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Behaviour and Some Properties of Wood Plastic Composite Made from Recycled Polypropylene and Rubberwood

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Abstract

The current demand for green construction has encouraged the pursuit of alternative products made from new materials such as composite materials built on renewable resources extracted either from nature or, most notably, from industrial waste so that reuse methods can be facilitated. The main focus of this research presented in this article is to study and show the behaviour and some properties of wood plastic composite made from recycled polypropylene and rubberwood when exposed to moisture. Wood polymers have been studied for water absorption properties under cyclical and ageing conditions. In this research, the flexural strength was evaluated before and after water immersion. Water absorption and thickness swelling of wood-recycled polypropylene composites were also studied. A significant relationship was observed between the thickness of the swelling and the increase in the weight gained, the maximum thickness of the swelling and weight increased. To show how flexural strength can be significantly affected by water absorption cycles. Repetition of water absorption cycles has a significant effect on the mechanical properties and effect of the cycle.

Keywords: Wood-plastic composites; Recycle polypropylene; Rubber-wood flour; Mechanical and physical properties; Chemical contents.

1. Introduction

There has been a great deal of interest in the development of wood plastic composites (WPCs) over the last decades. This was owing to the intrinsic benefits of WPCs such as strong stiffness, low density and small price relative to other inorganic additions, such as glass fibres, calcium carbonate or talc. Polyethene (PE), polypropylene (PP) and Polyvinyl chloride (PVC) are the thermoplastic polymers most frequently used in the production of WPCs [1, 2, 3, 4, 5].

Recycled rubber wood is a promising material for use in wood-plastic composites due to its high lignin content, which can enhance the mechanical properties of the composites [6,7]. The properties of recycled rubber wood composites can be improved by using recycled polypropylene as the matrix material. The addition of recycled polypropylene can increase the thermal stability and impact resistance of recycled rubber wood composites [2,4].

Moisture absorption can significantly affect the behaviour and properties of wood-plastic composites [8,9,10,11]. The presence of moisture can cause swelling and degradation of the composite, which can lead to a reduction in mechanical properties. The extent of moisture absorption and swelling in wood-plastic composites depends on the type of wood, the type of plastic, and the processing conditions [12, 13].

In recycled rubber wood composites, moisture absorption and swelling can be reduced by modifying the surface of the rubber wood particles. Surface modification can improve the compatibility between the rubber wood particles and the polypropylene matrix, which can lead to improved mechanical properties and reduced moisture absorption [5].

The effect of moisture on the properties of recycled rubber wood composites can be evaluated by measuring the flexural strength before and after water immersion, as well as by measuring the water absorption and thickness swelling of the composites [13].

The increasing requirement for fresh building products with enhanced mechanical properties and other operating features worthy of replacing traditional products, such as; steel and wood, is the cornerstone of the growth of the industry for synthetic wood (WPC). In Europe, WPC manufacturing has risen from, 150 000 tonnes in 2010 to 250,000 tonnes in 2015 with an annual growth pace of eleven percent [1,14]. WPC also has the potential for recycled plastic applications due to the large proportion of plastic in the WPC composition, up to 50% of weight/volume [15]. Several studies have been published, mainly examining the mechanical properties of WPC produced from plastic waste [16,17]. Because WPC is usually used in an outdoor application, sustainability is a major problem for producers and clients. WPC's lifespan is restricted owing to the adverse effect on its features of ambient climate circumstances. However, both virgin and recycled plastic suffered from the same environmental-climate effects. Therefore, because of its performance loss under various environmental variables, realistic WPC design values should include corrections [18,17,16].

Possible immiscibility between different polymer grades in the recycled polymer mixture along with weak matrix/filler

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interactions may harm the wettability of the material. Wettability, as it is known, is a critical factor affecting the durability of the composite material [19].WPCs are thermoplastic composites consisting of natural fibres (such as wood, bamboo, bagasse, rice bran, etc.), polymers (such as polyethene (PE), High-density polyethene (HDPE), polypropylene (PP), polyvinyl alcoholand additives. Water absorption is a significant variable affecting the characteristics and durability of WPC products [20].

The research on the effect of moisture on Wood Plastic Composites (WPC) made from recycled polypropylene and rubberwood can have several novel implications: Improve the durability of WPC, development of sustainable materials, understand the behaviour of WPC when exposed to moisture and enhance product performance for various applications. Overall, the behaviour and properties of recycled rubber wood composites are influenced by a variety of factors, including the type of wood, the type of plastic, and the processing conditions. The effect of moisture on the properties of the composites can be reduced by surface modification of the wood particles and can be evaluated by measuring the flexural strength, water absorption, and thickness swelling of the composites.

In following the literature review of relevant works, this paper seeks to contribute the result obtained from the ongoing research to effectively evaluate the efficiency of WPCs through the properties of the Recycled Rubber-Wood material when exposed to moisture or in contact with water.

The main focus of this research presented in this article is to study the effect of moisture on recycled rubber wood composite. In this research, the Flexural Strength (FS) was evaluated before and after water immersion. Water absorption and thickness swelling (TS) of wood-recycled polypropylene composites were also studied. A significant relationship was observed between the thickness of the swelling and the increase in the weight gained, the maximum thickness of the swelling and weight increased. To show how flexural strength can be significantly affected by water absorption cycles. Repetition of water absorption cycles has a significant effect on the mechanical properties and effect of the cycle.

2. Literature review

Several studies have investigated the use of recycled materials in WPCs. [21] investigated the effect of recycled HDPE and waste paper on the properties of WPCs. They found that the addition of waste paper improved the mechanical properties of WPCs, and the use of recycled HDPE reduced the cost of WPCs. [22] investigated the use of recycled polyethene terephthalate (PET) in WPCs. They found that the addition of recycled PET improved the mechanical properties of WPCs, and the use of recycled materials reduced the environmental impact of WPCs. Several studies have also investigated the effect of moisture on the properties of WPCs. [23] investigated the effect of water immersion on the mechanical properties of WPCs made from recycled HDPE and bamboo fibres. They found that the water absorption and thickness swelling of the composite increased after water immersion, which reduced the flexural strength and modulus of elasticity of the composite. [24] investigated the effect of water absorption on the mechanical properties of WPCs made from polypropylene and rice husk. They found that the water absorption and thickness swelling of the composite increased with the increase in the rice husk content, which reduced the flexural strength and modulus of elasticity of the composite.

Previous studies have shown that the existence of water in WPC reduces mechanical characteristics and durability, including interfacial shear strength, complete elongation, maximum strength, tensile characteristics, flexural strength, and microbiological exercise [25]. It was also noted by previous researchers that the absorption of water offered a favourable atmosphere for the development of the fungi immediately or partially improved WPC's susceptibility to a fungal assault, which further led to swelling and warping. It has been reported that all WPC exits the interfacial gap between the fine wood and the polymer matrix, mycelium appears to be concentrated in the gap and mycelium penetrates the materials [16, 26, 27]. Previous studies have shown that the weathering properties are the weak point of composite plastic wood, which hinders its durability and outdoor application. Two main elements can significantly affect the performance of wood polypropylene composites, water, and ultraviolet radiation [20,25].Hydroxyl cellulose groups are mainly responsible for water absorption in wood-polymer composites. The hydrophobic polymer would protect the wood against moisture in the case of total encapsulation. However, the encapsulation of wood fibres in the composites is incomplete at wood loadings of 40% or higher [25,28]. The wood particles on the surface absorb water and swell. Water absorption by wood polymer composites has been shown to influence their mechanical properties, dimensional stability, and freeze-thaw resistance, and to enhance the microbiological activity, including decay [29].

Different climatic conditions, according to past research, cause millions of dollars of material damage each year, and huge expenses may be involved in replacing these damaged products. It is therefore essential to determine how durable the material will be in a range of environmental conditions when fresh material is produced. Consequently, in colder areas where cold is common, the durability of wood can be of excellent significance in determining the service life of WPCs [28, 29, 30]. WPCs have been revealed to be extremely susceptible to environmental aggressors. In extremely humid and wet environments, for example, natural fibres in WPCs carry moisture that can trigger degradation of fabric characteristics and spatial disturbance and boost susceptibility to biological fungal attacks under steady mechanical stresses, high-temperature compounds creep deformation, while the low temperature, in conjunction with dissolved moisture, promotes decay in frost-induced conditions [28,31]. Therefore, studies on the impacts of prevalent environmental exposures encountered in the end-use of the product should be carried out in preparation to properly evaluate the efficiency of WPCs.

Moisture and frost-induced dimensional changes cause loss of mechanical properties in WPCs. Flexural stiffness and strength of fully saturated maple and pine wood floor-reinforced HDPE matrix, WPCs were reported to have decreased by 49 percent, 21%, 37% and 5% after 15 freeze-thaw cycles, respectively [30, 32, 33, 34]. The previous study noted the impact of wood-derived fillers (WDF) on mechanical strength and water absorption in the static and dynamic conditions of the PP matrix [35]. Composites comprising wood fibres at varying temperatures showed the greatest flexural strength [36]. There was a significant distinction in water uptake in dynamic trials between PP neat and composites containing wood flour filler. The study showed the mechanical characteristics of composite samples from sawdust / HDPE. The findings revealed that, until saturation was reached, greater water diffusion in the matrix contributed to reduced tensile and flexural forces in distilled water [34, 35].

The related study shows that the treatment of temperature according to different changes in time has a high influence on the size of HDPE and WPC. HDPE, therefore, exhibited a dramatic change with increasing temperature, while WPC increased at treatment temperatures greater than 20^0C and decreased at temperatures less than 20^0C, increasing WF and other additives, and a gradual release of potential processing [36, 37]. However, with prolonged treatment time, the change ratio decreased gradually (linear expansion coefficient k = 1.7 × 10-5) after 16 days. Due to the hydrophilic nature of the wood, moisture is the main cause of swelling in the wood cell walls, resulting in the subsequent degradation of the mechanical bond between the wood and the plastic and a decrease in the strength and stiffness of the composite [34,38, 39, 40, 41].

Researchers have reported that the limited degree of bonding between hydrophilic "water-loving" wood and hydrophobic "water-hating" plastics can also be disrupted by physical activities such as freezing and thawing [42]. This would be a critical performance issue for temperate exposures. Earlier research revealed that freezing-dew-cycling on maple or pine-based PVC composites showed that full-cycle loss properties were similar to loss-only water-immersion properties, while loss-on-free water-immersion-free cycling properties were negligible [37]. It has been observed that absorbed moisture degrades the interfacial interaction of the composite, reducing the transfer of stress and therefore lowering the mechanical properties [43]. Also, the presence of water causes the swelling of wood particles, which leads to stress in the matrix and micro-cracking formation. Micro-cracks then contribute to the further ingress of water into the composite at a later exposure [17, 35].

The related study revealed that the presence of carbonyl peaks in untethered samples is usually attributed to the thermal degradation of the polymer during composite processing, the presence of additives, or some other reason, as well as the ageing of the secondary plastic source [14, 36]. It was also discovered that an increased level of hydroxyl in composites, giving proof that degraded products of lignin and cellulose happened with extended exposure time. It also implies that lignin is more susceptible to degradation because the internal chromophoric regions are photolabile [25, 44].

When a sample of natural fibres is included in the hydrophobic polymer matrix, moisture sorption has a significant impact because the water diffusion processes in these products have caused variability in the adhesion value between the oils and the matrix [38, 45, 46, 47]. In our situation, the high-water sorption of wood fibres has influenced the adhesion to the polyethene matrix and may contribute to premature ageing due to the failure of resistance and some degradation. As described above, the presence of water in the fibre/matrix interface is one of the main long-term effects of interfacial cracking, followed by a reduction in the mechanical properties of the composite [18].

3. Materials and Methods

3.1. Materials

The recycled polypropylene (rPP) was used as a polymeric matrix with a melt flow index of 12 g/10 min, and a density of 0.83 g/cm3 supplied from WithayaIntertrade Co., Ltd, Thailand for the samples. Rubber-wood flour (RWF), used as the reinforcing material, is supplied by a local furniture manufacturer in Trang, Thailand. The size of the rubber wood flour particles was smaller than 180 mm (<80 mesh) and dried in an oven at a temperature of 110 ^{0}C for 8h. to reduce the moisture content by less than 3%. Maleic anhydride-grafted polypropylene (MAPP) with a rate of 8–10% Sigma-Aldrich, Missouri, USA was used as the coupling agent. Paraffin wax as a lubricant was purchased from Nippon Seiro Co., Ltd. Yamaguchi, Japan. The ultraviolet stabilizer supplied by TH Color Co., Ltd. Samutprakarn, Thailand was also used as a light stabilizer additive in the samples. The sample was supplied in pellets by the Prince of Songkhla University Thailand.

3.2. Manufacture of the Composite Sample

The ratios of the materials used in this study were rPP: 50.3%, RWF: 44.5%, MAPP: 3.9%, UV: 0.2% and Lub: 1% by weight. In the first stage, WPCs pellets were manufactured before they were compounded into composite samples employing a twin-screw extruder, Model CTE-D25L40 [48]. The temperature from the feeding to the die zone was controlled in the range of 170 to 200^0C, while the screw rotation speed was fixed at 50 rpm. In the next stage, the WPCs pellets were carefully dried before use in an oven at a temperature of 50^0C for 24 h. The samples were compressed in a hotpress having a temperature of 190^0C at a pressure of 870psi for 30min with a sequence of pre-heating, compressing, and cooling. Finally, the specimens were machined complying with ASTM standards before any tests were carried out.

3.3. Water absorption and thickness swelling of the sample

Water absorption (WA) and thickness swelling (TS) of the samples were carried out following ASTM D570-88. Specimens with sizes 10 mm × 20mm × 3 mm were cut out of the panels. Five replicates of each combination were dried in the oven at a temperature of 50 ^{0}C for 24 hours until you have a constant weight. The weight and density of the frozen samples were evaluated at 0.001g and 0.01mm, alternately. The sample was then put in water and stored at room temperature for 13 weeks. For each test, the samples were separated from the water tank, washed off with tissue paper and measured instantly. The proportion of water absorption and thickness of the swelling was calculated.

$$WA = \frac{W1-W0}{W0} \times 100 \quad (1)$$

Where WA is the water absorption, W0 is the initial mass of the sample and W1 is the mass of the samples after immersing in water.

$$TS = \frac{T1-T0}{T0} \times 100 \quad (2)$$

Where TS is thickness swelling at a given time t, T0 is the initial dry weight, and T1 is the soaked weight of the specimen, both at the given time t.

3.4. Mechanical properties

Flexural characteristics of composites were evaluated using the Universal Testing Machine (UTM) ag-1/100KN (Shimadzu Corporation, Japan). The samples were dried in the oven at a temperature of 50^0C for 24 hours. Before the experiments [49]. For the flexural experiment, a three-point tuning experiment focused on ASTM D790-92 was carried out at a cross-head velocity of 2 mm/min, using a length of 80 mm. The nominal sizes of the tuning experiment specimens were 15 mm × 100 mm × 4 mm.All tests were performed at room temperature with five replicates of each combination.

3.5. Scanning Electron Microscopy (SEM)

SEM observations were made using a 10kV Jeol JSM-5800 LV microscope working. The specimen was fractured in such a way that the internal portion could be exposed without deformation by cutting tools. During 5 to 10 seconds, the samples are covered with a thin layer of gold by plasma sputtering.

3.6. Fourier Transform Infrared (FTIR) Analysis

A Spectrum 100 FTIR (Perkin-Elmer, UK) spectrometer fitted with an Attenuated Total Reflection Accessory (ATR) (Perkin Elmer) was used for surface analysis of the composite. The spectra were obtained by co-adding 14 scans with a resolution of 4 cm-1 in the range between 4000 and 400 cm-1. The common peak intensity of PP, 2917 cm-1 (CeH band) will standardize all spectra. This peak was chosen as the point of comparison because it changed the least through weathering. To estimate the degree of ageing of the specimens in the carbonyl groups, 1800-1600 cm-1 was measured. For each form of composite, five replicates.

4. Result and Analysis

The experimental outcomes were statistically evaluated for five samples of each experiment with a 5%-fold significance level (a = 0.05).

4.1. Water absorption, thickness swelling, and mass changes

The amount of moisture retained in the composites was determined by the weight and the swelling discrepancy between the coated specimens subjected to distilled water and the wetting and drying samples. Composite shows the percentage of ingested moisture measured against the number of days of the cycled specimens as revealed in Figure 1. The samples absorbed water very rapidly during the first and second cycles (2 days) reaching a certain value, the saturation point, where no more water was absorbed and the content of water in the composites remained the same.

The previous study proposed that higher concentrations of wood can facilitate the absorption of liquid. The stability between wood (hydrophilic) and plastic (hydrophobic) particles may influence the absorption of water by increasing the number of wood particles in the WPC composite, increasing their polarity, and resulting in higher water content [16, 18]. It was also found that the epoxy used to cover all sides of the specimen tended to slow down the absorption of water, although some of the specimens retained water due to the penetration of air through the uncoated layer [19]. The analysis also found that the longer the specimen stayed in the distillate liquid, the epoxy used to cover the specimens contributed to the faster absorption of heat.

Therefore, according to the number of days, the level of swelling was detected as shown in figure 2. The first cycle showed a rise in the specimen's thickness as a function of the water absorbed through the composite's opening and surface and as a result of the composite's hydrophilic nature, in turn, affects the mechanical properties. The third cycle shows that the specimen increased significantly due to the number of days spent in the distilled water.

4.2. Flexural test properties for water fatigue absorption

The bending forces of the materials typically decrease after water absorption as a result of the influence of aquatic molecules that degrades the fibre, matrix and interface composition and properties as seen in figure 3. Once the liquid penetrates the composite materials, it leads the material to swell. The moisture absorption through processes including chain reorientation and shrinkage was also influenced by the matrix layout. Any ageing in a cyclic moisture state or drying can also contribute to natural fibres being damaged by a hydrolysis reaction. Water penetration and its consequences lead to performance failure [19,50, 51].

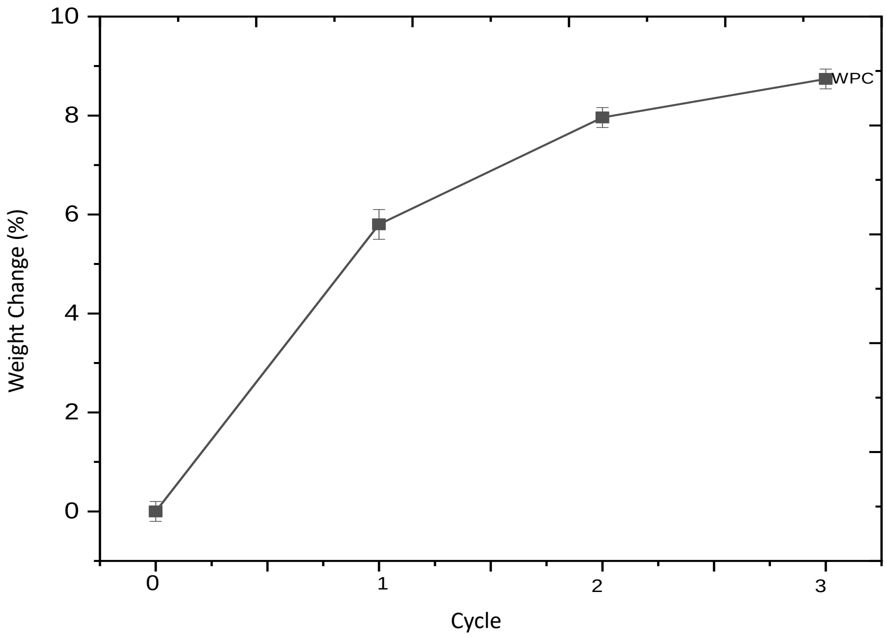

Figure 1. Percentage change in weight of WPC subjected to water absorption.

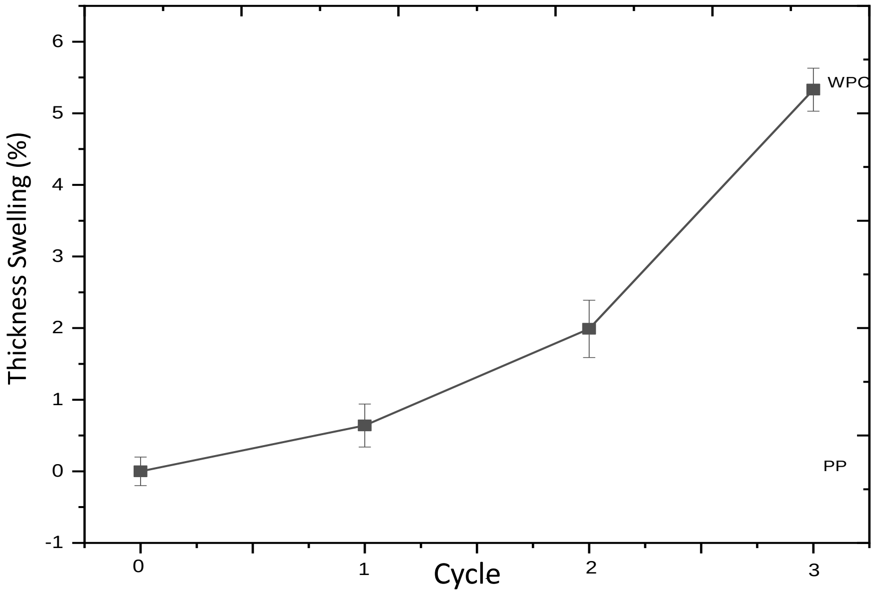

Figure 2: Percentage change in thickness swelling of WPC and PP during the freeze-thaw process.

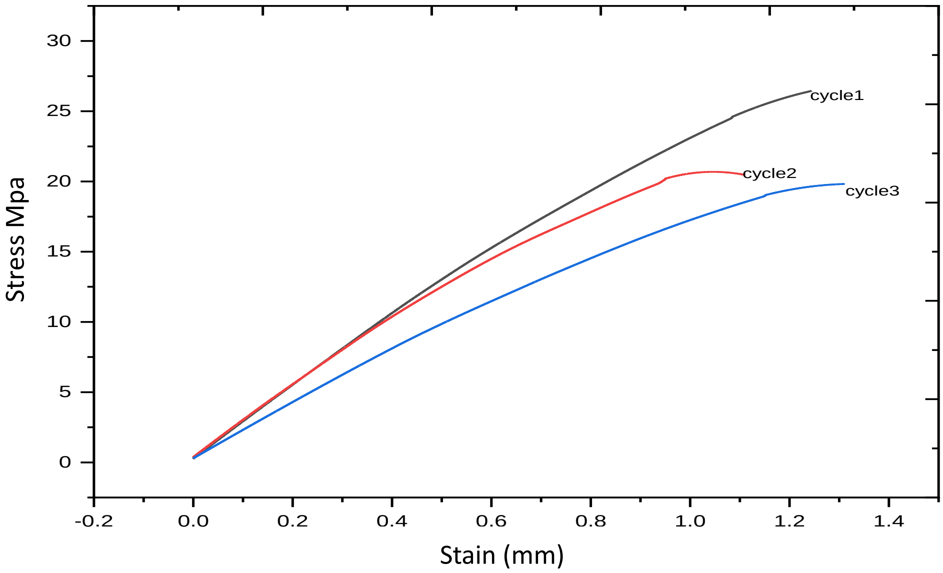

Figure 3. The typical flexural properties of the wood polymer composite after five freeze-thaw cycles.

Several processes are responsible for the loss of mechanical properties as a result of sensitivity to water absorption cycles as seen in figure 3. The major mechanism involved is the influence of moisture on the degradation of the interface and the resulting lower stress transfer on the WPC. Ageing with water absorption alone is effective in reducing the mechanical properties of wood flour polymer composites. [38,52]. The epoxy was added to the specimen to prevent water from entering the material, which helped in increasing the mechanical performance. Thus, the coating of the substrate with epoxy can be inferred by offering moisture coverage on its surfaces enhancing the strength of the studied composites [53].

4.3. Fourier Transform Infrared (FTIR)

For reference, composites assigned with wood and polypropylene component were observed on the entire FTIR spectra Figure 4. The composite had very strong absorbance in the region 1400-2900 cm^{-1}. The FTIR spectra of the control composite at different exposure times can be seen in Figure 4. Where most of the spectral fracture has gone through significant changes after exposure to water absorption. It was revealed in wood/polypropylene composite that hydrothermal degradation also contributed to carbonyl formation [34].The carbonyl indexes of the composites were found to increase with exposure time. The carbonyl indexes compared with other cycles were similar, at a different time the carbonyl indexes compared with the untreated sample showed a similar trend of event.

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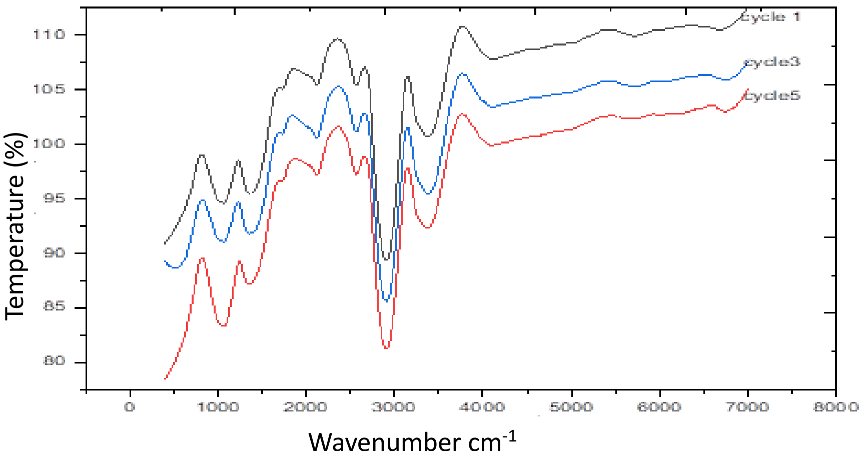

Figure 4. FTIR spectra showing WPC after the water absorption.

5. Conclusion

The current demand for green construction has encouraged the pursuit of alternative products made from new materials such as composite materials built on renewable resources extracted either from nature or, most notably, from industrial waste so that reuse methods can be facilitated [54]. This research shows mechanical properties, and WPC behaviour when exposed to moisture. Wood polymers have been studied for water absorption properties under cyclical and ageing conditions. A thickness swelling test was performed as a physical property indicator. After each cycle, the mechanical characteristics of the composites were evaluated using three-point flexural tests and the losses in mechanical properties were studied. Results indicated that the thickness of the swelling was affected by the absorption of water during the cycling while a significant relationship was observed between the thickness of the swelling and the increase in the weight gained, the maximum thickness of the swelling and weight increased. Flexural strength values have been significantly affected by water absorption cycles. Repetition of water absorption cycles has a significant effect on the mechanical properties and effect of the cycle. Nonetheless, the loss of 30–20 percent of mechanical properties suggests that the composite materials manufactured should be secured against in-service water absorption periods.

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