PROPERTY ENHANCEMENT AND OPTIMIZATION OF POLYPROPYLENE MATRIX FOR AUTOMOBILE APPLICATION: INFLUENCE OF COIR FIBER PROPORTION AND LENGTH

**Akinwande Abayomi Adewale, Barnabas Abel Adeiza, Balogun Oluwatosin Abiodun,
Daniel P. T. and Shittu S. A.**

Department of Metallurgical and Materials Engineering, Federal University of Technology,
Akure, Ondo State, Nigeria.

*Corresponding author email: abypublications@gmail.com

Abstract

Coir-polypropylene composite was developed by the addition of coir fiber treated with 1.7 M NaOH solution for 24 hours at fiber loading 0 – 30 wt. % for automobile application. The fibers were cut to different length of 20 -50mm. Samples produced were subjected to test to examine tensile and flexural strengths and moduli, impact strength and hardness. Microstructural analysis was also carried out. Results obtained reveal rise in tensile strength with increasing fiber proportion up to 15 wt. % before a decline down to 30 wt. %. Increasing fiber length was observed to contribute to appreciation in strength up to 40 mm. Tensile modulus (TM) trended upward with in increased fiber loading up to 30 wt. % for length from 20 to 40 mm and for fiber cut to 50 mm, TM appreciated up to 15 wt. % before eventual depreciation. Results of flexural strength and modulus showed that flexural strength rose with increasing fiber loading up to 30 wt. % for coir fibers cut to 20 to 40 mm. Coir cut to 50 mm, gave increase up to 15 wt. % before eventual decrease in value. Flexural modulus rose from 0 to 30 wt. % for all fiber length except when 50 mm length was incorporated into the composite resulting lower modulus when compared with the ones recorded for coir of 40 mm length.

Keywords: Automobile, Coir fiber, fiber proportion, fiber length, optimization.

1. INTRODUCTION

Automobile is a complex vehicle propelled by internal combustion engine designed to convey passengers or goods from one location to another and it's made of many parts[1]. Some parts are made of metals and their composites, some ceramics and their composites while others are made of polymers and their composites. For fuel efficiency, emphases are made on light materials to be incorporated into vehicles. Of these classes of materials aforementioned, polymer and its composites are the lightest and as such they have drawn attentions of automobile makers. Utilization of these polymers in vehicles has made cars lighter when compared with ones made in the 60s and 70s. Polymeric materials employed in automobile parts are ABS, polyvinyl chloride, polycarbonate and polypropylene. These polymeric materials were chosen based on their engineering properties.

Of these highlighted polymers, the cheapest is polypropylene. Therefore, utilization of polypropylene (PP) in applications where ABS and polycarbonates are used in automobile could be encouraged especially when properties of PP are enhanced despite its limitation.

Improvement on properties of PP can enhance its usage in engineering applications; in this case automobile. In achieving improvement in properties, additives are introduced which could be particulates[2-4] or fibers[5-10] or combination of both [11, 12]. Natural fibers have been engaged by different researchers in enhancing properties of polymer [13, 14] of which polypropylene is not excluded. These fibers are sisal, banana fiber, bamboo fiber, oil palm fruit fiber, kenaf fibers to mention but a few. Selection and utilization of these natural fibers are based on different mechanical properties exhibited. Since natural fibers are cheap, incorporating them into polymer may not necessarily increase the price of polymer composites beyond affordability when compared to the synthetic ones [15, 16]. These fibers have produced different changes in the matrix and properties of the parent materials[17, 18]. Particulates or powders are another form of additives which when integrated in polymer provoke different properties in the finished composite. Particulate/powders serve as fillers [19] in the matrix and can be nano fillers[20], bio-fillers[21, 22] or synthetic fillers [23-25]. In some studies, both fibers and particulate are blended into polymer matrix producing hybrid composites [26-28] of different grades. Consequently, hybrid composites made of the mix of two fibers are common practice in materials development [29-32].

Previous works carried out engaged fibers in polymer matrix produced different results in mechanical and physical properties. Utilization of bamboo fiber in polymer has provided different results in polymer matrix. Bamboo treated in NaOH for 12 hours was incorporated in epoxy composites [33] at different fiber length. Observation made was that at fiber length proportion of 10-30 wt. %, flexural modulus improved. Equally, the same property was enhanced with increasing fiber length. From the study, it could be noticed that incorporation of NaOH treated fiber cut to increasing length of 5, 10 and 15 mm enhanced flexural properties of the fiber. Treatment of fiber, results in removal of wax on fiber surface which eventually promote interfacial adhesion enhancing mechanical and physical properties. Addition of bamboo fiber up to 50 % was noted to give proportional enhancement in PP properties, however, at 60 %, there

was lowering of the values which can be affixed to possible fiber pull out[34]. Another very useful fiber for reinforcement is banana and jute fiber. [35] used banana fiber, jute fiber and combination of the two in epoxy resin. It was observed that longitudinal tensile strength trended upward from 10 – 30 wt. % fiber loading. Jute fiber presented higher longitudinal tensile strength than banana fiber even as combined fiber gave the highest enhancement. [35] linked the fact that lowest value of transverse tensile strength to lower reinforcement-matrix bonding or possible incomplete adhesion of the fiber with matrix. Highest value of property was recorded on incorporation of jute-fiber combination and this was linked to decrease in porosity. Transverse tensile strength peaked at 20 wt. % of the fibers with highest value occurring on addition of the fiber combinations and trended downwards at 30 - 40 wt. % fiber loading depicting a quadratic regression model. Transverse flexural strength peaked at 10 % loading with fall in value from 20 wt. % while the longitudinal tensile strength attained its maximum at 30 wt. % fiber loading. Improvement of up to 126 % were recorded in this study for banana/jute fiber combination based on higher compatibility, as well as dispersion in hybrid composites amounting to even stress distribution within composite. Owing to availability and the cheaper cost of coir fiber, the fiber was utilized in the study with respect to varying proportion and fiber length as carried out in epoxy [36], polyester [37], high density polyethylene [38] and polypropylene [39]. Coir fiber and coconut shell powder were utilized in enhancing properties of PP matrix for automobile application putting into consideration the fact that polypropylene is cheaper than commonly used plastics used in automobile (ABS, PC, PVS) and coir fiber and coconut shell powder are cheaper since they are agro waste materials.

2. MATERIALS AND METHODS

Materials used in the study are polypropylene, coir fiber obtained from coconut shell, coconut shell powder which was gotten by milling of the shell and sieving to $-75\ \mu\text{m}$, sodium hydroxide (NaOH) and distilled water. The coir fibers were washed using distilled water and air dried for 3 days after which they were treated in 1.7 M NaOH aqueous solution for 24 hours. Afterwards the fibers were rinsed with distilled water and air dried for another 5 days. Sequel to this was the cutting of the fiber into lengths of 10, 20, 30 and 40 mm. Polypropylene composite samples were produced by the blending of coir (cut to the length of 20, 30, 40 and 50 mm) at varied proportion of 0, 5, 10, 15, 20, 25 and 30 wt. % of polypropylene with coconut shell powder (10 wt. %). Compounding was done in even distribution of the fiber and compression moulding machine was used in moulding into samples for different tests. Tests were carried out for tensile and flexural properties, hardness and impact strengths in line with [40-43] [ASTM D3039M-17] [ASTM D790-17] [ASTM D256-10] [ASTM D785-08] respectively. Tensile test was carried out using dumb bell shaped samples of dimension 90 mm x 10 mm x 5 mm employing a universal testing machine (WDW-100). Applied load of 100N was applied at 5 mm/min. Average value of the three test samples representing each mix was obtained and further evaluation was carried out in determining tensile strength and tensile modulus. Flexural test was carried out on samples of 120 mm length, width of 15 mm with thickness of 3 mm under 3 points bending tests using the same testing machine and loading rate of 10 mm/min. Izod impact test was done on samples 64 mm long and 11 mm having thickness of 3mm and notched at the center. Hounsfield balanced impact testing machine (serial number 3915-h10-5) was employed and values after fracture were

recorded. Rockwell hardness was done on samples 6mm thick using a ball indenter of diameter 1.588 mm and applied force of 100 N in line with [43] [ASTM D 785].

3. RESULTS AND DISCUSSION

3.1 Tensile strength (TS) and tensile modulus (TM)

a. Analysis of experimental results

Fig. 1(a): Influence of coir weight fraction (0, 5, 10, 15, 20, 25 and 30 wt. %) and fiber length (20, 30, 40, 50 and 60 mm) on (a) tensile strength (b) tensile modulus.

Influence of fiber proportion and fiber length on tensile strength revealed (Fig. 1) was noted to appreciate in value from 0-20 wt. % fiber for 20 mm fiber length, after which there was fall in value. For 30-50 mm length of fiber, TS rose from 0 and peaked at 15 wt. % fiber after which there was depreciation in the values. The increase in the strength with fiber weight fraction can be associated with enhanced interfacial adhesion with the matrix at that weight fraction. Alkaline modification exposes the roughness of the fiber surface thereby improving fiber matrix adhesion[44]. Reduction in TS was experienced attributable to fiber clog/intertwine and complex fiber network formed within matrix which further inhibits the stretching of the samples. Results obtained in Fig. 1 as per performance at respective fiber fraction corroborates the observations of [45, 46, 47, 48] in which values of TS peaked at 15-20 wt. % fiber. TS rose with increasing fiber length up to 40 mm (Fig 1) after which there was consistent reduction up to 50 mm implying coir fiber length up to 40 mm is adequate in increasing tensile strength. With fiber presence > 40 %, there is higher tendency of fiber interlocking amounting into reduced flexibility of fiber.

TS was found to improve with increasing coir fiber length up to 40 mm after which there was reduction. Higher fiber length improves interfacial bonding and flexibility. Reduction in the strength when introducing 50 mm coir fiber may be connected to possible fiber interlocking. For optimum value of TS coir fiber length ≤ 40 mm is recommended.

Values obtained in this study ranged from 18.4 to 35.9 MPa with 39.5 being the highest TS when 15 wt. % coir fiber of length 40 mm was incorporated into polypropylene matrix which is higher than the value obtained in previous study [45, 47] where 1-3mm fiber length was used. The discrepancy is traced to fiber length utilized in that the fiber is longer in this study as compared to length of fiber employed in that study[47].

Tensile modulus (TM) as indicated in Fig. 1(b) trends upward with increment in fiber weight fraction. This ensued based on increased toughness as a result of fiber inclusion. Presence of fiber within matrix serve as obstacle to the free movement of dislocation [49] and this improves strain hardening with consequent increase in strain, effectuating higher stiffness. As per tensile modulus, result obtained tallies with observations of [46, 50, 51]. TM was noted to increase from 0-25 % in the study. With respect to the fiber length, the modulus appreciated in value from 20 mm to 40 mm. A contrast behaviour was exhibited when 50 mm fiber length was added, in that tensile modulus reduced. Also, when considering weight fraction of coir fibers cut to 50 mm, TM trended upward between 0 and 20 wt. % and at 25 and 30 wt. % there was reduction. Therefore maximum value was attained for TM fiber length when 30 % of treated coir fiber cut to 30 mm was incorporated into polypropylene matrix. In [52], TM increased with coir fiber length from 0 to 35 mm. This observation agrees with the result obtained in this study affirming the reinforcement ability of coir fiber.

b. Regression model of Tensile strength and tensile modulus of coir-polypropylene of varying lengths

Fig. 2: Regression model for Tensile strength at varied coir fiber proportion and lengths of (a) 20 and 30 mm (b) 40 and 50 mm

Fig. 2 presents regression model reflecting relationship between tensile strength and coir fiber weight percent with models depicting quadratic equations for the 4 models. Coefficients of determination R^2 are 0.9457, 0.9524, 0.9817 and 0.8469 for fiber length 20, 30, 40 and 50 mm length. From the value of the R^2 , deduction made is that as fiber length increased, there is higher

correlation between tensile strength and weight fraction of the fiber which climaxed when fiber length was 40 mm.

c. Regression model of tensile modulus of coir-polypylene of varying lengths

Fig. 3: Regression model for tensile modulus at varied coir fiber proportion and lengths of (a) 20 and 30 mm (b) 40 and 50 mm

Fig. 3 highlights linear regression model reflecting the relationship between tensile modulus (TM) and coir fiber weight percent at 20mm to 50 mm length. Coefficients of determination R^2 are 0.9691, 0.9807, 0.9767 and 0.8469 for fiber length 20, 30, 40 and 50 mm length. From the value of the R^2 , deduction made is that as fiber length increased from 20 to 30mm, there is higher correlation between tensile modulus and fiber proportion. With increasing fiber loading (coir fiber 40 mm), the value was lower, however the model still shows 98% correlation. In the case of coir fiber of 40 mm, the relationship is linear as depicted in Fig. 3b with 97 % correlation. Correlation for tensile modulus vs fiber weight fraction for coir fiber cut to 50 mm is quadratic (best line of fit) with R^2 of 0.9403.

d. 2D contour and 3D response surface plot for tensile strength

TS and TM represent tensile strength and tensile modulus.

Fig. 4: Variation in tensile strength and modulus with simultaneous combination of fiber proportion and fiber length as represented in (a) 2D contour plot (b) 3D response surface plot for tensile strength and (c) 2D contour plot (d) 3D response surface plot for tensile modulus.

From the plot (Fig 4a), region A indicates area in which TS is greater than 30 MPa (area in which maximum TS value of 35.9 MPa was attained). The implication is that to achieve TS value above 30 MPa, coir fiber proportion (treated in 1.7M NaOH solution) is between 13 and 22.8 wt. % while fiber length is in the range of 20 to 47 mm. As the plot trended towards region B, the strength reduced (between 28 and 30 MPa). In attaining 28 – 30 MPa, fiber proportion would be between 9.5 – 13 wt. % and 22.8 – 26.5 %, while fiber length will be in the range of 20-50 mm. Region C is the portion where tensile of 26 to 28 MPa can be attained with fiber

proportion of 7.2 - 9.5 MPa and 26.5 -29.5 MPa while fiber length lies between 20 to 50 mm. Tensile strength of 24 – 26 MPa lies in region D with fiber loading 5.4-7.2 % and 29.5 – 30 %. Region E with fiber proportion of 3-5.4 coir fiber and length 20-50 mm length will produce composite of 22-24 MPa, while region F requires fiber content of 2.2-3 wt. % (length 20-30 mm) will produce 20-22 MPa. Also, region G and H are portions where strength value of 18-20 MPa at fiber proportion of 0.9-2.2 wt. % (length 20-30 mm) is attained.

The 3D response surface plot (3DRSP) (Fig. 4b) is dome shaped affirming the quadratic regression model obtained at varying fiber proportion. This plot shows increasing value for TS as a consequence of increasing fiber wt. fraction and fiber length up to maximum (turning point) after which there was further decline. Optimization response carried out depicts optimum tensile strength of 31.8 MPa with the inclusion of 17 % wt. coir fiber, length 30.9 mm.

e. 2D contour and 3D response surface plot for tensile modulus

From the plot (Fig. 4c), region A indicates area in which TM is between 1.2-1.4 GPa (area in which maximum TM value of 1.59 MPa was obtained). Implication of this is that to achieve TM value between 1.2-1.4 GPa coir fiber proportion (treated in 1.7M NaOH solution) must be between 27 and 30 wt. % while fiber length is in the range of 20 to 42 mm. Consequently, in region B tensile modulus ranged between 1-1.2 GPa; which is achieved with fiber proportion of 16.8 to 27 wt. % coir fiber cut to length of range of 20 to 50 mm. Region C is characterized with modulus value of 0.8 – 1.0 GPa and this can be realized when fiber proportion of 8.5-16.8 wt. % was added at fiber length of 20 to 50 mm. Region D also presents region in which less than 0.8 GPa modulus will be recorded. Alkaline treated fiber of length 20 to 50 mm at weight fraction of 0 - 8.5 % will achieve that.

The 3D response surface plot (3DRSP) (Fig. 4d) shows uptrend at the combination of fiber proportion and fiber length up to peak. Optimization response carried out depicts optimum tensile modulus of 1.49 GPa with the inclusion of 30 % wt. coir fiber, length 29.7 mm.

3.2 Flexural strength (FS) and flexural modulus (FM)

a. Analysis of experimental results

Fig. 5(a): Influence of coir weight fraction (0, 5, 10, 15, 20, 25 and 30 wt. %) and fiber length (20, 30, 40, 50 and 60 mm) on (a) flexural strength (b) flexural modulus.

Flexural strength (FS) of treated coir fiber reinforced polypropylene composite is depicted in Fig. 5a. FS peaked at 30 wt. % coir fiber addition (cut to 40 mm) which is in tandem with the study of [46, 51]. Maximum value attained in this study for FS is 61.5 MPa which gave an increase of 95.9 % relative to 31.4 MPa recorded at 0 wt. % fiber.

While considering fiber length, it was observed that flexural strength improved with increasing fiber length from 20 – 40 mm. The increase can be linked to fiber network formed and improved adhesion as a result of alkaline treatment of the fiber. Addition of 50 mm fiber length presented appreciation in FS from 5 to 15 wt. % coir while depreciation was noted from 20 to 30 wt. % coir addition and this can be traced to fiber clog and interlocking which reduced resistance to bending. [53] reported higher value of FS with increment in fiber length from 10 to 30 mm. This validates the discovery made in this study as per variation in fiber length. Studies of [54] exposed rise in flexural strength of developed polypropylene composite reinforced with Banana/glass fiber from 0 to 30 % of the fiber, a scene also reported in this study. The study of [55] also affirm rise in flexural strength of up to 40 % on addition of kenaf fiber to polypropylene matrix. This observation validates observations made in this research in that incorporation of agro waste fibers enhances flexural strength.

Flexural rigidity (modulus) varies increasingly with fiber loading up to 25 % before slight reduction in value on incorporation of 30 wt. % coir fiber. With fiber length from 20 mm to 50 mm rigidity improved on the dint of even stress distribution and transfer within matrix based on fiber presence. Alkaline treatment of the fiber contributed to the feat. The uptrend in FM with fiber loading corroborates the study of [50] [56] [57] [51]. At increasing fiber content, lower

flexural strain was reported indicating enhanced rigidity at higher weight fraction of fiber. [50] linked this to entanglement between polymer chain and fiber.

b. Regression model of flexural strength of coir-polypropylene of varying length

Fig. 6: Regression model for flexural strength at varied coir fiber proportion and lengths of (a) 20 30 mm (b) 40 and 50 mm.

The regression model as represented in Fig 6 a and b is linear reflecting a linear relationship between flexural strength (FS) and coir fiber weight percent at 20mm to 40 mm length. Best line of fit at 50 mm length presented a quadratic regression model in which TS value rose to a peak before decline. Coefficients of determination R^2 are 0.9774, 0.9753, 0.9589 and 0.9378 for fiber length 20, 30, 40 and 50 mm length respectively. From the value of the R^2 , deduction made is that as fiber length increased from 20 to 40mm, there is lower correlation between FS and fiber loading.

c. Regression model of flexural modulus of coir-polypropylene of varying length

Fig. 7: Regression model for flexural modulus (FM) at varied coir fiber proportion and lengths of (a) 20 and 30 mm (b) 40 and 50 mm.

The regression model as represented in Fig 7 a and b is linear reflecting a linear relationship between flexural modulus (FM) and coir fiber weight percent at 20mm to 50 mm length. Coefficients of determination R^2 are 0.9454, 0.8931, 0.8881 and 0.8792 for fiber length 20, 30, 40 and 50 mm length respectively. From the value of the R^2 , correlation between the data values and flexural modulus response reduced with curing length, though increased with fiber loading.

Fig. 8: Variation in flexural strength and modulus with simultaneous combination of fiber proportion and fiber length as represented in (a) 2D contour plot (b) 3D response surface plot for tensile strength and (c) 2D contour plot (d) 3D response surface plot for tensile modulus.

d. 2D contour and 3D response surface plot for flexural strength

From the 2D contour plot (Fig 8a), region A indicates area in which FS is above 50 MPa (area in which maximum FS value of 61.5 MPa was obtained). Therefore, in attaining FS value above 50 MPa, coir fiber proportion (treated in 1.7M NaOH solution) should be between 15.5 and 30 wt. % while fiber length is in the range of 21.8 to 50 mm. Region B flexural strength ranged between 45 and 50 MPa; which is achieved with fiber proportion of 9.5 to 15.5 wt. % coir fiber cut to length of range of 20 to 50 mm. Region C is characterized with flexural strength of 40-45 MPa and this can be realized when fiber proportion of 4.8-9.5 wt. % fiber is added at length of 20 to 50 mm. Region D (flexural strength 35 to 40 MPa) presents region in which 35 to 40 MPa flexural strength will be realized with incorporation of coir cut to 20 to 50 mm length in weight fraction of 0-4.8 %. In the case of region E alkaline treated fiber of length 20 to 36 mm and 45.7 to 50 mm at weight fraction of 0 –5.8 % will give FS value of 30 to 35 MPa. Finally, region F shows that attainment of 25 to 30 MPa flexural strength of treated coir-polypropylene composite requires fiber proportion of 0-4.2 wt. % at fiber length of 20 to 25.7 mm.

The 3D response surface plot (3DRSP) (Fig. 8b) shows uptrend at the combination of fiber proportion and fiber length up to peak. Optimization response carried out depicts optimum tensile modulus of 54 MPa with the inclusion of 29.7 % wt. coir fiber, length 36.05 mm.

e. 2D contour and 3D response surface plot for flexural modulus

From the 2D contour plot (Fig 8c), region A indicates area in which FM is above 1.6 GPa (area in which maximum FS value of 1.68 GPa was obtained). Therefore, in attaining FM value above 1.68 GPa, alkaline coir fiber proportion should be between 23.5 and 30 wt. % while fiber length is in the range of 32 to 50 mm. Region B FM ranged between 1.5 and 1.6GPa; which is achieved with fiber proportion of 14.2 to 23.5 wt. % coir fiber cut to length of range of 26.8 to 50 mm.

Region C is characterized with flexural modulus of 1.4-1.5 GPa and this can be realized when fiber proportion of 19.2-30 wt. % fiber is added at length of 20 to 50 mm. In region D, FM of 1.3 to 1.4 GPa will be attained with incorporation of coir cut to 20 to 50 mm length in weight fraction of 9.7-19.2 %. Region E is the area in which 1.2 – 1.3 GPa flexural modulus can be attained and in achieving this, coir fiber of length 20 to 50 must be incorporated into polypropylene matrix in weight fraction of 3.7 – 9.7%. F shows region in which flexural modulus will be less than 1.2 GPa when 0-3.7 wt. % fiber cut to 0 to 26.5 mm is added.

The 3D response surface plot (3DRSP) shows uptrend at the combination of fiber proportion and fiber length up to peak. Optimization response carried out depicts optimum tensile modulus of 1.63 GPa with the inclusion of 30 % wt. coir fiber, length 45.15 mm.

3.3 Impact strength (IS) and Hardness (HD)

a. Analysis of experimental results

Fig. 9: Influence of coir weight fraction (0, 5, 10, 15, 20, 25 and 30 wt. %) and fiber length (20, 30, 40, 50 and 60 mm) on (a) impact strength (b) hardness.

Impact strength

Fig. 9 presents variation of Izod impact strength at different weight fraction of coir fiber at different length between 20 to 50 mm. There was rise in impact strength from 0 wt. % to 25 wt. % of the fiber cut to 20 – 30 mm. This feat ensued on account of strong interfacial linkage formed and the ability to absorb energy [48]. Integration of 30 wt. % fraction of fiber resulted in lower impact strength. According to [58], with increasing fiber content, there is increased tendency of fiber agglomeration which serves as region of stress concentration impacting brittleness in the material. Similar to the occurrence when 20 to 30 mm fiber was added, effect of 40 mm coir fiber length improved impact strength but up to 15 wt. %. Lowering of impact strength at 20 to 30 wt. % of fiber cut to 40 mm length can be associated with agglomeration of fiber and entanglement. Maximum impact strength was realized when 25 wt. % fiber of length 30mm and when 20 wt. % of length 40 mm were integrated into the polymer matrix. Utilization

of bamboo fiber in polypropylene in [59] was observed to give increasing value for impact strength up to 60 wt. % of the fiber. Same experience was noted in [60] in which IS increased up to 30 wt. % of coir affirming result of this study. Also, in [61], utilization of bamboo fiber as reinforcement in polypropylene led to appreciation in impact strength with fiber loading from 17 to 58 % bamboo fiber just as highlighted in this study.

Hardness value of polypropylene reinforced with coir fiber at fiber loading 0 to 30 wt. % cut to 20 to 50 mm length pinpoint appreciable increase in hardness with respect to fiber loading. Meanwhile, with respect with fiber length, there was no appreciable increase implying fiber length contributes little to hardness of the composite developed. Hardness increase with respect to fiber loading is linked to increase stiffness exhibited in the composites [60]. It is also traced to enhanced interfacial adhesion within the matrix. Maximum hardness is attained when 30 % weight fraction of the fiber (length of 50 mm) was utilized in reinforcing the polymer. At that point, enhanced hardness may ensue based on complex fiber network created within the matrix resulting in enhanced resistance to indentation.

b. Regression model of impact strength of coir-polypropylene of varying length

Fig. 10: Regression model for impact strength (FM) at varied coir fiber proportion and lengths of (a) 20 and 30 mm (c) 40 and 50 mm.

The regression model of the best line of fit are as represented in Fig 10 a and b. The models are quadratic with coefficient of determination (R^2) being 0.8221, 0.9243, 0.956 and 0.9757 for coir fiber weight percent at 20mm to 50 mm length. From the value of the R^2 , correlation between the impact strength response and fiber weight proportion increased with fiber length.

c. Regression model of hardness of coir-polypropylene of varying length of coir

Fig. 11: Regression model for hardness (HD) at varied coir fiber proportion and lengths of (a) 20 and 30 mm (c) 40 and 50 mm.

The regression model as represented in Fig 11 a and b is linear reflecting a linear relationship between hardness (HD) and coir fiber weight percent at 20mm to 50 mm length. Coefficients of determination R^2 are 0.9803, 0.9927, 0.9868 and 0.9926 for fiber length 20, 30, 40 and 50 mm length respectively. From the value of the R^2 , there is very high level of correlation between the data fiber input and hardness response.

d. 2D contour and 3D response surface plot

Fig. 12: Variation in impact strength (IM) and hardness (HD) with simultaneous combination of fiber proportion and fiber length as represented in (a) 2D contour plot (b) 3D response surface plot for tensile strength and (c) 2D contour plot (d) 3D response surface plot for tensile modulus.

d. 2D contour and 3D response surface plot for impact strength

From the 2D contour plot (Fig 12a), region A indicates area in which IM is above 65 J/m (area in which maximum FS value of 68 J/m was obtained). Therefore, in attaining IS value above 65 J/m, coir fiber proportion (treated in 1.7M NaOH solution) should be between 14.5 and 22.5 wt. % while fiber length is in the range of 27.5 to 38 mm. Region B IS ranged between 60 and 65 J/m; which is achieved with fiber proportion of 5.75 to 29.7 wt. % coir fiber cut to length of range of 20 to 47.5 mm. Region C is characterized with impact strength of 55-60 J/m and this can be attained when fiber proportion of 9.2-30 wt. % fiber is added at length of 20 to 50 mm. Region D presents region in which 50 to 55 MPa flexural strength will be realized with incorporation of coir cut to 20 to 50 mm length in weight fraction of 5-9.2 % and 30 wt. %. In the case of region E alkaline treated fiber of length 20 to 30.3 mm at weight fraction of 2.2 – 5.8 % will give FS value of 45 to 50 J/m. Finally, region F shows that attainment of less than 45 J/m impact strength of treated coir-polypropylene composite requires fiber proportion of 0-2.2 wt. % at fiber length of 20 to 22.5 mm.

The 3D response surface plot (3DRSP) (Fig 12b) is dome shaped affirming the quadratic regression model obtained at varying fiber proportion. This plot shows increasing value for IS as a consequence of increasing fiber wt. fraction and fiber length up to maximum (turning point) after which there was further decline. Optimization response carried out depicts optimum tensile modulus of 65.77 J/m with the inclusion of 17.88 wt. coir fiber, length 44.94 mm.

e. 2D contour and 3D response surface plot for hardness

From the 2D contour plot (Fig 12c), region A is the portion in which hardness records value above 105 HRc and fiber proportion is between 28 to 30 wt.% at fiber length of 37.2 to 50mm. Second region from the left (region B) is characterized with hardness value between 100 and 105

HRc and attained between fiber portion of 23.8 and 30 wt. %; fiber length between 20 and 50 mm. In region C, hardness value of 95 to 100 HRc can be achieved at fiber fraction between 17.8 and 23.8 %; length of 20 to 50 mm. The 4th portion (region D), with fiber loading of 11.4 and 12.8; length 20 to 50 mm, hardness value of 90 to 95 HRc can be realized. To achieve HD of 85 to 90 HRc, fiber loading of 4.2 to 11.4 wt. %; length of 20 to 50 mm is adequate. Finally, for hardness less than 85 HRc, fiber proportion of 0 to 4.2 %; length of 20 to 50 mm will suffice.

The 3D response surface plot (3DRSP) (Fig. 12d) is trended upward with increasing combination of fiber proportion (0 to 30 wt. %) and fiber length (20 to 50 mm) affirming the linear regression model obtained at varying fiber proportion. Optimization response carried out depicts optimum tensile modulus of 105.83 HRc with the inclusion of 30 wt. coir fiber, length 50 mm.

Optimization

Minitab 17 was employed in analyzing property values towards realizing optimum mix proportion with respect to fiber content and length. Optimum value was fiber proportion of 25.76% at fiber length of 34.85mm with desirability of 0.7513. Table 2 indicates optimum value for each property considered.

Table 1: Optimized Values of property of Coir/Coconut shell powder (25.76 wt. % Coir fiber of length 34.85 mm.

Properties	Value	Desirability
Tensile strength	29.41 MPa	0.6291
Tensile modulus	1.4282 GPa	0.7926
Flexural strength	53.6916 MPa	0.7221
Flexural Modulus	1.5829 GPa	0.7978
Impact strength	64.0909 J/m	0.8036
Hardness	99.9218 HRc	0.7792

Conclusion

Influence of coir fiber weight fraction and length on polypropylene matrix was evaluated and optimized. From the result, it was analysed that coir fiber improved enhanced strengths with increasing proportion even as fiber length up to 40 mm improved the properties. Optimization carried out via surface response employing Minitab version 17 shows that mix proportion of 25.67 wt. % and 34.85 mm length will give optimum performance of automobile application.

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