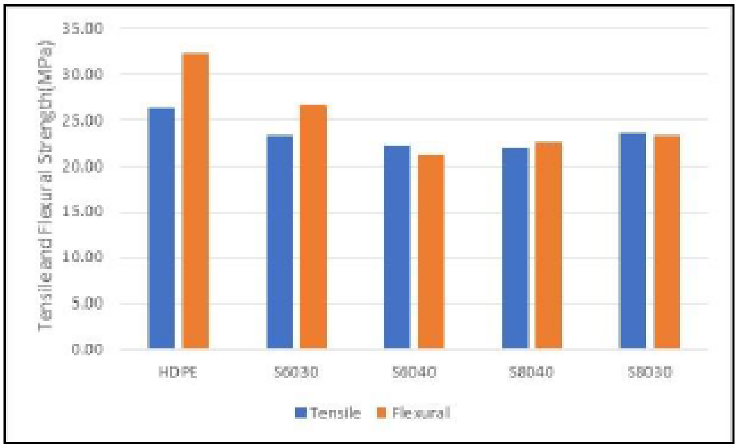

Figure 4. Effect of weight and particle size on tensile and flexural strength on pecan shell

Strength	HDPE	W6030	W6040	W8040	W8030
Tensile(Mpa)	26.45	35.69	37.60	35.18	34.59
Flexural(Mpa)	32.32	43.31	46.39	40.34	39.77
	HDPE	S6030	S6040	S8040	S8030
Tensile(Mpa)	26.45	23.37	22.34	22.06	23.63
Flexural(Mpa)	32.32	26.64	21.32	22.55	23.37

Table 4 Results of fiber and weight effect on tensile and flexural strength. Pecan shell(s) , pine(w).

Final comments

Summary of results

In this study was analyzed the response of two fibers in composites based in pine pecan shell and pine flour using statistical design. The study analyzed the effect of both particle size and fiber type. The statistical analysis provided an insight of the effect of weight and particle size in wood plastic composites with good statistical results. The Anova analysis gave significant results of P values and are small compared to $P<0.05$. However, with was observed that for pecan shell the response was not significantly better than HDPE base values. For the pine wood all values are higher than HDPE base values.

Conclusions

The results show that understand the bonding mechanism in wood plastic composites is necessary in order to improve the mechanical response. Is necessary to analyzed more in depth the particle size effect since bigger particle size had the higher response for both fibers. These results have impact on previous research since this data does not agree in some extent with some of that data. One factor that may be necessary to analyze is injection molding temperature since this factor may cause degradation on the fiber.

Recommendations

For those interested in composites with natural fibers will be recommended to investigate two factors: the particle size and for the injection molding temperature for a possible effect of degradation at the temperature that was used in this investigation.

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