The Effect of using the Flour of Kiwi (*Actinidia sp.*) Twigs and Refined Fibers in the Production of Polypropylene/Wood Plastic Composites

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This study uses a combination of wood flour, obtained from kiwi twigs, together with refined fibers and polypropylene material to make a hybrid composite of polypropylene/wood/fiber. The materials were mixed in a twin-screw extruder, and the samples were made *via* an injection molding method. The tensile, flexural, and impact strengths, as well as the physical characteristics were measured based on ASTM standards. The results indicated that when the flour dimensions were reduced from 20 mesh to 40 mesh, the tensile and flexural strength, tensile and flexural modulus, and elongation at break were reduced. The notched impact strength, water absorption, and thickness swelling during 2 h and 24 h of immersion in water, and the water absorption and thickness swelling during 2 h immersion in boiling water, increased. In addition, by increasing the amount of refined fiber instead of kiwi wood flour, the tensile and flexural strength, tensile and flexural modulus, elongation at break, and the notched impact strength were increased. The water absorption and thickness swelling during 24 h of immersion in water and the water absorption and thickness swelling during 2 h immersion in boiling water were decreased.

Keywords: Kiwi twig flour; Refined fibers; Tensile modulus; Notched impact strength

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INTRODUCTION

Wood plastic composites (WPCs) are a group of versatile materials, and their production has gained global attention. Currently, this material is used in the automobile, construction, and furniture industries. In production, a wide range of polymers has been used as the matrix or as fillers. In particular, lignocellulose (organic) material can be used either in the form of flour or fiber. Lignocellulosic materials are hydrophilic and polar according to their main components (cellulose, hemicellulose, and lignin), and polymers are hydrophobic and non-polar. Therefore, using these two materials in the production of WPCs can lead to the production of a new crop with similar advantages. This issue is highly related to the improvement of mixing conditions, compound formula, type, size, and structure of wood material, as well as the amount of adapter (Yang *et al*. 2006; Najafi *et al*. 2007). Fibers are relatively abundant and cheap with a low density and high ability to fill the gaps and give proper strength; they are recyclable and have a low thermal expansion. Meanwhile, fibers also have a low dimensional stability against moisture and they are corruptible against biological agents. In contrast, polymers are thermoplastic materials, which are hydrophobic and resistant to environmental damages (Liew *et al*. 2000; Fowler *et al*. 2006).

Lignocellulosic fillers are often used in the form of flours or fibers in the production of WPCs, and their type, amount, and dimensions can affect the final features of the product. Kiwi twigs from annual pruning can be a suitable source for producing natural lignocellulosic fibers that can be used in the production of WPCs. These wastes have been made from thin twigs with erratic shapes. The distribution manner of wood flour and wood fibers in the polymer matrix can affect WPCs physical and mechanical features (Le Baillif and Oksman 2009; Ghani and Ahmad 2011).

Wood steaming is one of the common methods for reducing water absorption and improving the dimensional stability of wood through reducing hydroxyl groups, as a result destroying the hemicelluloses (Li *et al*. 2007). Also, the dimensional stability of wood-based composites is an issue that industrial producers intend to improve by common treatments such as thermal treatment (Hosseinihashemi *et al*. 2016). In addition, this process can lead to better compatibility of lignocellulosic materials with the polymer matrix, as a result of the destruction of hemicelluloses and reduction of wood's hydrophilic features (Eslam and Samariha 2015). A thermal treatment is widely used to improve the features of lignocellulosic materials. Thermal treatments can increase dimensional stability and rot resistance, and can also reduce the water absorption and the equilibrium moisture content of wood (Enayati *et al*. 2009).

Brugnago *et al*. (2010) found that steaming at higher pressures is one of the common methods for analyzing lignocellulosic materials such as wood, to its three main components. This process eliminates the hemicelluloses and lignin of the fibers. The cellulose component leads to a high level of crystallization because it hydrolyzes the amorphous areas. Therefore, steaming leads to having better features in composites (Brugnago *et al*. 2010).

Based on the issues above, the purpose of the present study was to consider the use of the wood flour of kiwi wastes in two sizes at different levels, and also the addition of refined fiber at different levels to make a WPC.

EXPERIMENTAL

Materials

The fillers used in this study were particles of kiwi wood flour and refined fibers (wastes). The kiwi wood flour was used at four levels, 10 wt.%, 20 wt.%, 30 wt.%, and 40 wt.%. The dimensions of the kiwi wood flour were 20 mesh (+40/-20, and the distances between particles were 0.400 to 0.841 mm) and 40 mesh (+60/-40, and the distances between particles were 0.250 to 0.400 mm). The wood fibers of this study were provided from the refined wastes of Nashtarod Pars Neopan Co. (Tonkabon, Iran). Pieces of poplar wood were first transformed to chips. They were washed at atmospheric pressure and 20 °C temperature, then they were kept in atmospheric pressure and at 50 °C to 60 °C. Next, the chips were digested (Sund Co. Sweden) and conditioned under the temperature of 160 to 180 °C at a pressure of 5.5 to 7 bar, for 5 to 7 min in the presence of water vapor. Finally, the chips were refined (Sund Co., Sweden). To measure the slenderness ratio (ratio of length to diameter of the fibers), 300 fibers were selected and a laboratory microscope (Nikon eclipse 50i, Tokyo, Japan) equipped with an image analyzer was used.

In this study 60% polypropylene from Petrochemical Co. (Bandar Imam, Mahshar, Iran) was used with a melt flow index of 7 to 10 g/10 min at 190 °C as the polymer matrix. Maleic anhydride polypropylene (MAPP) of Eastman Chemical Products Inc. (Tennessee, USA) was used as an adapter between the fillers and polymer material with a molecular weight of 52,000, a melt point of 158 °C, and a melt flow index of 64 g/10 min.

Methods

Composition of material mixture

Table 1 shows the manner for making the polypropylene/kiwi wood flour/refined fibers composite. Before mixing, the kiwi wood flour and refined fibers were put in an oven for 24 h at 75 °C. A twin-screw extruder (GmbH Company, Ebersberg, Germany) was used to mix the materials at 5 temperature points, 170, 175, 180, 185, and 190 °C, and a rounding speed of 60 rpm. The mixture was transformed into granules by a semi-industrial chipper and was put in the oven for 12 h.

Table 1. Mixture Manner for Making the Composite

Treatment Code	PP (%)	WF (%)	F (%)	MAPP (%)	Mesh (Size)
40WF/0F/20	60	40	0	3	20
40WF/0F/40	60	40	0	3	40
30WF/10F/20	60	30	10	3	20
30WF/10F/40	60	30	10	3	40
20WF/20F/20	60	20	20	3	20
20WF/20F/40	60	20	20	3	40
10WF/30F/20	60	10	30	3	20
10WF/30F/40	60	10	30	3	40
PP= Polypropylene WF = Wood Flour F= Refined Fiber					

The samples for the mechanical testing were made by a semi-industrial injection molding method, using equipment model MPC-40 (cylinder temperature 150, 155, and 160 °C, injection pressure 80 bar) supplied from Aslanian Co. (Tehran, Iran). The samples were also prepared for the tensile and flexural strength, notched impact strength, and water absorption tests. Before performing the physical and mechanical tests, the samples were kept in controlled conditions for two weeks to reach equilibrium moisture, at a temperature 20 °C ± 2 °C and a relative moisture of 65% ± 5%. For the tensile, flexural, and notched impact strength tests, and the water absorption and short term swelling tests relating to the physical features, ASTM D-638-10 (2010), ASTM D-790-10 (2010), ASTM D-256-10 (2010), and ASTM D-7031-04 (2004) standards were used, respectively.

For each treatment level, three replicates were measured for each property, and the average values are reported.

Statistical analysis

With relation to the variable factors and their levels, the composite samples were made completely randomly. Comparison and classification were implemented using the Duncan Multiple Range Test at a 95% confidence level. To perform a data analysis, SPSS statistical software (IBM Software, Armonk, NY, USA; version 11.5) was used.

RESULTS AND DISCUSSION

Figure 1 illustrates the relative frequency of the refined fibers' slenderness ratio, which follows a normal distribution with a proper approximation.

Statistical Analysis

The *F* and *p*-values are shown in Table 2. The independent effect of the mixture ratio (WF + F) on the flexural modulus, notched impact strength, the independent effect of mesh size on the strength and also notched impact strength were significant in 95% level, as well as the interaction effect of mixture ratio (WF + F) materials and particle size on tensile modulus. The independent effect of the mixture ratio (wood flour + fiber) and mesh size on the tensile strength and modulus, elongation at break, and flexural strength, as well as the interaction effect of mixture ratio (WF + F) materials and mesh size on the tensile strength and modulus, elongation at break, flexural modulus, and notched impact strength were found not to be significant at a 95% level.

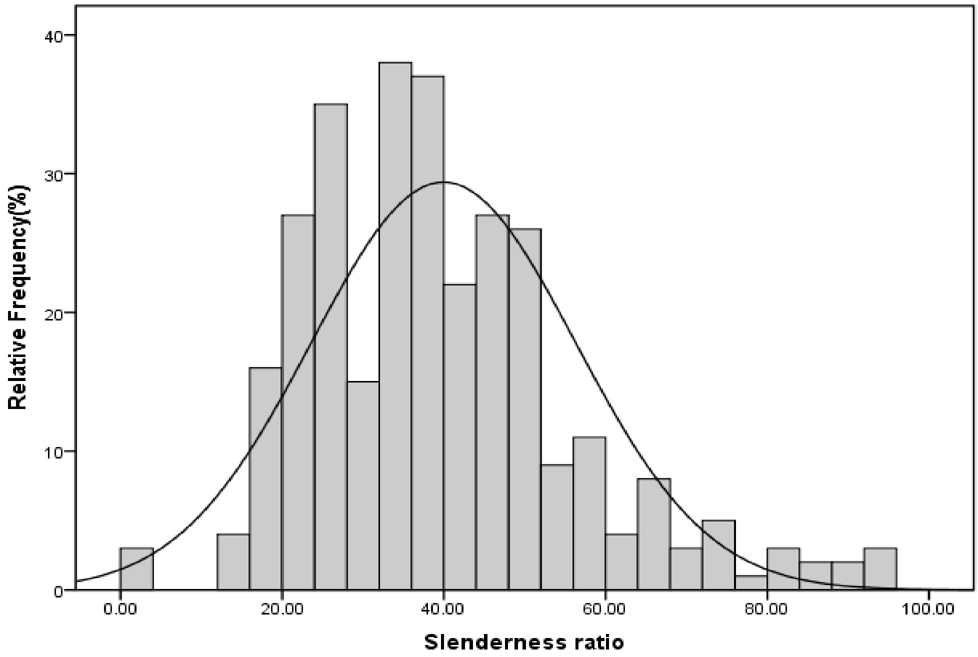

Fig. 1. Relative frequency of refined fibers' slenderness ratio

Table 2. Variance Analysis (*F*- and *p*-values) of under Consideration Factors

Variable Features	Tensile Strength (MPa)	Tensile Modulus (MPa)	Elongation at Break (%)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Impact Strength (J/m)
Mixture Ratio (WF + F)	0.543 ns	0.249 ns	1.548 ns	4.187 *	2.577 ns	45.545 *
Kiwi wood flour size	3.598 ns	1.551 ns	0.191 ns	4.349 ns	10.860 *	34.180 *
Mixture Ratio + Kiwi wood flour size	2.416 ns	4.005 *	0.890 ns	2.59 ns	0.394 ns	0.371 ns

Significance level: 95%*, ns- non-significant

Generally, the physical and mechanical features of WPCs are affected by their component's features, the quality of intersection between polymer mixtures, between the polymer matrix and lignocellulosic material, as well as the process conditions (Adhikary *et al*. 2011).

Tensile Modulus

Figure 2 shows that the composite's tensile modulus was 10% more than that of the polymer matrix tensile modulus, while Fig. 3 indicates a 81.8% enhancement of the composite's flexural modulus compared to the polymer matrix. Thus, the addition of wooden material, *i.e.*, kiwi wood flour, fibers, or their mixture, can improve both the tensile and flexural modulus.

A composite's flexural and tensile moduli are affected by their components' modulus. Therefore, using natural fibers in the polymer matrix can enhance its modulus (Febrianto *et al*. 2006; Razavi-Nouri *et al*. 2006). Because cellulose materials have a relatively high modulus, they can improve the composites tensile and flexural modulus (Oksman and Clemons 1998).

The addition of a lignocellulose discontinuous phase to a polymer continuous phase has changed the nature of material from a plastic to an elastic hybrid composite. This feature can be attributed to the elastic characteristics of particles or refined fibers. This finding is in line with the findings of various studies this issue (Li *et al*. 2001; Jayaraman and Bhattacharyya 2004; Chaharmahali *et al*. 2008).

Moreover, the results showed that the enhancement and substitution of refined fibers in the mixture with kiwi wood flour can increase the tensile and flexural modulus. In addition, composites that are the results of larger wood flour (20 mesh) have had a higher modulus.

A higher modulus can be attributed to an efficient mixture of wood flour with refined fibers. The use of wood flour, which has a larger slenderness ratio than wood flour particles, can improve a composites' flexural and tensile moduli; this indicates the potential positive role of these materials (Migneault *et al*. 2008). Refined fibers possess an even better strengthening effect due to their higher slenderness ratio.

The addition of refined fibers to the flour form mostly plays a filling role and improves some of the mechanical features. However, addition of more refined fiber plays filler role and improves some mechanical features; but refined fibers have higher boosting role because of their significant slenderness ratio or tensile coefficient. Furthermore, they create more contact surfaces in both the continuous and discontinuous phase of intersection. This can lead to more joints in the presence of the coupling factor and enhance the strength features, such as the flexural and tensile modulus (Stark and Rowlands 2007).

With the addition of fibers to wood flour, or the complete substitution with flour, it can increase the tensile modulus relatively, and larger flour particles (20 mesh) have produced a higher modulus in composites. This is in line with findings from previous studies on this issue (Chen *et al*. 2006).

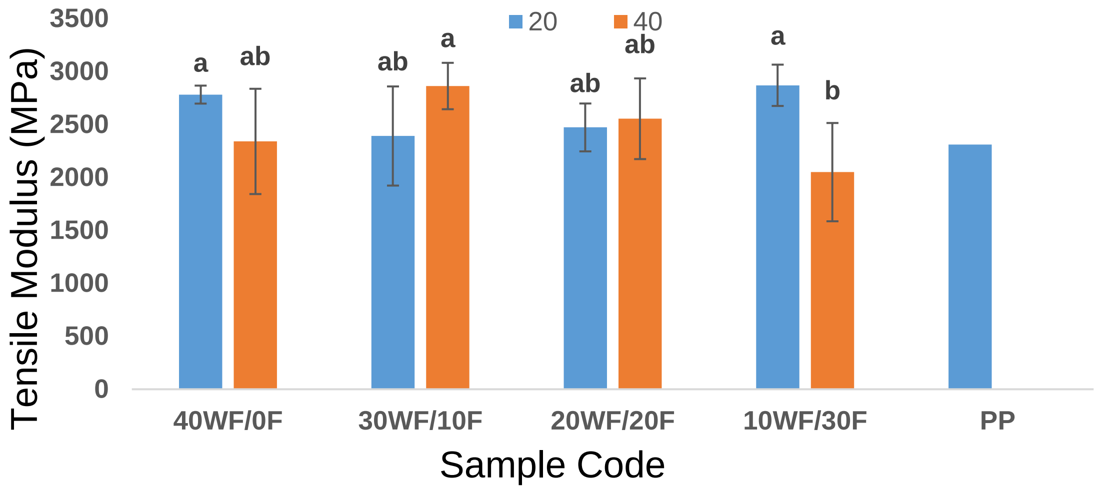

Fig. 2. The effect of the mixing ratio of mixture ratio (WF + F) and mesh size on the tensile modulus (small letters indicate Duncan ranking of the average values at a confidence interval of 95%)

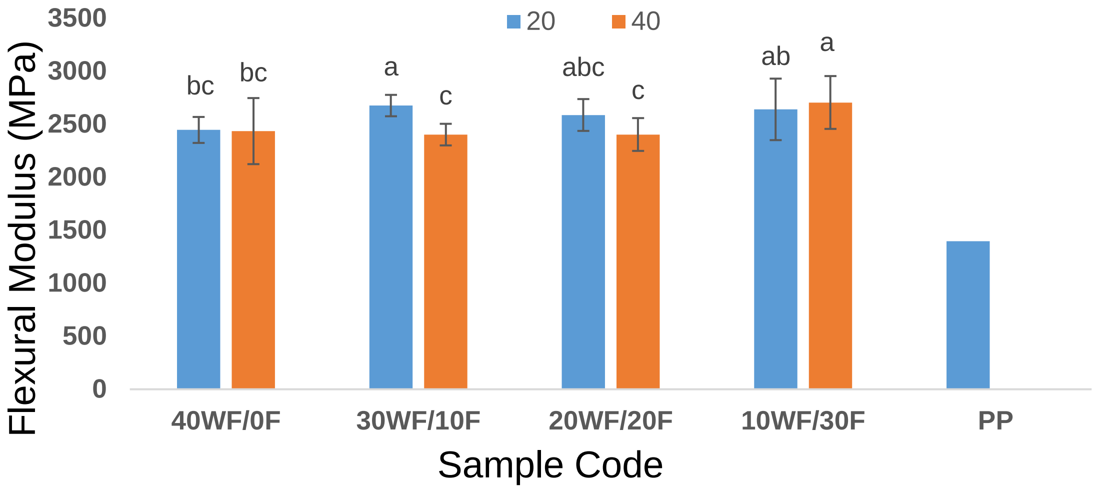

Fig. 3. The effect of the mixing ratio of mixture ratio (WF + F) and mesh size on the flexural modulus (small letters indicate Duncan ranking of the average values at a confidence interval of 95%)

Tensile Strength

The tensile strength of the polypropylene matrix was more than that of the composites, implying that the addition of flour and refined fibers can weaken the polymer matrix (Fig. 4). Lignocellulosic materials have a polar nature and they tend to adhere together when they are mixed with a non-polar matrix; therefore, they do not have a homogeneous distribution. Due to this and a weak adherence in the intersections, the tensile strength of WPCs has been observed to decrease (Le Baillif and Oksman 2009; Ghani and Ahmad 2011). In addition, the enhancement and substitution of wood fibers instead of kiwi wood flour increased the composites' tensile strength. Moreover, composites composed of wood flour of 20 mesh exhibited higher tensile strength in comparison with composites prepared with 40-mesh flour.

Better transference of stress from polymer to fiber and enhancement of composites' strength has been attributed to a higher slenderness ratio and higher fiber sets strength. It is claimed that this feature can transfer huge amounts of stresses from the polymer to the fiber, and it can increase the composites' strength (Hemmasi *et al*. 2013).

In this study the findings of present study are in line with the findings of Lai *et al*. (2005), where it was claimed that the reason of such a phenomenon is because of the effect of fewer intersections between the polymer and filler, while some researchers claim that the enhancement of the tensile strength during a reduction of flour size occurs because of the increase of contact surfaces (Nourbakhsh *et al*. 2010).

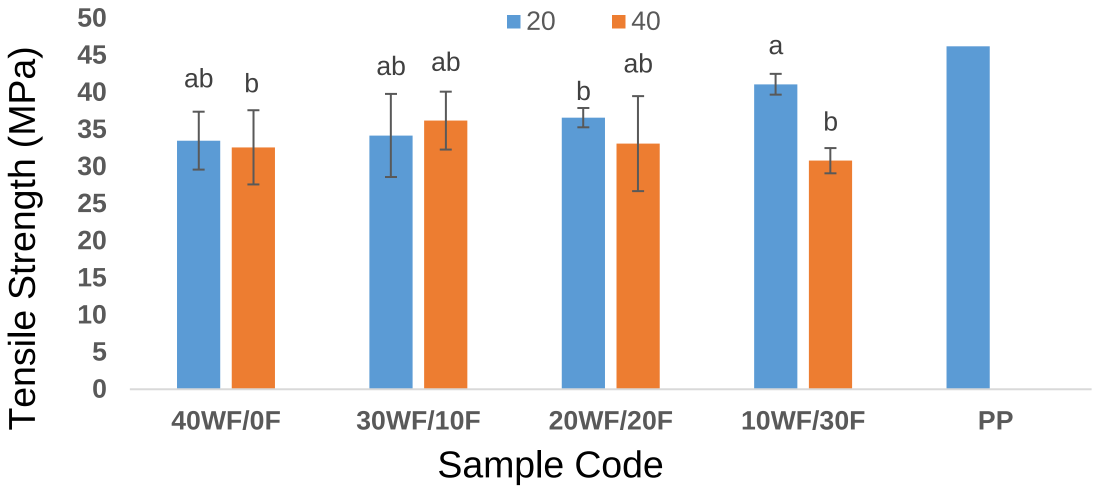

Fig. 4. The effect of the mixing ratio of mixture ratio (WF + F) and mesh size on the tensile strength (small letters indicate Duncan ranking of the average values at a confidence interval of 95%)

Flexural Strength

In flexural testing, under the entered force, one side of the sample has been extended and the other side has been pressed. Therefore, the two factors of distribution levels and fibers' wetting have affected this feature (Gao *et al*. 2008).

The flexural strength of composites that are the result of different combination ratios of refined fiber/flour is higher than that of the polymer material, *i.e.* the addition of a lignocellulosic filler can increase flexural strength.

Composites' flexural strengths that are the result of a wood flour of 20-mesh size are higher than that of the composites of 40-mesh particles. The results indicated that the flexural strength of studied composites were about 60% higher than that of poly propylene composites. Flexural strength in composites were reduced by increasing the amount of refined fibers and reducing wood flour ratios (Fig. 5).

In fact, a better distribution and homogeneity of fibers across the polymer matrix, the enhancement of interaction between lignocellulosic material and polymer matrix, and finally the enhancement of composites tolerated have increased the overall flexural strength. Similar results have been obtained by Balasuriya *et al*. (2001) and Gao *et al*. (2008).

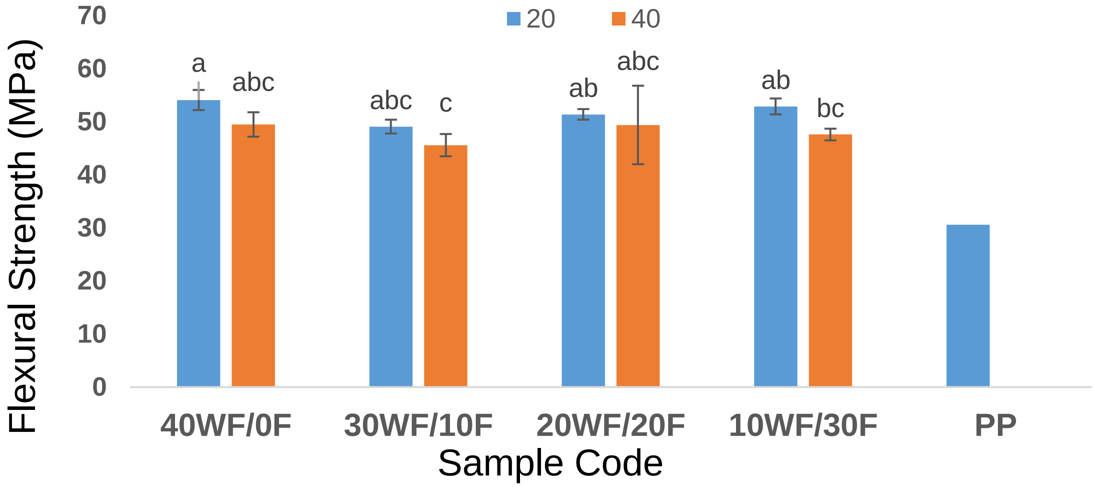

Fig. 5. The effect of the mixing ratio of mixture ratio (WF + F) and mesh size on the flexural strength (small letters indicate Duncan ranking of the average values at a confidence interval of 95%)

Elongation at Break

According to Fig. 6, the elongation at break of the composites was remarkably less than that of the polymer matrix. This means that the presence of wooden material as a filler can change the nature of the polymer matrix from a plastic form to a new nature in composites.

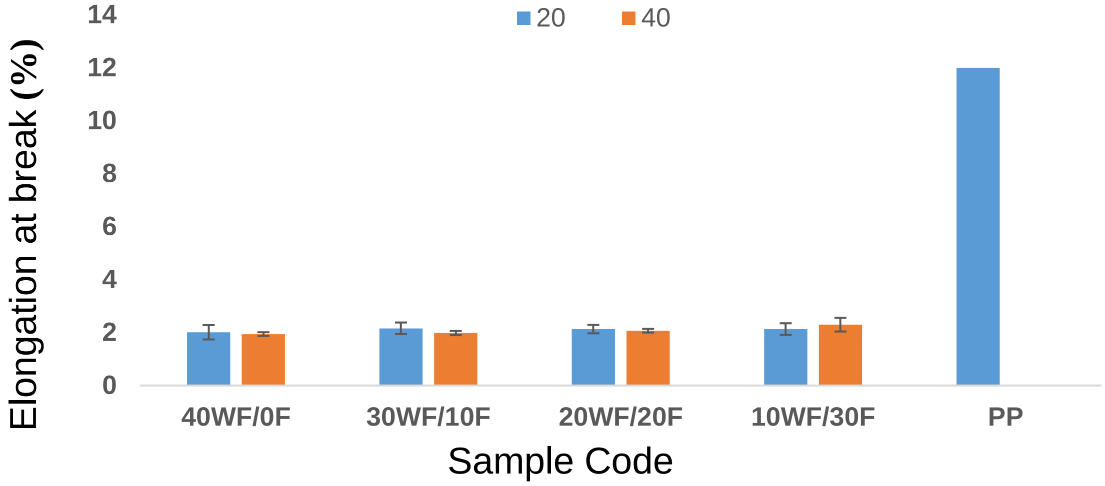

Fig. 6. The effect of the mixing ratio of mixture ratio (WF + F) and mesh size on the elongation at break

Impact Strength

Figure 7 shows the results of the impact strength testing of samples and the polymer matrix. The addition of a wooden material (wood flour, fiber, or their combination) to the polymer matrix greatly weakened the strength of this material against impact. The substitution of a refined fiber instead of kiwi wood flour was found to potentially improve impact strength, gradually.

The smaller particles of wood flour had more impact strength. This phenomenon happens through the better transference of stress effect by smaller particles, *i.e.* smaller particles are able to produce more collaborative environment and can tolerate more stress than larger particles. However, perhaps, larger particles act as a factor for focusing stress and creating places for primary cracks, which can easily cause composite breakage. In addition, shorter fibers (smaller particles) are higher in frequency, so they have more special levels, more homogeneous distribution, and more compatibility between the matrix and the fiber (Caraschi and Leão 2002).

Regarding the impact strength results, the mean of the impact strength was 1/4 that of the polymer matrix. In contrast, using a lignocellulosic filler caused that malleable polymer to transform into a fragile composite.

Longer fibers toughness increased and the impact strength decreased. The refined fibers caused that composite behavior to change from malleable to fragile (Ghasemi *et al.* 2008). Thus, the improvement of fiber composites' features happens more noticeably than in wood flour composites.

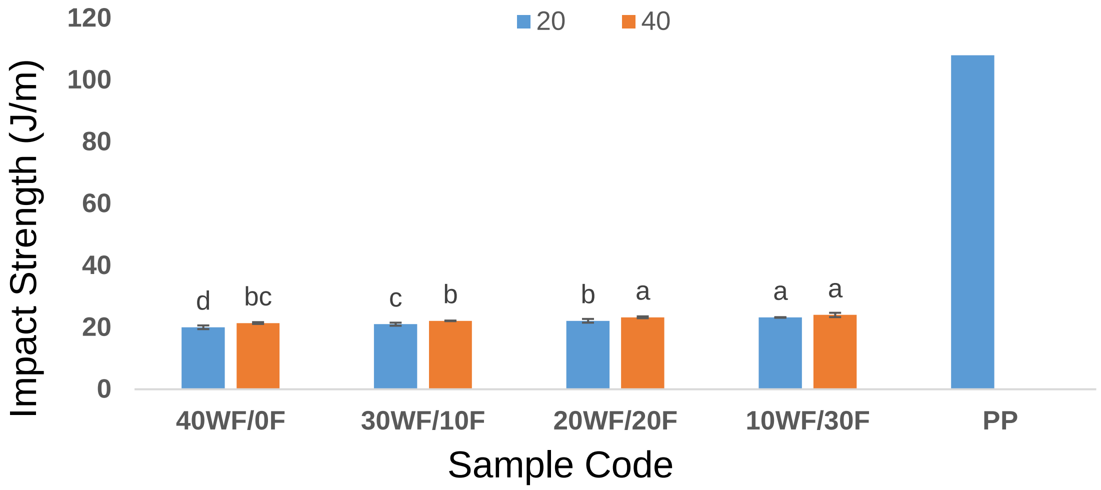

Fig. 7. The effect of the combination ratio of mixture ratio (WF + F) and mesh size on the impact strength (small letters indicate Duncan ranking of the average values at a confidence interval of 95%)

Physical Features

Lignocellulose materials (flour or refined fiber) tend to absorb water and they will have a higher swelling dimension. Therefore, because this product may be used under different conditions of temperature and moisture, short term and long term, measurements of such features can lead to useful results for recognizing characteristics and optimizing future application.

The composite’s behavior was evaluated in relation to water (short term), and this behavior was compared in relation to common temperatures and at the temperature of boiling water. To do so, the samples were kept for 2 h and 24 h immersed in water, and for 2 h immersed in boiling water. Then the relative amount of water absorbed by the samples and their thickness swelling were measured.

Water Absorption and Thickness Swelling

As shown in Table 3, the water absorption and thickness swelling of the composites, which are made of different ratios of wood flour/fiber, was very slight. However, the increase of immersion time to 24 h, this quantity increased gradually. Meanwhile, with the substitution of refined fiber instead of wood flour, a reduced water absorption amount of composite was visible. The sample’s immersion in boiling water significantly increased its water absorption and thickness swelling; but, in these conditions, the addition and substitution of fiber instead of wood flour limited the water absorption and thickness swelling. Processing the refined fibers at the preparation stage faced with water vapor in higher temperatures can eliminate some of the moisture absorbing material (Fowler *et al*. 2006). This reduced the absorption tendency of the composites. The reduction of hydroxyl groups and fiber hydrophilic characteristics has been proved in thermal-humidity treatments (Tjeerdsma and Militz 2005).

The destruction of hydroxyl groups of hemicellulose reduced their hydrophilic nature, so the reduction of this feature in wood flour caused better compatibility with the polymer. As steaming eliminates the hydroxyl groups, the water absorption and thickness swelling were reduced (Eslam and Samariha 2015).

With relation to the effect of the mesh size, it can be said that although the composites' water absorption after 2 h of immersion was negligible, using smaller particles of wood flour caused an increase in the water absorption capability. An increase in the immersion time to 24 h and the immersion in boiling water increased the water absorption capability, while the differences between the composites water absorption of wood flour with two different mesh sizes was reduced significantly (Table 3). The smaller particles have higher specific levels and an increased possibility of moisture accessibility, which increased their water absorption level and thickness swelling. Migneault *et al*. (2008) claimed that increases in water absorption and thickness swelling occur as a result of the reduction of dimension. They said that this is due to the increase in the number of smaller particles per volume unit.

Table 3. Results of Water Absorption and Thickness Swelling (%)

Treatment Code	Water Absorption (2 h)	Water Absorption (24 h)	Boiling Water Absorption (2 h)	Thickness Swelling (2 h)	Thickness Swelling (24 h)	Boiling Thickness Swelling (2 h)
40WF/0F/20	0.04	0.1	1.22	0.02	0.14	0.89
40WF/0F/40	0	0.03	0.9	0.04	0.13	0.86
30WF/10F/20	0	0	0.77	0.04	0.16	0.9
30WF/10F/40	0	0	0.98	0.02	0.16	0.84
20WF/20F/20	0	0.03	0.6	0.04	0.13	0.8
20WF/20F/40	0.05	0.1	0.73	0.05	0.13	1.01
10WF/30F/20	0	0.03	0.82	0	0.09	0.88
10WF/30F/40	0.04	0.06	0.82	0.06	0.14	0.79

CONCLUSIONS

1. When the flour dimensions were reduced from 20 mesh to 40 mesh, the tensile and flexural strength, tensile and flexural modulus, and the elongation at break were reduced.
2. When the flour dimensions were reduced from 20 mesh to 40 mesh, the notched impact strength increased.
3. The increase in the refined fiber amount, more so than the amount of kiwi wood flour, led to an increase in the tensile and flexural strength, tensile and flexural modulus, elongation at break, and the notched impact strength.
4. When the flour dimensions were decreased from 20 mesh to 40 mesh, the water absorption and thickness swelling increased during 2 h and 24 h of immersion in water; and the water absorption and thickness swelling increased during 2 h of immersion in boiling water.
5. The increase in the fiber amount over the kiwi wood flour decreased the water absorption and thickness swelling during 2 h and 24 h of immersion in water, and decreased the water absorption and thickness swelling during 2 h of immersion in boiling water.

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