Chemical and Materials Engineering 5(4): 75-82, 2017 http://www.hrpub.org
DOI: 10.13189/cme.2017.050401

Effect of Coconut Shell Powder as Filler on the Mechanical Properties of Coir-polyester Composites

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Abstract Coir mat was used as reinforcement, polyester resin was used as matrix and coconut shell powder (CSP) was used as filler material which was employed as 10, 20, 30, 40, 50, 60 and 100% by weight in the composites. Coir mat/polyester resin composites were made by hand lay-up technique. Mechanical properties such as tensile strength (TS), bending strength (BS), tensile modulus (TM), bending modulus (BM), elongation at break and impact strength (IS) were also investigated. The maximum increase of TS, BS, TM, BM and IS were found to be 44.44, 128.00, 17.96, 112.09 and 62.50% respectively for 30% filler content on the composites. It was revealed that the strength properties of the composites were increased with the increase in filler content up to 30% by weight, however, further increase in filler content the value decreased. Gamma radiation of 100, 250 and 300 krad doses were applied on 30, 40 and 60% filler content composites. Gamma radiation dose of 250 krad showed better result than that of other doses. IS of the composites improved 48.08, 26.67 and 17.50% for 30, 40 and 60% filler content respectively at 250 krad, where 30% filler content composites displayed the highest improvement. Degradation tests of the composites for up to 50 days were performed in a soil medium. It was revealed that BS decreased for all the composites.

Keywords Coir Mat, CSP, Polyester Resin, Filler, Gamma Radiation

1. Introduction

Natural fiber polymer composites have gained huge attention from the last decade due to the environmental concern. Generally, natural fibers are biodegradable and renewable, so it has no harmful effect on the environment. Besides, it is available, cheap, low weight, low abrasion, high toughness, acceptable specific mechanical properties, durable and ease of processability [1-7]. That is why scientists are so much attracted to make the fiber useful in our daily life and try to make it an alternative solution for synthetic fibers. Several investigations have been carried out to assess the potential of natural fibers as reinforcement in the polymers. The results have shown that natural fibers present potential to be used as reinforcement for plastics, but generally they do not attain the full mechanical performance levels of glass fibers reinforced plastics [8-16].

Among all the natural fibers, coir is a very common in South Asian subcontinent and widely used in various applications such as brushes, floor mats, heavy cord, coarse nets etc. The seed hair fiber coir is obtained from the outer shell or husk of coconut fruit *Cocus nucifera* from the tropical plant of Arecaceae (Palmae) family. This coconut shell is inedible part of coconut fruit which is solid lignocellulosic agro waste. It is an eco-friendly cheap fiber which can be even less expensive than sisal and jute [17]. Coconut shell is 15-20% of coconut; it includes 36-43% cellulose, and related substance containing 41-45% hemicelluloses, 0.15-0.25% lignin, and 3-4% pectin. The cell length is about 0.8 mm, spiral angle 41-45º holding tensile strength of 131-175 MPa, elongation at break 15-40% and tensile modulus of 4-6 GPa [18-21] that is hydrophilic glucan polymer along with linear chain of 1,4-β bonded anhydroglucose unit, which contains alcoholic hydroxyl groups [22]. Coconut fiber is the toughest fiber (21.5 MPa) amongst natural fibers and able to taking strain 4-6 times more than that of other fibers [23, 24]. The chemical components and the mechanical properties of some natural fibers are summarized in Table 1 [21, 25, 26].

Table 1. Chemical composition and structural parameters of some natural fibers

Chemical composition (%)	Types of fiber				
	Coir	Jute	Flax	Sisal	Cotton
Cellulose	36-43	61-71.5	71	67-78	82.7
Hemicelluloses	41-45	13.6-20.4	18.6-20.6	10-14.2	5.7
Lignin	0.15-0.25	12-13	2.2	8-11	-
Pectin	3-4	0.2	2.2	10	-
Wax	-	0.5	1.7	2	0.6
Cellulose length (mm)	-	0.8	2.3	20	2.2
Spiral angle (°)	41-45	8	10	20	-
Moisture content (%)	8	12.6	10	11	-
Water soluble (%)	Some	1.1	3.9	1.2	-
Tensile strength (MPa)	131-175	393-773	354-1100	468-640	287-800
Elongation at break (%)	15-40	1.16-1.5	2.7-3.2	3-7	7-8
Young's Modulus (GPa)	4-6	13-26.5	27.6	5.5-12.6	5.5-12.6

For low cost roofing materials, Cook et al. [27] studied the applications of coconut fiber reinforced cement composites and various parameters such as fiber lengths, fiber volumes, casting pressure for low cost roofing materials. The best results found for composites which contained 3.75 cm length, 7.5% volume fraction and under 1.67 MPa pressure and it was cheaper than that of locally available roofing stuffs. The effect of fillers such as fly ash, Al_2O_3, $Mg(OH)_2$ and hematite powder on the mechanical properties of E-glass/epoxy composites were investigated by Devendra et al. [28]. Composites filled by 10% volume $Mg(OH)_2$ exhibited maximum ultimate tensile strength and hardness and fly ash filled composites found superior impact strength. Harish et al. reported the average values of tensile strength, bending strength and impact strength of 17.86 MPa, 31.08 MPa and 11.49kJ/m² respectively for randomly oriented coir fibers/epoxy composites [29]. The tensile properties of coir-polyester composites were analyzed by Junior et al. [30] and the mechanical features of coir fiber reinforced cement sand mortar were investigated by Slate [31]. The variation of bending strenght with the mass fraction of coir fibers and molding pressure were studied by Monteiro et al. [32]. To increase the mechanical properties and minimize the water absorbency, grafting of monomers onto cellulose based natural fibers by application of radiation can be an effective technique [33]. Sathyanarayana et al. [34] carried a study of fibers from various structural parts of the coconut palm tree have been experimented for properties such as size, density, electrical resistivity, ultimate tensile strength, initial modulus and elongation%. Sandhyarani et al. [35] continued the above methodology and obtained remarkable enhancement on the mechanical characteristics of coir-epoxy composites. Yao et al. [36] studied the use of coir fiber to get good impact toughness of composites. Research is ongoing to replace synthetic fibers with lignocellulosic fibers as reinforcing fillers [37-41]. Nowadays, synthetic polymers are incorporated with various reinforcing fillers to enhance the mechanical properties and obtain the characteristics demanded in actual application [42-44].

The present study deals with the fabrication and mechanical analysis of coir mat reinforced polyester composites. The major purpose of this work was to study the effect of filler materials on the physico-mechanical properties of the composites. After that, to study the effect of filler content, soil degradation test and gamma radiation were performed.

2. Experimental

2.1. Materials

Coir yarn was collected from local market at Sirajgonj and Coir shell powder (CSP) from local market at Barisal, Bangladesh. Unsaturated polyester resin and Methyl Ethyl Ketone Peroxide (MEKP) were collected from Polynt Composite Malaysia.

2.2. Methods

2.2.1. Fabrication of the Composites

Fabrication of composite was done by conventional method called hand lay-up method. A mold of dimension $210\times210\times40mm^3$ was used. Polyester resin with its corresponding hardener (MEKP) in a predetermined ratio was thoroughly mixed. Mold releasing silicon spray was applied to mold releasing sheet and then the chopped fiber, mixed with the resin was gently poured on the sheet which was placed inside the mold. The purpose of releasing agent was to facilitate easy removal of the composite from the mold after curing. The mixture was allowed to set inside the mold for a period of 4 hours under a pressure of 20kg over the cast. After removing the weight, the composite was kept in room temperature for 72 hours. Then the specimen was cut into appropriate dimension for mechanical testing. In this fabrication procedure, seven classes of composites were made with different compositions of CSP in the composites such as 0, 10, 20, 30, 40, 60, 100% filler content by weight. Composites with 0% filler content indicates only coir-polyester composites and filler is not used here. On the other hand, 100% filler content composite indicates CSP filler-polyester composites and coir fiber is not used in this case.

Figure 1. Coir mat reinforced polyester composite with 30% CSP filler

2.2.1.1. Irradiation of the Composites

The composite samples were irradiated using a Co-60 gamma source (25kci) of the Atomic Energy Research Establishment, Savar, Dhaka, for different doses (100, 250 and 500 krad).

2.2.2. Mechanical Testing of the Composites

2.2.2.1. Tensile Test

Tensile tests were conducted according to ASTM Designation: D638-03 using a Universal Testing Machine (model: H50KS-0404, Hounsfield Series S, UK) with a cross-head speed of 10mm/min at a span distance of 50mm. The dimensions of the test specimen were 120mm×15mm.

2.2.2.2. Flexural Test

Static flexural tests were carried out according to ISO 14125 method using the same testing machine mentioned above with a cross-head speed of 60mm/sec at a span distance of 25mm. The dimensions of the test specimen were 60mm×15mm.

2.2.2.3. Impact Test

The impact tests were conducted on unnotched mode composite specimens according to ASTM D 6110-97 using a Universal Impact Tester (HUNG TA INSTRUMENT CO. LTD, Taiwan), hammer mass of 2.63kg, gravity distance of 30.68mm and lift angle of 150º.

2.2.2.4. Water Absorption

Composite samples were immersed in the static water beaker at room temperature for different time periods up to 72 hours. Prior to immersion in water, the specimens were dried in an oven at 105°C, cooled in a desiccators using silica gel and weighed. After certain periods of time, samples were taken out from the bath and wiped using tissue paper, then weighed. Water uptake was determined by the subtraction from final weight to initial weight.

2.2.2.5. Degradation in Soil

Composites samples were buried in soil (having at least 25% moisture) for 50 days. After the composites were withdrawn carefully and washed with distilled water. The excess water from the sample surface was removed by tissue paper. These samples kept at room temperature for 24 hours and then measured the tensile strength properties.

3. Result and Discussion

3.1. Mechanical Properties

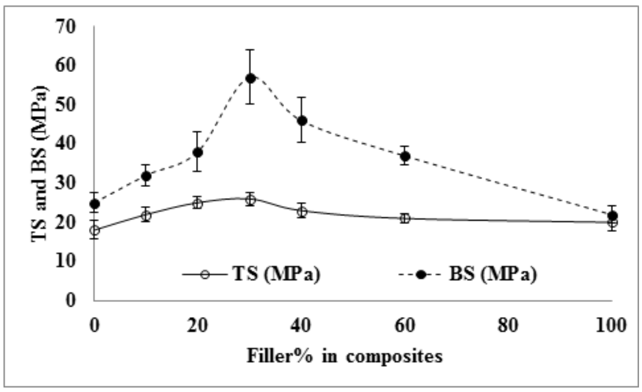

Figure 2. Effect of filler% on tensile strength (TS) and bending strength (BS) of coir-polyester composites

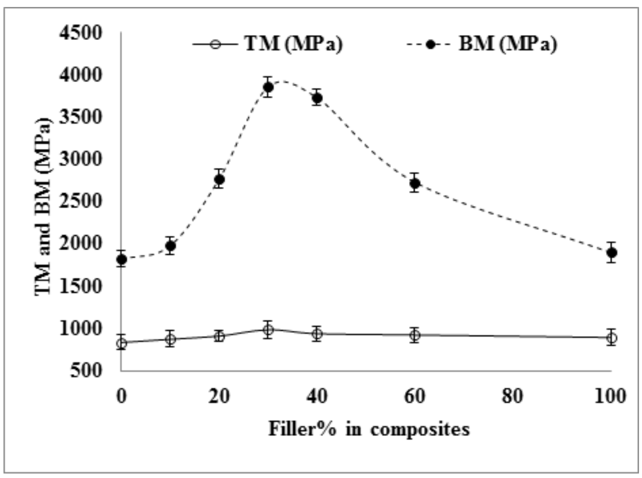

Figure 3. Effect of filler% on tensile modulus (TM) and bending modulus (BM) of coir-polyester composites

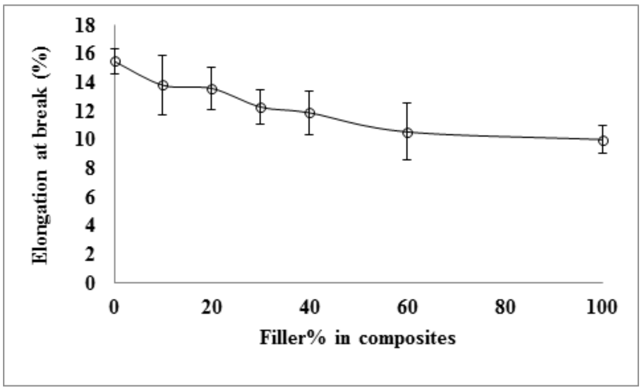

Figure 4. Effect of filler% on elongation at break of coir-polyester composites

Figure 2 shows the effect of filler content (wt%) on TS and BS of the coir mat reinforced polyester composites. It is observed that for 0, 10, 20, 30, 40, 60, 100% filler content the value of TS and BS found to be 18, 22, 25, 26, 23, 21, 20 MPa and 25, 32, 38, 57, 46, 37, 22 MPa respectively. The highest increase of TS and BS found be 44.44% and 128.00% respectively at 30% filler content composites than that of the unfilled one (0% filler), and then the TS and BS of the composites decrease with the addition of filler% in the composites as shown in Figure 2. Leha et al. also studied the effect of filler from 10 to 40% and revealed that 25% filler content composite exhibited the highest TS and BS, then with the addition of filler% it displayed a decreasing trend of mechanical properties up to 40% filler [45]. This decline might be attributed to two reasons: one possibility is that due to the presence of pores at the interface between the filler particles and the matrix, the interfacial adhesion may be too weak to transfer the tensile stress; the other is that the corner points of the irregular shaped particulates result in stress concentration in the matrix body. As the filler content increases, instead of dispersion the gathering of fillers take place and the resin cannot wet the fibers due to non-entrance of resin in-between the two adjacent fibers. The reduction in BS of the composites with filler content is probably caused by an incompatibility of the fillers and the polyester matrix, leading to poor interfacial bonding. The lower values of bending properties may also be attributed to fiber to fiber interaction, voids and dispersion problems. However, it also depends on other factors such as the size, shape and type of the filler material.

TM of the fabricated composites are found to be 835, 873, 910, 985, 939, 924 and 894 MPa for the addition of 0, 10, 20, 30, 40, 60 and 100% filler content respectively. The increase of TM are found to be 4.55, 8.98, 17.96, 12.46, 10.66 and 7.07% for the addition of 10, 20, 30, 40, 60 and 100% filler content respectively as shown in Fig. 3. On the other hand, the BM are 1820, 1980, 2270, 3860, 3730, 2730 and 1900 MPa for 0, 10, 20, 30, 40, 60 and 100% filler content respectively. The increases of BM are found to be 8.79, 52.20, 112.09, 104.95, 50 and 4.40% for 10, 20, 30, 40, 60 and 100% filler addition respectively. It is evident that TM and BM increases with the increased of filler materials up to 30% (by weight) and then it decreases as shown in Fig. 3. Normally, the fibers in the composite restrain the deformation of the matrix polymer, reducing the tensile strain [46, 47]. So even if the strength decreases with filler addition, the TM of the composite is expected to increase as has been observed in the present investigation. But further increases in filler content up to 100 wt%, the TM of the composites are found to be decreasing. The reasons for the lower bending properties at higher filler content are probably due to the weak fiber-to-fiber interaction, void and poor dispersion of fiber in the matrix. Generally, CSP filler offer greater resistance to crack initiation and propagation in the composite. Due to which there is an increase bending strength of composites with coir shell powder filler as compared to without filler.

The elongation at break (%) of the composites for the addition of filler content of 0, 10, 20, 30, 40, 60 and 100% are found to be 15.51, 13.84, 13.61, 12.32, 11.91, 10.58, 10.04% respectively as shown in Fig.4. The elongation at break of the composites decreases with increasing filler content because the addition of filler reduce the mobility and increase the brittleness of the composites. Increasing the amount of filler decreases the amount of fiber available for elongation (Figure 4). The reasons for the lower elongation properties at higher filler content are filler fill-up the void portion of the composites. Generally, CSP filler offer greater resistance to crack initiation and propagation in the composites. Due to which there is a decrease of elongation% of composites with CSP filler as compared to without filler.

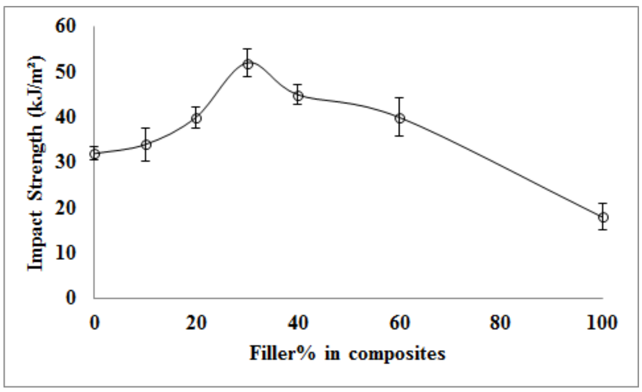

Figure 5. Effect of filler% on the impact strength (IS) of coir-polyester composites

The IS of a material is its capacity to absorb and dissipate energies under impact or shock loading. IS of the composites are found to be 32, 34, 40, 52, 45, 40 and 18kJ/m^2 for the filler content of 0, 10, 20, 30, 40, 60 and 100% in the composites respectively. From the Figure 5, it is observed that the IS increases with the increase in filler content up to 30 wt.% (62.50% improvement than unfilled one) and further it exhibits a declining trend upon filler addition. It has been reported that higher filler content increases the probability of fiber agglomeration and it stress concentration requiring less energy for crack propagation. The maximum IS of the composite increase with filler content up to 30 wt.%. Similar trend were found by Leha et al. [45] where 20% filler content composite showed the best result (0.082 J), then with the increase of filler% in composites, the IS declines up to 0.056 J for 40% filler content composite. The reasons are that the filler is capable of absorbing energy and compression pressure which removes the voids contents in the composites because of appreciative mix-up filler and matrix.

3.2. Effect of Gamma Radiation

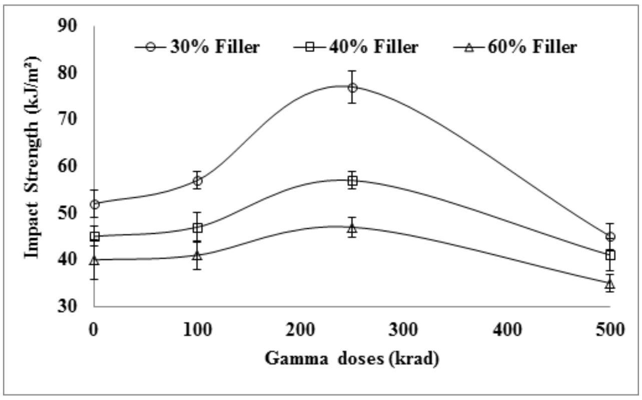

Figure 7. Effect of gamma radiation on impact strength (IS) of the filler content coir-polyester composites

Three types of composites such as 30, 40 and 60% filler content coir mat polyester composites have been treated by gamma irradiation at 100, 250 and 500 krad doses and IS found to be 57, 77, 45 kJ/m^2, 47, 57, 41 kJ/m^2 and 41, 47, 35 kJ/m^2 for the composites of 30%, 40% and 60% filler content respectively as shown in Fig. 7. It is revealed that at 250 krad dose of gamma irradiation, all composites show the maximum improvement of IS which are 48.08, 26.67 and 17.50% for 30, 40 and 60% filler content composites respectively, where 30% filler content composites displays the highest improvement (48.08% increase of IS). IS of the composite is influenced by the interfacial bond strength, the matrix and the fiber. Gamma irradiation may affect the polymeric structure of the coir fiber and polyester matrix, which may produce active sites that can contribute to better fiber and matrix bonding. At low radiation dose, bond scission and cross-linking occurred, but at higher dose scission was preferred. Gamma irradiation may also remove moisture from the composite, which in turn contributed to better fiber matrix adhesion. This may be the reason behind the increased mechanical properties of the composites.

3.3. Soil Degradation of the Composites

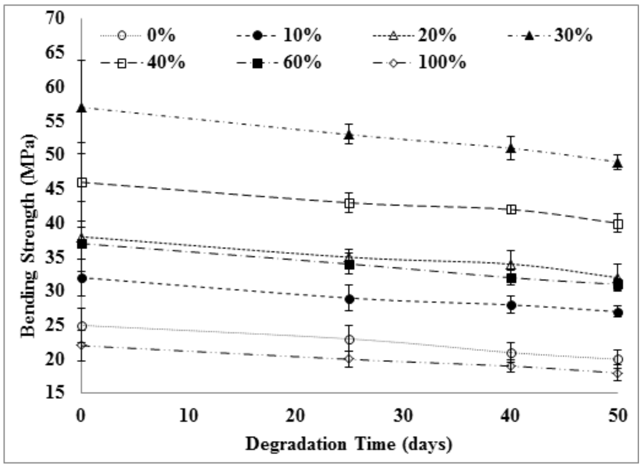

Figure 6. Effect of soil degradation on bending strength (BS) of the filler content coir-polyester composites

After buried in soil for 25 days of the test specimens, the BS are 23, 29, 35, 53, 43, 34 and 20 MPa for 0, 10, 20, 30, 40, 60 and 100% filler content composites respectively as shown in Fig. 6. The loss of BS has been observed 6.6, 8.86, 8.69, 7.03, 7.67, 9.77 and 7.49% for 0, 10, 20, 30, 40, 60 and 100% filler content composites respectively after 25 days of soil degradation. After buried in soil for 40 days, the BS are 21, 28, 34, 51, 42, 32, 19 MPa and loss of BS found to be 13.74, 18.17, 17.88, 15.92, 16.35, 19.02, 16.81% for the composites of 0, 10, 20, 30, 40, 60 and 100% filler content respectively. Finally, after 50 days of soil degradation, the BS are 20, 27, 32, 49, 40, 31, 18 MPa and loss of BS are found 13.74, 18.17, 17.88, 15.92, 16.35, 19.02, 16.81% for the composites containing 0, 10, 20, 30, 40, 60 and 100% filler respectively. Maximum loss of BS is observed 19.02% for 60% filler and minimum loss of BS observed 13.74% for 0% filler content specimens. It is revealed that increasing degradation time reduces the possibility of strength loss of the composites and composite without filler exhibits less BS loss where 60% filler content sample shows highest loss of BS. Moreover, composites containing filler materials display loss of BS drastically. Coir is a natural biodegradable fiber and, because it is cellulose-based, it absorbs water within a couple of minutes, indicating its strong hydrophilic character. Cellulose has a strong tendency to degrade when buried in soil [48, 49]. During soil-degradation tests, water penetrates from the cutting edges of the composites in coir-based samples and degradation of cellulose occurs in coir, microbial degradation may also take place; as a result, the mechanical properties of the composites decrease significantly.

4. Conclusions

Coir polyester composites successfully fabricated with the incorporation of CSP as filler materials. It was revealed that by the incorporation of fillers the mechanical properties were improved than that of the composite without fillers and the maximum improvement were found for 30% filler content. The addition of filler% on composites increased the mechanical properties up to 30% filler but after that it showed a decreasing trend. Gamma radiation of 250 krad exhibited better improvement of impact properties of the composites but further higher doses of radiation decreased the properties. The soil degradation experiment displayed the loss of BS for all the composites where coir mat/polyester composite (without fillers) exhibited minimum loss of BS than that of filler content composites. Finally, it can be concluded that filler% and radiation has significant influence on the mechanical properties of coir polyester composites. The proper optimization of these processing parameters can be a better or viable solution of this composite for our domestic applications.

Acknowledgements

The authors have been acknowledged to the Institute of Radiation and Polymer Technology (IRPT), Atomic Energy Research Establishment (AERE), Bangladesh Atomic Energy Commission, Savar, Dhaka for using their laboratory to complete this work.

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