Original Article

Recycling Of High Density Polyethylene Plastics (Hdpe) Reinforced With Coconut Fibers For Floor Tiles

Zhou, Yi[1], Ammar A.M.Al Talib[2], Jonathan Yung Chun Ee[3]
[1, 2, 3] Faculty of Engineering, Technology & Built Environment, UCSI University, Kuala Lumpur, Malaysia
Email: 1001956766@ucsiuniversity.edu.my
DOI: 10.47750/pnr.2022.13.S07.295

Abstract

The increasing amount of plastic waste and biomass waste has become a growing global environmental problem, and combining the two to form composite materials is one way to solve the problem. HDPE (High Density Polyethylene) is a common material in a variety of industries, including packaging and automobiles. HDPE, on the other hand, has a number of disadvantages, including not biodegradable and of poor thermal stability at high temperatures. HDPE may be recycled by employing it in composites as a matrix. Meanwhile, natural fiber may be made from biomass waste, which is a low-cost resource that can be used to substitute scarce resources. In this study, HDPE is mixed with fibers from coconut shells to make a bio-composite material, which is then tested for mechanical properties (Tensile test, flexural test and impact test), hardness test, water absorption test and thermal insulating test. The purpose of this study is to confirm the suitability of coconut fiber reinforced HDPE composites for the manufacture of floor tiles and to confirm the scope of their application. Pure HDPE, and blends of 5%, 10%, 15% and 20% are tested. The results have proven that the material is suitable for exterior floor tiles, such as tile paths in parks and tiles in public places, due to the good mechanical properties, thermal insulation and low water absorption rate of the composite.

Keywords: Coconut Fiber, Composite, Floor Tiles, HDPE

INTRODUCTION

Polyethylene is a polymer that is primarily utilized in the manufacture of plastic bags, film, and containers. Despite the fact that polyethylene accounts for roughly 34% of the overall plastics market [1], polyethylene production has produced environmental issues due to its lack of biodegradability [2], so researchers are attempting to utilize it as a matrix for bio-based composites.

Natural fibers are fibers derived from the bodies of plants and animals that can be used as composite material components. Natural fibers are employed in high-tech applications like automotive composite parts. Natural fibers have various advantages over industrial fibers, including low cost, low environmental impact, biodegradability, and the fact that they are renewable [3]. They are also effective in insulating vibrations and noise [4]. Furthermore, unlike glass fibers, natural fibers are susceptible to bacterial degradation once they have been decommissioned. Natural fibers, in reality, have a small market share compared to other fibers. Plant-based fibers like jute, flax, and hemp make up 5.7% of the global market (6 metric tonnes per year), while animal fibers like wool and silk make up slightly over 1% of annual production, as the potential of natural fibers continues to be exploited, their market share is increasing [4].

Natural fiber reinforced polymer composites (NFRPC) are materials made up of a polymer matrix with natural fiber reinforcement embedded in it [5]. Plant, animal, and mineral fibers are the three types of natural fibers. Plant fiber composites have garnered researchers' attention among the numerous natural fibers since many of their qualities are similar to those of manufactured glass fiber composites [6]. Natural fibers including coconut, flax, jute, pineapple, and banana fibers have various advantages in polymer composites, including low density, thermal stability, recyclability, and biodegradability [7]. Hybrid composites based on natural fibers provide a competitive market for a variety of industrial applications [8]. In recent years, the market for natural fiber-reinforced polymer composites has grown in popularity for automotive, aerospace, construction, and sports applications [9].

Plastic trash is currently a serious global environmental issue. Plastic trash generation has been found to pose a number of risks to human life, including contamination of water and land [10] and the spread of illness [11]. Reduce the amount of plastic items used, recycle plastic waste for new applications, and develop environmentally friendly plastics that are easier to degradation than standard polymers are all possible solutions to this problem (e.g. biopolymers). Plastics are organic polymers that can be used to make a wide range of items, including packaging and bottles [12]. In 2019, the worldwide plastic manufacturing hit 368 million tonnes [13], and this number is rising year after year. The low cost of the raw material is the key reason for such high volume production, another key element is its durability [14]. Although many different materials can be used to replace plastic, they do not last as long as plastic in the same circumstances. Today, however, it is recognized that all of these advantages come at a cost: pollution!

Plastic pollution can be reduced by recycling plastic trash and converting it into composite materials. Thermoplastics and thermosets are two types of plastic polymers. Unlike thermoset polymers, HDPE is a reusable thermoplastic polymer [15]. Thermoplastic high-density polyethylene is made of hydrogen and carbon atoms that are combined to generate high molecular weight products. The range of its density is 0.941 to 0.965 g/cm^3. HDPE offers excellent biocompatibility [16], stiffness, strength, and good creep properties [17]. Furthermore, In terms of toughness, strength, and chemical resistance, high density polyethylene (HDPE) outperforms low density polyethylene (LDPE) and linear low-density polyethylene (LLDPE), although it lacks flexibility [18]. HDPE is commonly used to make bottles, pipe systems, packaging, and other items [19]. The global demand for high-density polyethylene (HDPE) resins has increased at a 3.3 % yearly pace from 11.9 million tonnes in 1990 to 43.9 million tonnes in 2017 [17].

Coconut fiber is extracted from coconut shells and refined by a process of dehusking, retting, defibering, and finishing [20]. Coconut fiber, which is made up of three primary components: cellulose, lignin, and hemicellulose, is used in a range of sectors, including composite materials [21], flooring and ropes. Global production of coconut fiber is approximately 250,000 tonnes per year, its physical and mechanical properties are thought to have a lot of potential for improving composite ductility, flexural toughness, and energy absorption, these fibers' exceptional toughness and flexibility allow reinforced composites to have improved post-cracking behavior [22].

The goal of this study is to research the mechanical properties of tensile strength, flexural strength, impact strength, hardness, thermal insulation and water absorption rate of recycled HDPE with 5%, 10%, 15%, and 20% coconut fibers, in order to find the best blending ratio in the production of floor tiles, and to conduct the appropriate related tests.

METHODOLOGY

Chemical Treatment

Natural fiber composites are becoming more popular, however their mechanical and interfacial properties are poor [23]. The problems can be solved by chemically treating natural fibers. Potassium hydroxide (KOH), sodium hydroxide (NaOH), and water glass (sodium silicate) solutions are common activators [24]. Compared to KOH treatment, shrinkage from NaOH treatment was noticeably greater at the same concentration [25]. Fibers that have been treated with NaOH have better mechanical properties than fibers that have not been treated [26]. The phenolic compounds, fatty acids, hemicellulose, lignin and waxes may have disintegrated and leached out of the fibers during the NaOH treatment, causing the fibers to become thinner. The fibers become stiffer and more rigid when these binding substances are removed. Better fiber wetting is made possible by the NaOH treatment's increase in reactive sites [27]. In this study, coconut fibers are chemically treated by 2% NaOH solution. The coconut fibers have been immersed in a solution of sodium hydroxide for 24 hours, after which they have been dried in a dryer at a temperature of 50 degrees for 24 hours. Tests have been conducted on pure HDPE and HDPE with 5%,10%,15% and 20% coconut fiber fillers.

Samples Preparation

The test samples are manufactured by the compounding process. Firstly, a grinding machine was used to grind the coconut fibers into powders. Secondly, the HDPE and the chemically treated coconut fibers are mixed in proportion to each other in an internal mixer set at 50 rpm,(BRABENDER Plastograph EC, Germany). The barrel has been heated to 190°C. A certain number of shredded HDPE were then poured in, followed by the coconut fibers at the different percentages for each different set of tests. Thirdly, the blend is placed in a compression moulding machine (Technopress - 40HC - B, Malaysia) and the mould have been heated to 190°C. The material has been preheated for 10 minutes, compressed for 10 minutes and then transferred to a cold plate to cool for 30 minutes. 145mm x 145mm x 4mm specimens are obtained. Finally, the specimens are cut into a specific shape by a cutting machine.

Tensile Testing

The test procedure entails fixing the specimen between the two jaws and gradually stretching it until it breaks. The samples are tensile tested on the Gotech Testing Machine (Al - 3000) according to test standard ASTM D638 - 04, with the cross head speed set at 50 mm/min and the temperature set at 23 ℃ of room temperature. The test has been repeated three times for each type of specimen and the average value is taken.

Flexural Testing

The three-point bending flexural test was used to test the flexural modulus and flexural strength of the composite. The specimens in the current study are tested using the Gotech Testing Machine (Al - 3000) at a crosshead speed of 2 mm/min, in standard with ASTM-D790. Three samples have been manufactured for testing and their average test values are recorded.

Impact Testing

The impact test is divided into IZOD impact test and charpy impact test, and IZOD impact test has been applied in the current study. The Izod impact strength test is a technique for assessing a material's impact resistance. The test is comparable to the Charpy impact test, but the test sample arrangement is different. The hammer has swung downwards and fractured the notched sample in this test, with the initial angle of the hammer being 150 degrees. The Advanced Pendulum Impact System (RR/IMT, Ray-Ran, UK) has been employed for this test. The standard used for this test is ASTM D256.

Hardness Testing

Shore hardness meters are the instrument that is most frequently used. When a rigid ball is placed under a spring stress or dead load, the amount of indentation it leaves behind is used to calculate the hardness. The harder the material is, the higher the value on the hardness durometer, and the less hard it is, the lower the value. The most commonly used shore hardness testers are shore A and shore D. Given that HDPE exhibits high rigidity behaviors [17], the test has been conducted using a shore D hardness durometer in accordance with ASTM D2240.

Water Absorption Test

The water absorption test examines the increase in weight of a sample. The test method is as follows. Firstly, cut the samples into a specific dimension according to ASTM D570, then weigh them. Secondly, the samples are to be dried in a dryer for 24 hours at 55 degrees before being immersed in pure distilled water. Finally, A 28-day water absorption test is performed and the weight of the sample is recorded using a digital scale. Finally, the water absorption rate of the samples is calculated according to equation (1),

$$C = (M_2 - M_1) / M_1 \quad (1)$$

Where, C denotes the water absorption, M_1 denotes the weight of the sample before immersion, and M_2 is the weight of the sample after immersion.

Thermal Insulating Test

A crucial physical indicator of a material's capacity to insulate heat is thermal conductivity, which describes the amount of heat that is transported over the course of a unit of time to a unit area of a material subject to a unit temperature gradient. A superior energy-conservation effect was produced by the thermal insulating material with decreased thermal conductivity [28]. The rate of heat transfer through the materials is influenced by a number of factors, including thickness, area, temperature difference and material types.The capacity of any substance to allow heat to pass through it is measured by its specific conductivity K. Equation (2) was used to calculate the K value,

$$Q = [KA(T_2 - T_1)] / X \quad (2)$$

Where, Q denotes the heat flow, K is the specific conductivity, A is the sample area, T_1 is the cold side of the sample temperature, T_2 is the hot side of the sample temperature, and X denotes the thickness of the sample. Due to the thermal insulation of the polyurethane foam, the samples were placed on the polyurethane foam and then the samples were heated using a heat lamp for 20 minutes, and the temperature of both the inner and outer sides of the samples were measured every 5 minutes. The thickness and area of the sample were also measured, and finally the data were substituted into the equation to calculate the K value.

RESULTS

Tensile Testing Results

Table II shows the modulus of elasticity and tensile strength of the samples. The results of the tests show that the addition of coconut fiber to HDPE increases the tensile modulus, with the HDPE reinforced with the 20% coconut fiber demonstrating the highest tensile modulus (870.1 MPa). Based on HDPE, 5% and 10% coconut fiber content decreased the composite tensile modulus by 31.9% (523.8 MPa) and 28.7% (548.8 MPa), respectively. The addition of 15% and 20% coconut fiber content increased the tensile modulus by 5.1% (808.8 MPa) and 13%, respectively. Pure HDPE, on the other hand, demonstrated the highest tensile strength (24.1 MPa), while the addition of coconut fiber significantly reduced the tensile strength. The tensile strength of the composite samples based on pure HDPE and 5%, 10%, 15%, 20% fiber content filler decreased by 49.4% (12.2 MPa), 45.2% (13.2 MPa), 44.8% (13.3 MPa), and 32.8% (16.2 MPa), respectively. Considering that coconut fiber is a hydrophilic material [29] and HDPE is a hydrophobic material [30], the hydrophobic polymers and hydrophilic fibers have relatively weak interfacial interactions, which has an impact on the characteristics of the resulting natural fiber/polymer composites [31]. However, the tensile and flexural strengths gradually increased as the fiber content rose because an increasing number of fibers participated in the tensile fracture process [32]. The tensile strength results are close to the plastic tile strength (18 MPa) studied by Akhmad, Sabarudin et al [33].

Flexural Testing Results

The mean values of the flexural modulus and flexural strength of the HDPE/coconut fiber composites fabricated in this study are shown in Table 1. It can be observed that the addition of 10%, 15% and 20% coconut fiber was able to increase the flexural modulus of HDPE. The flexural modulus value of the 20% coconut fiber composite is 10.2% higher than that of the pure HDPE and is the highest of all composites (647 MPa). This is because the coconut fibers inhibit the mobility of the polymer chains, thus causing a stiffening effect [34]. The flexural modulus of pure HDPE, 5%, 10% and 15% coconut fiber composite samples are 581 MPa, 448 MPa, 584 MPa, 618 MPa respectively. On the other hand, pure HDPE presents the highest flexural strength (19.88 MPa). In the same way as the tensile properties, the weaker interfacial bond between hydrophilic coconut fibers and hydrophobic HDPE leads to a decrease in mechanical properties, while the higher the fiber content, the higher the bending properties, as more and more fibers are involved in the bending fracture. Compared to pure HDPE, the flexural strength of the composite samples with 5%, 10%, 15% and 20% coconut fiber content decreased by 32.64% (13.39 MPa), 21.18% (15.67 MPa), 20.82% (15.74 MPa) and 16.90% (16.52 MPa), respectively. The test results all exceeded the minimum flexural strength of 3 MPa required for terrazzo tiles according to the British Standard (BS 4131) [35]. This indicates that the samples in this study have the ability to replace terrazzo tiles in terms of flexural properties.

Table 1. *The Different Tests Results*

	HDPE	5%CF	10%CF	15%CF	20%CF
Tensile strength (MPa)	24.1	12.2	13.2	13.3	16.2
Tensile modulus (MPa)	769.8	523.8	548.8	808.8	870.1
Flexural strength (MPa)	19.88	13.39	15.67	15.75	16.52
Flexural modulus (MPa)	581	448	584	618	647
Impact strength (kj/m^2)	68.55	10.75	12.04	14.47	17.82
Hardness (HD)	62.33	63	63	63.3	64
Water absorption rate (28 days)	0.96%	0.89%	1.38%	5.53%	6.28%
thermal conduction coefficient (W/m·K)	0.5	0.480	0.444	0.393	0.371

Impact Testing Results

The results of the notched IZOD impact test have shown that the addition of coconut fiber reduces the impact strength of the sample. These results are very similar to those of other authors' impact tests on PP-HDPE-CF [34] and Coir-EFB-PP [36]. The reasons for this are probably manifold, such as the weak interfacial bonding of the coconut fibers to the HDPE mentioned earlier and the fact that the incorporation of fibers influences crack generation, crack width and crack spacing [37]. In the test, pure HDPE had the highest impact strength (68.55 kj/m^2), followed by 20% coconut fiber reinforced HDPE (17.82 kj/m^2), and the lowest was 5% coconut fiber reinforced HDPE (10.75 kj/m^2). The impact strengths of the composite samples with 15% and 10% fiber content are 14.47 kj/m^2 and 12.04 kj/m^2, respectively.

HARDNESS

Table II shows the Shore D hardness values, from which it can be seen that as the fiber content increases, the hardness of the samples also increases. In this test, the composite sample with 20% CF (coconut fiber) exhibited the highest hardness (64 HD), this is closely followed by the hardness of the composite samples with 15%, 10% and 5% fiber content, which increased by 1.6% (63.3 HD), 1.1% (63 HD) and 1.1% (63 HD), respectively, compared to the pure HDPE, while pure HDPE showed a lowest hardness (62.33 HD). According to the results, it can be found that the increase in fiber content does not make a big difference to the hardness of HDPE. However, according to Sathish, T. et al. a natural fiber content of between 20% and 40% will increase the hardness of the sample, and at 50% it will decrease [38]. Therefore, the hardness of composites with higher coconut fiber content will be investigated in the future. Despite this, a higher hardness means a better quality floor tile, so the 20% CF composite sample showed the best performance in this study.

Water Absorption Rate

The water absorption test has been carried out according to ASTM-D570 and the samples are subjected to a gradual increase in water absorption at a room temperature of 23 ℃. According to Table II, it can be seen that as the fiber content increases, the water absorption rate also increases. This is because the fibers utilized as reinforcement are hydrophilic and hygroscopic. An increase in fiber content results in an increase in water absorption rate [39]. In this test, the HDPE reinforced with 20% coconut fiber sample showed the highest water absorption (6.28%). This was closely followed by the water absorption of the samples with 15%, 10% and 5% coconut fiber content with 5.53%, 1.38% and 0.89%, respectively. And since HDPE is a hydrophobic material [30], it maintains a very low water absorption rate (0.96%) throughout the test. According to Zhao, Jitong et al research, the water absorption decreased with higher fiber content for all fiber types, this trend persisted up to a specific fiber concentration, after which water absorption rose [40]. For example, according to Safiuddin, Md et al.'s study of a 28-day water absorption test of carbon fiber composites, the water absorption decreases continuously as the fiber content increases from 0% to 3%. It was not until the fiber content reached 4% that the water absorption started to increase [41]. In the study by Ohama et al. the water absorption decreased as the fiber content reached up to 5% [41]. Meanwhile, fibers treated with alkali have a lower rate of water absorption and become more hydrophobic [42]. This is why the water absorption of composite samples with 5% fiber content is surprisingly lower than that of pure HDPE, while the water absorption is higher than that of pure HDPE when the fiber content reaches 10%. The water absorption increased as fiber content rose above a certain threshold [40], this was well reflected in the 15% and 20% fiber content samples, where the water absorption increased sharply for the 15% and 20% fiber content samples due to being well above the threshold value. As can be seen from the Table II, the samples with 15% and 20% coconut fiber content exhibited higher water absorption. However, water absorption can cause the composites' mechanical performances to deteriorate [47]. Therefore, in this test, in addition to the good water absorption of pure HDPE itself, the composite samples with 5% and 10% fiber content also showed good water absorption.

Thermal Insulating Test Results

The heat transfer capacity of the material can be obtained by calculating the value of the heat transfer coefficient k. High density polyethylene has a thermal conduction coefficient of 0.5 W/m·K [43]. Substituting this value into Equation 3, the value of the thermal conductivity k of the composite sample can be calculated. The thermal conductivity of the composite samples with 5%, 10%, 15%, and 20% fiber content were 0.480 W/m·K, 0.444 W/m·K, 0.393 W/m·K, and 0.371 W/m·K, respectively. It can be seen from Table 2 that the thermal conductivity of the composite samples shows a decreasing trend. This is because fiber content rises, which reduces heat conductivity and raises thermal resistance [44]. A decrease in thermal conductivity means an increase in thermal insulation rate. The heat conductivity coefficient of HDPE is lower [45], while the composite with added coconut fibers further reduces the thermal conductivity of HDPE, thus further reducing energy consumption. Construction and building materials should be made of materials with thermal conductivities between 0.03 and 3.0 W/m·K, whereas heat insulation is frequently made of materials with thermal conductivities under 0.25 W/m·K [46]. This means that although they cannot be thermal insulation tiles, all the samples in this study can be used as low thermal conductivity materials for the manufacture of floor tiles.

CONCLUSIONS

Recycling plastic waste and repurposing it to create new items is one way to reduce plastic waste. For example, plastic waste can be used to make industrial and construction products such as floor tiles. Given their low price and good durability, floor tiles made from waste plastic will have a place in the future.

In this study, the flexural strength of the composite floor tiles with pure HDPE and with 5%, 10%, 15%, and 20% coconut fiber filler are 19.88 MPa, 13.39 MPa, 15.67 MPa, and 15.75 MPa, 16.52 MPa, respectively. The final results were similar to the findings of Shimelis Mekonnen's study on the production of terrazzo tiles from HDPE waste, All samples' flexural strengths exceeded the 3 MPa minimum flexural strength requirement imposed by the British Standards Institution for terrazzo tiles used in external or outdoor applications [35]. The tensile strength of pure HDPE floor tiles, 5%, 10%, 15%, and 20% coconut fiber content of composite floor tiles were 24.1 MPa, 12.2 MPa, 13.2 MPa, 13.3 MPa, and 16.2 MPa, respectively. The tensile properties are higher than those of flexible tiles produced from waste tires and polyurethane resin composites [48]. Also, the tensile strength and tensile modulus are higher than the mechanical properties of rubber floor tiles with RPP (rock powder particle) filler [49]. The impact strength of pure HDPE was much higher than that of the composite samples, while the average value of the impact strength of the composite samples was lower than that of the reinforced polymer floor tiles (20.3 kj/m^2) studied by Alqadoori, Mustafa A. Ibrahim, et al., and higher than that of the polymer floor tiles before reinforcement (11.25 kj/m^2) [50]. Although HDPE and its composite floor tiles are not as hard as epoxy tiles (85 HD) and polyester tiles (82 HD), a substance is regarded as being very hard if its shore D value is greater than 50 [51]. So HDPE and its composite floor tiles both have a very high degree of hardness. Although coconut fiber is a hydrophilic material, HDPE is a hydrophobic material and the measured water absorption of the composite is very low. Based on their abilities to absorb water, tiles are classified into four groups by ISO 13006:1998. High water absorption is defined as larger than 6.0 percent, medium water absorption as greater than 3.0 percent but less than 6.0 percent, low water absorption as greater than 0.5 percent but less than 3.0 percent, and very low water absorption as less than 0.5 percent [52]. HDPE and its composite floor tiles are extremely low-absorbent or low water absorption materials according to this standard. And a very low water absorption rate means that the floor tiles are of good mechanical properties. Construction and building materials should be made of materials with thermal conductivities between 0.03 and 3.0 W/m·K, whereas heat insulation is frequently made of materials with thermal conductivities under 0.25 W/m·K [46]. The thermal conductivity of the samples in this study is within this range. Although the thermal conductivity embodied in the samples in this study is not sufficient to make it an insulating material, it can still be a low thermal conductivity building material. In summary, due to the acceptable mechanical properties and water absorption, the composite floor tiles in this study can be used for outdoor applications, such as pavement in parks, outdoor public places, etc. Also, due to its low thermal conductivity, the material can be used for low thermal conductivity building tiles, thus reducing building energy consumption. If floor tiles made from waste HDPE plastic and HDPE composites can be manufactured in large quantities, the pollution and environmental damage caused by HDPE waste could be reduced. In an era of sustainability, samples made from recyclable and reusable materials can yield good economic and environmental benefits.

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