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Some Properties of Wood Plastic Composites Made from Rubberwood, Recycled Plastic and Silica

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Abstract: The objective of this work was to evaluate some of the properties of experimental wood plastic composite (WPC) panels manufactured from a low percentage of rubberwood (*Hevea brasiliensis* Muell. Arg), waste polyethylene terephthalate (PET) and silica at three different ratios. It was determined that water absorption values of the samples decreased with the increasing amount of PET in the panels. The lowest absorption value of 0.34% was determined for the samples having 40% PET in their content as a result of 24-h soaking. The highest hardness value of 4492 N was found for the samples made with the combination of rubberwood, PET and silica at 10%, 40% and 50%, respectively. The compressive strength of WPC specimens also followed a similar trend with the hardness characteristics of the panel and improved with increasing PET percentage. Statistical analyses revealed that values of compression strength, hardness, 2-h and 24-h water absorption of the specimens made with 20, 30, and 40% PET content resulted in significant difference from each other ($p \leq 0.0001$). Based on the findings in this study it appears that increasing silica content in the samples adversely influenced their mechanical properties while creating a certain level of enhancement of water absorption of the specimens. It seems that using a combination of waste PET and a limited amount of silica with a low percentage of wood particles could have the potential to produce value-added environmentally friendly composites to be used for different applications.

Keywords: wood plastic composite; rubberwood; polyethylene terephthalate; silica

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1. Introduction

Wood-plastic composite (WPCs) are panel or lumber products made from recycled plastic and small wood particles or fibers being low-carbon and environmentally friendly value-added material. Wood plastic composites are relatively new as compared to the long history of natural lumber or traditional wood composites such as particleboard or fiberboard. They are manufactured by mixing wood particles as fine flour and recycled plastics to be used for indoor and outdoor applications in the U.S. and many Asian countries. Due to the ncreasing demand for WPC, new products are being developed such as door stiles, rails, and window lineal.A typical manufacturing process of WPC involves a combination of wood and thermoplastic, such as high-density polyethylene (HDPE), low-density polyethylene (LDPE), and polyvinyl chloride (PVC), which are mixed into a dough-like-consistency, called compounding. Mixing can be carried out by either batch or

continuous process. In addition to the main ingredient, which is wood with a grain size ranging from 20 to 60 mesh, plastic coupling agents, stabilizers, foaming agents or dyes are also added to enhance the properties of the final product for specific use, including window and stair rails [1–5].

Wood-plastic composites have satisfactory strength properties as well as excellent hydrophobic characteristics, which prevent water and entrapping air onto its surface, so they are ideal products for outdoor applications [6].

Globally, 6–7 billion tons of plastic wastes have been produced per year in the form of different materials such as disposed of polythene bags, single-use face masks, cups, and water bottles [7]. Polyethylene terephthalate (PET) is a widely used synthetic plastic that is polymerized by terephthalic acid (TPA) and ethylene glycol (EG) [8]. It has become an indispensable part of daily life since disposable plastic bottles were initially made in the 20th century [9]. Currently, the main methods used to manage and eliminate PET waste include landfilling, incineration, as well as physical and chemical recycling [10]. Some of the initial studies investigated the panels manufactured using PET as a partial substitute for sand in concrete [11,12]. Additionally, recent studies investigated the potential of PET to be used as a raw material in WPC production [13,14]. Additional works also evaluated the characteristics of WPCs manufactured from different wood species by the flat platen pressing process [15,16].

Rubberwood (*Hevea brasiliensis* Muell. Arg) is grown in tropical forest zones in the form of plantations and plays a significant role in the economy in Southeast Asian counties. Wood is comparable to oak, containing an amount of cellulose, hemicellulose and lignin with approximate values of 38–40%, 28–31% and 21–24%, respectively [17]. Rubbertree represents a renewable and environmentally friendly material and, typically, any tree that is over 7 years old can produce latex until it reaches 30 years. Nonproductive trees are mainly used for furniture production and wood-based panels including particleboard and fiberboard in Thailand [18,19].

In a previous study carried out by Ramesh et al. different aspects of wood based polymer composites were reviewed and the use of various additives to improve the overall properties, including mositure resistance and bonding strength of the experimental samples was emphasized [20]. The characteristics of wood plastic composites manufactured from pecan orchard waste were also investigated in a study, determining that increasing the amount of pecan flour in the panels increased their tensile properties [21]. Along this line, the dimensional stability and mechanical properties of WPC panels have been improved with different approaches including acetylation, silane treatment, and thermal treatment of wood particles [22–25]. Application of different materials as fillers, such as silica, would also be considered an alternative method within the perspective of these approaches [25]. It is a well-known fact that silica is one of the most abundant available materials with a low cost. It has been used as fillers in the manufacturing of WPCs in past studies [24–26].

It is a fact that waste plastic material is a major problem, creating an adverse influence on the environment. Therefore, it is vital to reduce, reuse, and recycle such waste resources so that they can be managed effectively and efficiently. Scientists have been searching for innovative and sustainable approaches to reuse and recycle plastic wastes to reduce their negative impact on the environment [27]. It is a well accepted fact that manufacturing value-added composite from waste plastic would be considered as one of these approaches. There are past studies that have investigated the properties of WPCs manufactured from different wood species, including rubberwood [28–32]. However, there is almost none or very limited information on the properties of experimental panels with a combination of rubberwood particles, recycled plastic and silica.

Therefore, the main objective of this work is to manufacture experimental panels from such combinations and determine their basic properties to understand how this material can be used with better effectiveness for different applications.

2. Materials and Methods

Commercially produced rubberwood (*Hevea brasiliensis* Muell. Arg) sawdust supplied by BNS Wood Industry Co., Ltd. In Surat Thani, Thailand, was used to produce the samples. Sawdust was classified into particle size on 18–40 mesh screen. Polyethylene terephthalate (PET) from plastic bottom waste was provided and shredded, employing a hammermill manufactured by Wagner Inc, in Austria into small particles. Silica with 18–40 mesh size was bought from Huatanon Co., Ltd., Kanchanadit, Surat Thani province, Thailand. Initially, both rubberwood particles and silica were dried at a temperature of 102 ± 3 °C for 24 h before the mixing process was carried out.

2.1. Manufacturing of the WPC Samples

The WPC samples were manufactured based on three different composition ratios of rubberwood, PET, and silica by weight, as displayed in Table 1. All materials were mixed in a laboratory-type reactor (PSU, Songkhla, Thailand) heated at a temperature of 180 °C and manually stirred for 5–10 min until becoming a homogeneous compound. In the next step it was transfored into a square frame of 300 mm by 300 mm in 5 mm thickness. Each mat was compressed using a pressure of 5.5 MPa at a temperature of 180 °C for 10 min in a computer-controlled press, Chareon Tut Co., Ltd., Bang Phli, Thailand. Afterward, the panels were cooled off for 20 min until they were formed and cured completely. Later, the panels were conditioned in a controlled room having a temperature of 25 ± 2 °C and relative humidity of 65 ± 2% for a week before the samples were cut for different tests. An average target panel density was 1.46 g/cm^3.

Table 1. The composition of WPC samples.

Sample Type	Rubberwood (%*w*/*w*)	PET (%*w*/*w*)	Silica (%*w*/*w*)
WPC-1	10	20	70
WPC-2	10	30	60
WPC-3	10	40	50

2.2. Water Absorption Test of the Samples

The water absorption test (WA) was carried out according to ASTM D1037-12 standard [33]. A total of nine specimens with dimensions of 50 mm by 50 mm by 15 mm from each type of panel were cut using a bandsaw for the tests. At the end of the 2-h and 24-h tests, the specimens were taken out from the water and all surface water was removed by wiping before they were weighed at an accuracy of 0.01 g.

2.3. Janka Hardness Test of the Samples

The Universal Testing Machine, Tinius Olsen, Series,100KU (Redhill, UK) was employed for the Janka hardness test. The ASTM standard [33] was applied. A total of 10 samples with dimensions of 50 mm by 50 mm by 15 mm from each panel type were used. The samples were embedded by a hemisphere steel having 11.2 mm diameter on their surface as depicted in Figure 1.

2.4. Compressive Strength Test of the Samples

The compressive strength test of the samples was carried out on the Automatic Compression Testing Machine, TTR-D 080G Series: KC-2000 based on ASTM C109/C109M-02 standard [34].

A total of 10 samples with the dimensions of 50 mm by 50 mm by 50 mm from each panel type were considered for the compression test. The compressive strength of each specimen was determined based on the equation below:

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

where CS is the compressive strength (N/mm^2), F is the maximum force or load (N) at the point of failure and A is the initial cross-section surface area (mm^2).



Figure 1. Hardness test of the samples.

2.5. Micrographs by SEM

Three samples of 5 mm by 10 mm by 6 mm were cut from each type of WPC panel for microscopic evaluation. The samples were coated with a thin gold layer before micrographs were taken on a scanning electron microscope (SEM), FEI Quanta 250.

2.6. Processing of Data

Analysis of variance (ANOVA) was used to evaluate the significant differences among the three types of WPC specimens by using XLSAT in Microsoft Excel 365® (Microsoft, Redmond, WA, USA). A confidence level of the p-value = 0.05 was considered as displayed in Table 2.

Table 2. Statistical analysis of the tests.

Analysis of Variance (Compressive Strength)					
Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	2	113.740	56.870	159.948	**<0.0001**
Error	6	2.133	0.356		
Corrected Total	8	115.874			
Analysis of Variance (Hardness)					
Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	2	11,907,613.333	5,953,806.667	7.861	**0.007**
Error	12	9,088,480.000	757,373.333		
Corrected Total	14	20,996,093.333			
Analysis of Variance (2 h WA):					
Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	2	11.074	5.537	705.830	**<0.0001**
Error	6	0.047	0.008		
Corrected Total	8	11.121			
Analysis of Variance (24 h WA):					
Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	2	24.150	12.075	158.278	**<0.0001**
Error	6	0.458	0.076		
Corrected Total	8	24.607			

3. Results and Discussion

3.1. Water Absorption of the Samples

Table 3 displays the results of water absorption characteristics of the samples.

Table 3. Water absorption values of the samples.

Samples Type	Water Absorption (%)	
	2-h Soaking	24-h Soaking
WPC-1	2.76 (0.08) *	4.28 (0.42)
WPC-2	1.28 (0.13)	1.68 (0.19
WPC-3	0.05 (0.02)	0.34 (0.14)

* Numbers in parentheses are standard deviation values.

Figure 2 also illustrates the images taken of surface of the water-soaked samples for 24 h by a single lens reflex digital camera. Panels with 40% PET and 50% silica along 10% rubberwood particles had the lowest water absorption values of 0.05% and 0.34% for 2-h and 24-h exposure, respectively. The corresponding findings were 1.28% and 1.68% for WPC-2 type panels manufactured with a 30%/60% PET and silica combination. The ANOVA of samples showed that the values are significantly different from each other ($p \leq 0.0001$). It appears that having higher silica content in the panels significantly enhanced their water absorption resistance. In addition, excellent water resistance of any kind of plastic-based materials is a well-known fact. In a previous study, experimental WPCs manufactured from eastern red cedar and polypropylene had improved dimensional stability when polypropylene content was increased in the samples [35]. Silica is widely used, where special applications for moisture resistance are desired. In the case of sample type WPC-3 with 40% PET and 50% silica increased the water resistance of the samples. Of course, using a relatively low amount of only 10% rubberwood with poor dimensional stability as compared to that of both PET and silica did not contribute to any substantial adverse effect in water absorption of the samples. Panel type WPC-1 manufactured with 20% PET and 70% silica had poor water resistance values. Such finding could be related to increased porosity due to gaps created using a large amount of silica content resulting in more void volume to attract water.

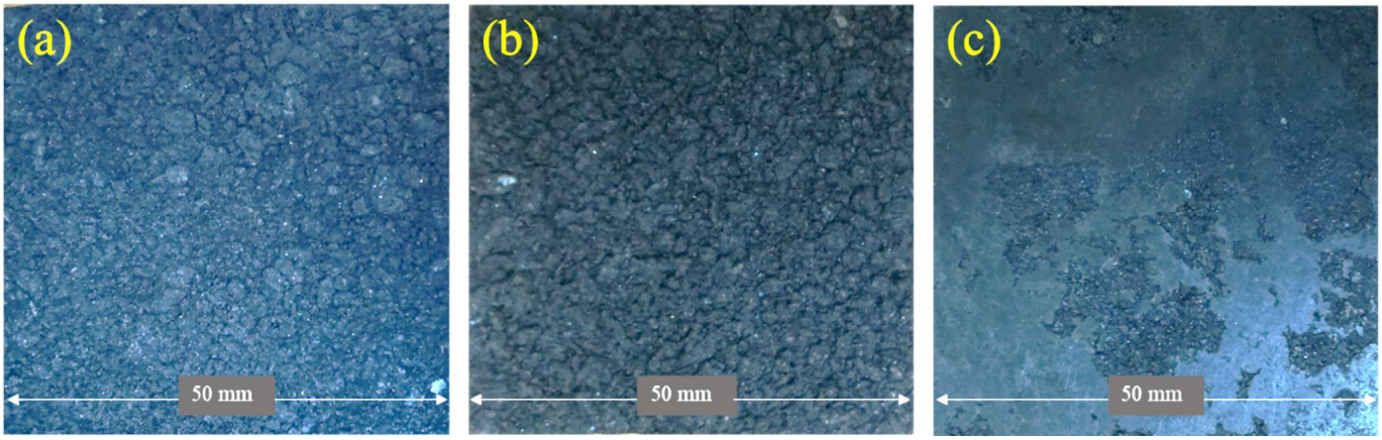


Figure 2. Surface of the water-soaked samples for 24-h: (**a**) WPC-1, (**b**) WPC-2, (**c**) WPC-3.

One should note that all three types of samples still had far better water absorption values that any other types of traditional wood composites such as particleboard or fiberboard.

In two previous studies, typical water absorption values for 24-h water soaking were found, ranging from 24.9% to 55.2% for particleboard and 25% to 30% for medium density

fiberboard [36,37]. Figure 3 also illustrates the water absorption values of the three types of panels.

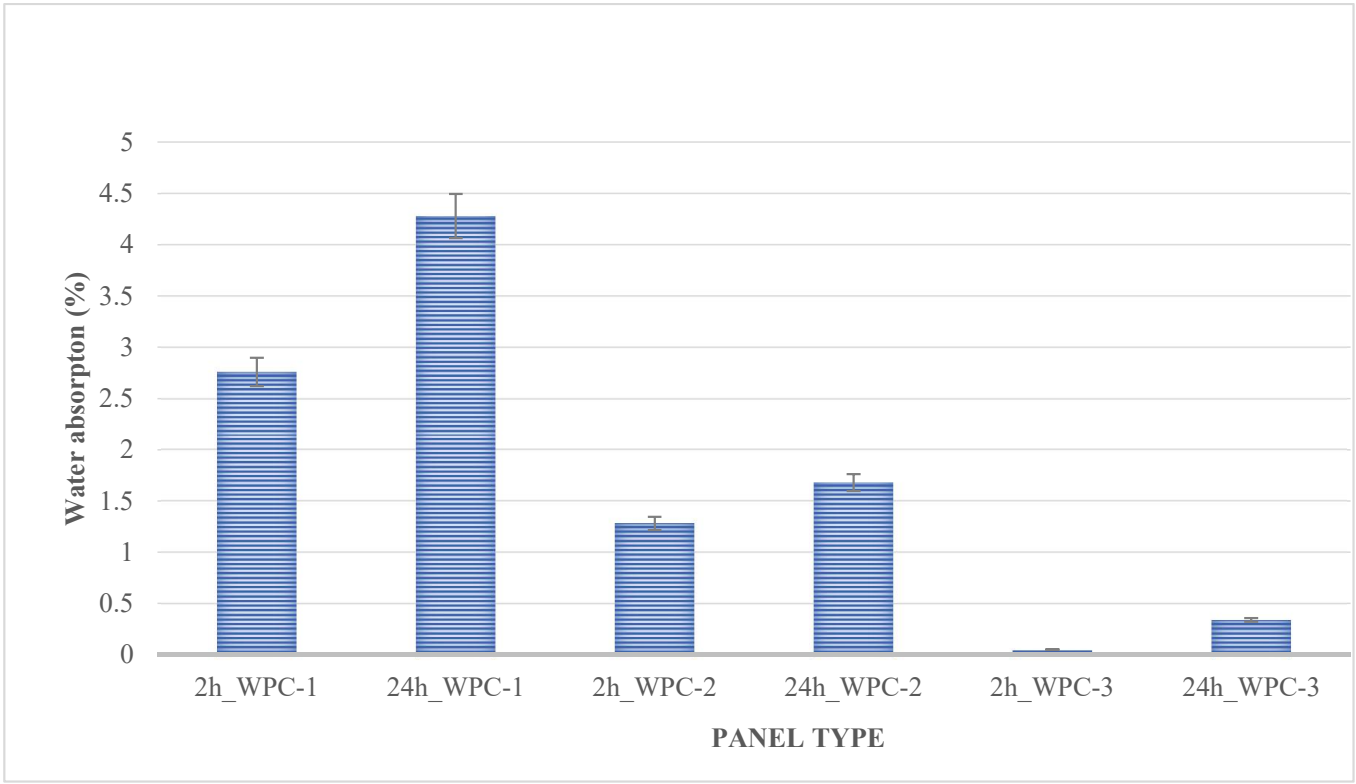


Figure 3. Water absorption of the samples.

3.2. Janka Hardness of the Samples

Mechanical properties of the samples are displayed in Table 4. The hardness of any kind of composites is an important characteristic, especially when they are targeted to be used for construction purposes. The hardness of WPCs is also a function of the polymer type, porosity of wood species, as well as its density. In general, a higher polymer load would result in a harder panel [38]. Having 50% silica and 40% PET in the samples showed the highest hardness value of 4922 N. Overall hardness of the samples reduced with decreasing PET content in the panels, as illustrated in Figure 4. An increasing percentage of silica in the samples also did not improve their hardness as in the case of panel type WPC-1 having 70% silica and 20% PET. In a previous study, it was also found that the initial addition of different types of fillers improved the hardness of WPC panels, however, their hardness was adversely influenced by the increase of those additives at the expense of polymer loading [38]. The means of groups are significantly different from each other, as shown in Table 2.

Table 4. Mechanical properties of the WPC samples.

Sample Type	Density (g/cm^3)	Hardness ** (N)	Compressive Strength ** (N/mm^2)
WPC-1	1.41 (0.07) *	2854 (292.80)	10.08(0.51)
WPC-2	1.41 (0.06)	4492 (1152.57)	15.55(0.31)
WPC-3	1.57 (0.02)	4922 (926.27)	18.69(0.84)

* Numbers in parentheses are standard deviations values. ** Highly significantly different ($p \leq 0.01$).

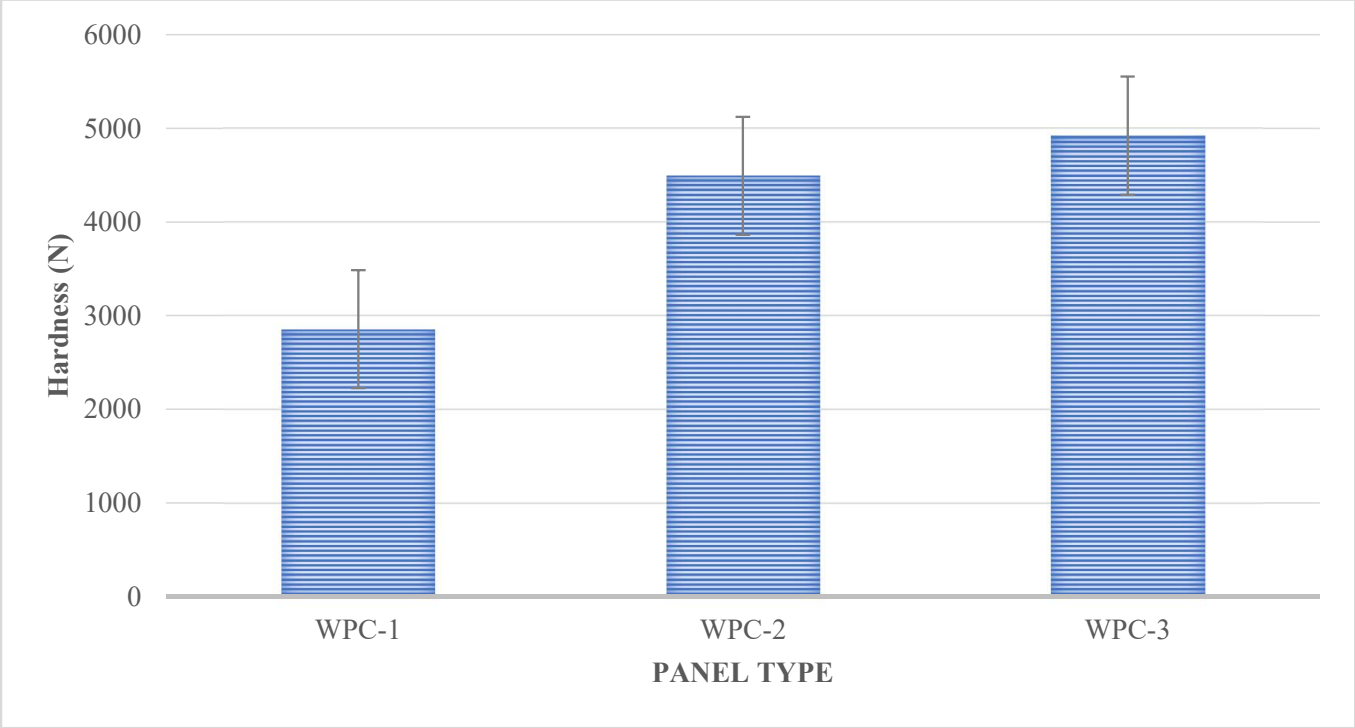


Figure 4. Hardness values of the samples.

3.3. Compression Strength of the Samples

The lowest compression strength value of 10.08 N/mm^2 was determined for the panel type WPC-1, having 20% PET and 70% silica, as shown in Figure 5. It seems that a high percentage of silica in the panels did not mix uniformly, creating a certain amount of gaps between the two major materials, resulting in lower strength values. This finding can be observed from the micrographs taken by SEM, as shown in Figure 6a. Similar to the hardness of the samples, the amount of polymer loading is also a main parameter influencing the overall mechanical properties of WPC. When the percentage of PET in the panels is increased sequentially from 30% to 40% with decreasing silica content, compression strength values of the samples was enhanced to a certain extent. An increased amount of PET in the samples had a more uniform mixture, resulting in higher compression strength values of the samples. The SEM micrographs taken from the panels surface of types WPC 2 and WPC 3 also supported such findings. The WPC-3 sample presented an increased value of the compression strength of 18.69 N/mm^2, which is almost 1.8 times higher than that of WPC-1 panels type.

It appears that both types of panels had a more uniform and homogeneous mixture of each material in the panels, so that their compression strength properties were improved, in WPC-2 and WPC-3, as shown in Figure 5. The compressive strength of WPC samples was also confirmed to be significantly different from each other based on the statistical analysis, as displayed in Table 4. The result showed statistical differences between the means of three independent groups ($p \leq 0.0001$).

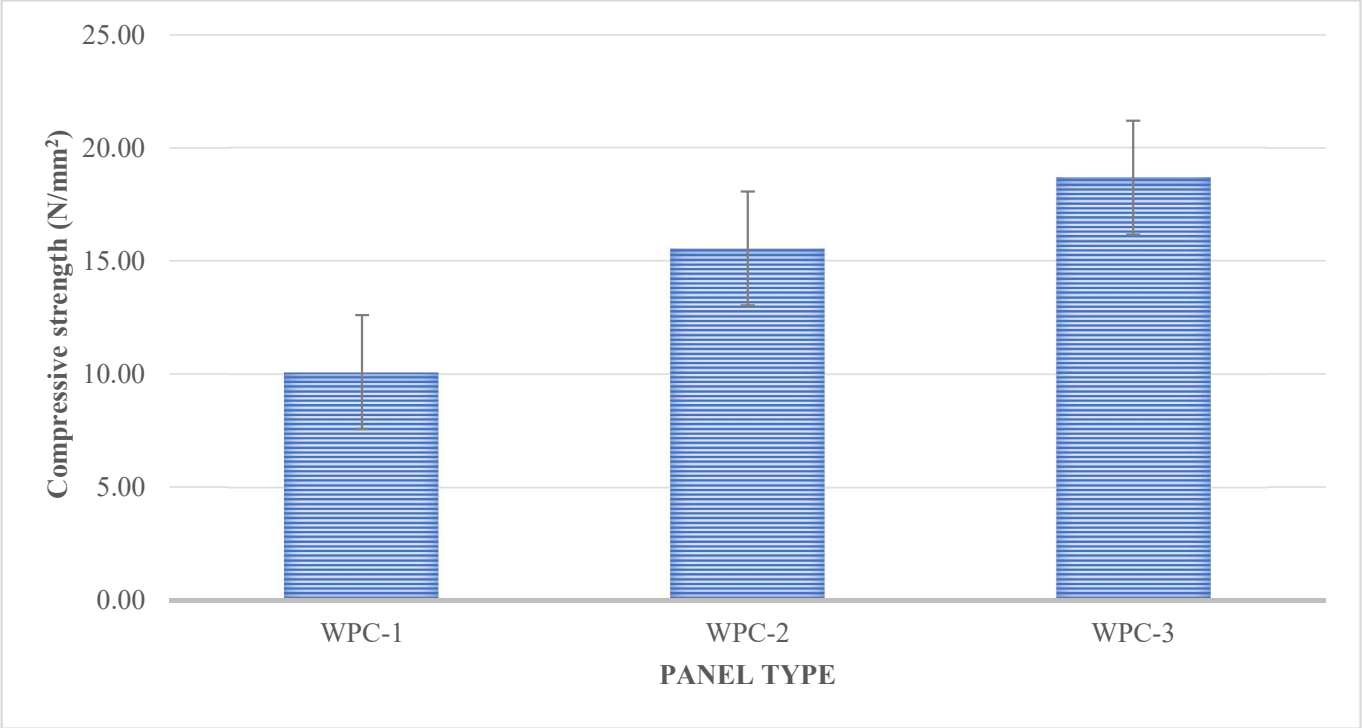


Figure 5. Compressive strength of the samples.

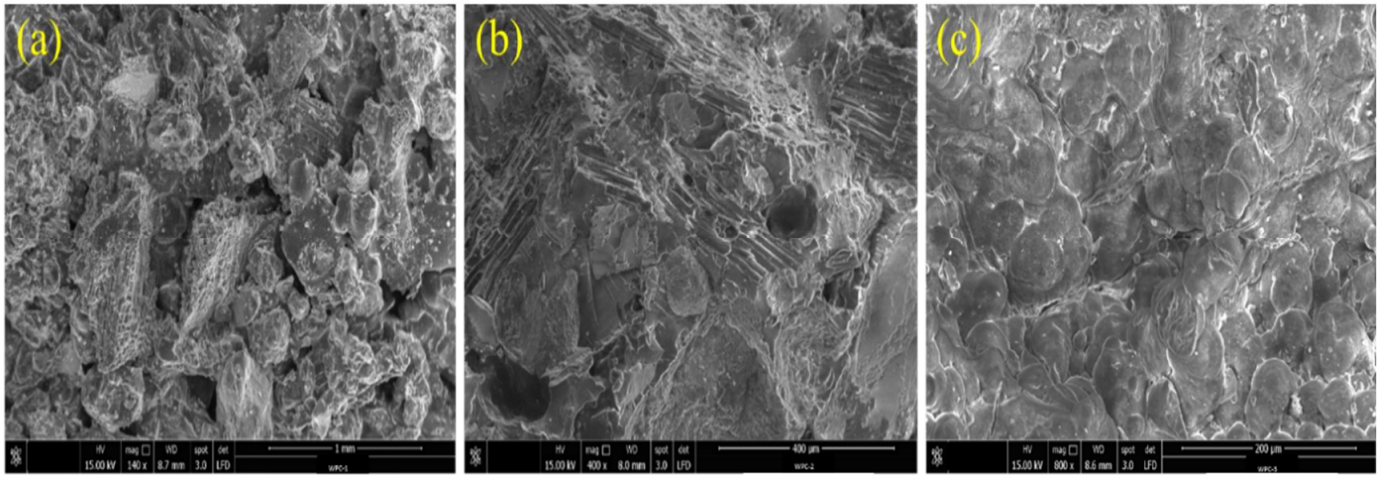


Figure 6. SEM micrographs of WPC samples: (**a**) WPC-1, (**b**) WPC-2, and (**c**) WPC-3.

4. Conclusions

In this work, some properties of experimental wood plastic composite (WPC) samples manufactured from a low percentage of rubberwood, waste polyethylene terephthalate (PET), and silica at three different ratios have been evaluated. Both hardness and compression strength values of the specimens were adversely influenced by increased silica content in the panels, while their water absorption properties were improved at a certain extent. It appears that using a higher amount of silica in the samples, creating a larger void volume for water to be located in, resulted in high water absorption characteristics. Overall, it seems that using a combination of waste PET and silica with a low percentage of wood particles could have the potential to produce value-added environmentally friendly composites to be used for different applications such as window and stairs rails.

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