Enhancement of behaviors of Areca Fine Fiber/Phenol Formaldehyde Composite by the Addition of Oxide and Carbide Particles

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Abstract: In this paper, the influence of silicon carbide (SiC) and alumina oxide (Al_2O_3) on the mechanical properties of areca fine fiber (AFF) reinforced phenol formaldehyde (PF) composites were studied in three stages. Virgin AFF/PF composites were prepared and studied to find out the optimal fiber content in order to attain improved mechanical properties in first stage. In the second stage, the impact of particle content on the mechanical properties of AFF/PF composites prepared by optimum fiber content was evaluated. The influence of grain size on the AFF/PF composites fabricated with the optimum particulate content was studied in the third stage. The results of fist stage revealed that 40% AFF composite showed the superior mechanical properties in comparison to others. It was observed from the results of the second stage that the SiC particles have better enhancing influence on mechanical properties of AFF/PF composite in comparison to the Al_2O_3 particles. The results of third stage revealed that the SiC particles (5 µm) filled AFF/SiC/PF composite revealed improved mechanical properties in comparison to the others. The optimal content for both the particulates were 7.5 wt%.

Keywords: Phenol formaldehyde, Areca fine fibers, Silicon carbide, Alumina oxide, Mechanical properties

INTRODUCTION

For the last decades, the uses of natural cellulose fiber-polymer composites in engineering and research fields have increased swiftly. Many works have been finished on the natural fiber polymer composites and their outcomes showed that the natural cellulose fiber reinforced polymer composites possess decent specific properties. Nevertheless, they do not compromise the strength of synthetic fiber-reinforced polymer composites [1,2]. Natural fibers have many advantages such as less weight, reduced cost, biodegradable and adequate specific assets, over man-made synthetic fibers (glass, carbon and aramid). Besides the advantages, they have several drawbacks such as low impact strength, dimensional instability, low thermal stability and high moisture absorption tendency [3, 4, 5]. The belongings of natural fiber polymer composites were enlarged by the addition of another element to it. It may be another fiber or filler (particulates). Several authors have made researches on the consequence of hybridization on the ability of the natural fiber polymer composites [6, 7, 8, 9]. Among various natural cellulose fibers, areca fibers are promising and very high potential fibers in various fields of applications. Areca plants come below the family of Palmecea and are abundantly available in the East and South region of Southern India. All parts of areca plants have been used in many traditional applications with a long history of usage. The arecanut has been extensively used as an anthelminitic in men, and particularly in veterinary practices. They are also used in paint, chewable gutka, chocolate and herbal tooth brush, etc. The arecanut has 60-80% of husk with the fiber, which have the average fiber length of 40 mm. There are two types of areca husk fibers: coarse and fine. These arecanut husks after removing of nut is thrown out as a waste material on the other plantation, which causes bad, harmful odor and also causes harmful effects on the quality of land. Therefore, the researchers are using these fibers as a reinforcing representative in polymer matrix freshly. Extensive learning has been executed on properties the areca fiber-reinforced polymer composites [10, 11, 12, 13, 14]. To strengthen the performance of areca fiber-reinforced polymer composites, areca fibers were treated many physical and chemical treatments and their consequence on the mechanical abilities of polymer composites were evaluated by several researchers [15, 16]. But, no one yet aimed to evaluate the mechanical effect of areca fiber-reinforced polymer composites with the inclusion of particles. Currently, there is no detailed literature available on the mechanical properties of areca fiber reinforced phenol formaldehyde filled the particulates like silicon carbide and alumina oxide. In this paper, a try is shaped to examine the effect of two particulates (carbide particle and one oxide particle) on the mechanical abilities of the AF/PF composites. The main aim of this paper is to identify the effects of these two different particulates, weight fraction and size of the particles on the mechanical properties of AF/PF composites. The weight fraction of the particulates is 2.5, 5, 7.5 and 10 wt%, respectively. Besides, the size of the particulates is 5, 10 and 15 microns, respectively. Composite plates with particulates are developed by hand lay-up technique at room temperature. Mechanical tests were performed on the composite specimens as per the ASTM standards at ambient temperature.

EXPERIMENTAL DETAILS

Materials

Areca fine fibers: The areca fine fibers are gathered from the DINA fiber industry, Nagarcoil, Tamilnadu, India. The fibers are cut into short form and utilized as reinforcement as obtained condition. The fibers are tested at SITRA, Coimbatore, Tamilnadu, India to obtain the chemical configuration and physical properties. The abilities of natural fibers varied according to the growing nature. The physical properties and chemical configuration of the areca fine fibers are tabulated in Table 1.

Table 1. The chemical configuration and physical properties of the areca fine fibers

Chemical Composition (%)		**Physical properties**	
Cellulose	57.52	Diameter (mm)	0.285-0.89
Hemicellulose	33.21	Length (mm)	18-40
Lignin	6.19	Density (g/cm^3)	1.05-1.25
Moisture content	1.80	Ultimate stress (MPa)	89.5-118.67
Ash content	1.28	Elongation at break (%)	11-12.5

Phenol formaldehyde: A resole type phenol formaldehyde resin was utilized as polymer matrix The physical properties of PF resin are measured in Saint Gobin India, Chennai, Tamilnadu, India. Table 2 gives the physical properties of PF.

Table 2. Physical properties of phenol formaldehyde resin

Physical properties	
Specific gravity	1.12-1.16
Polar surface area (Å^2)	9.23
Flash point (^{o}C)	72.5
Boiling point (^{o}C)	181.8
Composition	Carbon-Carbon
Elongation at break (%)	2
Density (g/cm^3)	1.3

Alumina oxide and silicon carbide particles: Alumina oxide (Al_2O_3) and silicon carbide (SiC) micro particles are purchased from SNAM Abrasives (p) Ltd., Hosur, Tamilnadu, India. The typical properties of particulates are tabulated in table 3.

Table 3. The typical properties of the areca fine fibers

Silicon carbide		Alumina oxide	
Density (g/cm^3)	3.1	Density (g/cm^3)	3.69
Flexural strength (MPa)	550	Flexural strength (MPa)	330
Elastic Modulus (GPa)	410	Elastic Modulus (GPa)	300
Poisson’s ratio	0.14	Poisson’s ratio	0.21
Hardness (Kg/mm^2)	2800	Hardness (Kg/mm^2)	1175
Compressive strength (MPa)	3900	Compressive strength (MPa)	2100

Manufacturing of Composite specimens

A mold box with the size of 150 mm x 150 mm x 3 mm was utilized to manufacture the composites. Prior to use, a releasing agent was sprayed inside the mold box to confirm the easy elimination of healed composite plates. The short fibers with the length of 3 mm are added with PF resin by using the mechanical stirrer for 30 min. Then the alumina oxide and the silicon carbide micro particles are also mixed with resin mixture and once again stirred mechanically for 30 min to ensure the homogeneous composition. Finally, the composition was poured into the mold uniformly and then, the mold box is sealed and permitted to heal at room temperature under ambient pressure.

Characterization of Composite specimens

The tensile properties of composite specimens are calculated as per the ASTM D638-10 on FIE universal testing machine. The 3-point flexural abilities are performed on the composite specimens as per ASTM D790-10 calibre using universal testing machine. All the tests are performed at room temperature and pressure. Five specimens are used for each combination at each test and their mean value was documented for further discussion.

RESULTS AND DISCUSSION

Influence of Fiber Content on the Mechanical Properties of AFF/PF Composite

In the first stage of this study AFF/PF composites with the different fiber stuffing of 10, 20, 30, 40 and 50 wt% were fabricated and characterized according to ASTM standards to evaluate the tensile and flexural properties.

Tensile Properties**:** The impacts of fiber content on the tensile abilities of the AFF/PF composites are indicated in Fig. 1. As the fiber content rises, the tensile properties of the composite specimen increase slowly. The higher rate of tensile strength of 49.7 MPa was noticed at an AFF fiber content of 40 wt%. When the fiber stuffing is rises the tensile strength increased up to fiber content of 40 wt% and then decreased. Besides, the tensile modulus rates were also improved linearly from 10 wt% to 40 wt%, after that decreased. The maximum tensile modulus 1271.7 MPa was obtained at 40 wt% composite.

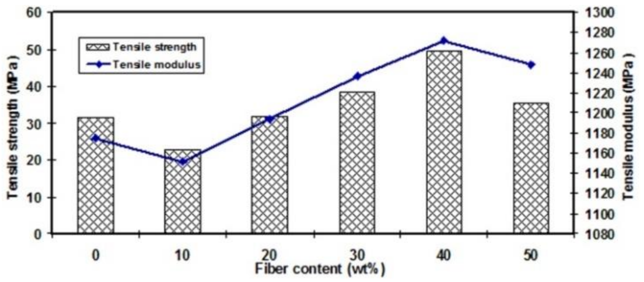

Fig.1. Variations of tensile properties of AFF/PF composite according to the fiber content

Flexural Properties: The influence of AFF fiber stuffing on flexural abilities of AFF/PF composites is indicated in Fig. 2. It is seen that the flexural ability of composites improved with increase of fiber strength up to 40 wt%, after that it is decreased. Moreover, the flexural modulus values are also increased linearly up to 40 wt%, like in tensile modulus. The higher rate of flexural ability and modulus are achieved at 40 wt%. The flexural ability and modulus of 40 wt% composite are 75.54% and 11.68% powerful than the zero fiber stuffing sample.

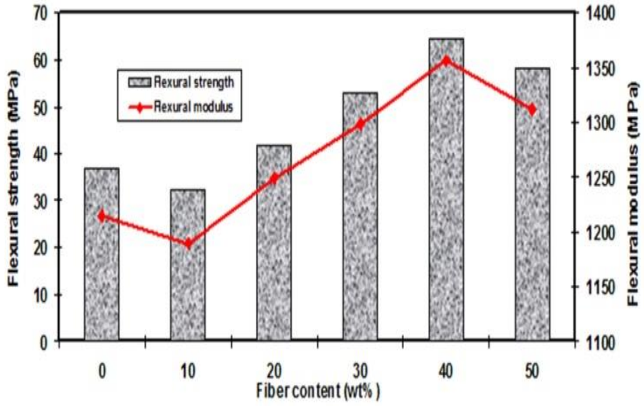

Fig. 2. Variation of flexural abilities of AFF/PF composite based on the fiber content

Influence of Particle Content on the Mechanical Properties

In the first stage of study, it was found that composite with the fiber stuffing of 40 wt% revealed the maximum strength values compared to the others. Therefore, this weight percentage (40 wt%) is taken to examine the impact of particle stuffing on the mechanical abilities of AFF/PF composite in the second stage. The two different composites (AFF/Al_2O_3/PF and AFF/SiC/PF) were produced by hand lay-up methodology and characterized based on the tensile and flexural properties.

Tensile Properties: To examine the effect of alumina oxide and silicon carbide micro particle's weight fraction on mechanical properties of AFF/PF composites, the mechanical tests on the composites were examined at atmosphere temperature and relative humidity of 50%. Fig. 3 shows the mechanical properties of AFF/PF composites and its hybrid composites made with the alumina oxide and silicon carbide particulate content. The tensile strength of AFF/PF composite increased from 49.7 MPa to 53.3, 58.9, 62.5 and 58.4 MPa for the Al_2O_3 particle content of 2.5, 5, 7.5 and 10 wt%. Among both the particle composites, AFF/Al_2O_3/PF composite specimens show the lower tensile properties compared to AFF/SiC/PF composite. It can be seen that with increasing the content of Al_2O_3 particles, the tensile ability of composite sharply increases with the increasing particulate stuffing up to 7.5 wt% and then decreased. Composite with the particulate stuffing of 7.5 wt% revealed improvements of 25.75% and 99.04% in tensile strength when compared to virgin AFF/PF composite and neat resin sample. The effect of the weight fraction of Al_2O_3 on the tensile modulus of AFF/PF composite is also indicated in Fig. 3. As the weight fraction of particulate increases in the composites, the tensile modulus of composite is also increasing linearly up to 10 wt% of particulate stuffing. The maximum tensile modulus of 1422.9 MPa is obtained at the composite with the particulate stuffing of 10 wt%.

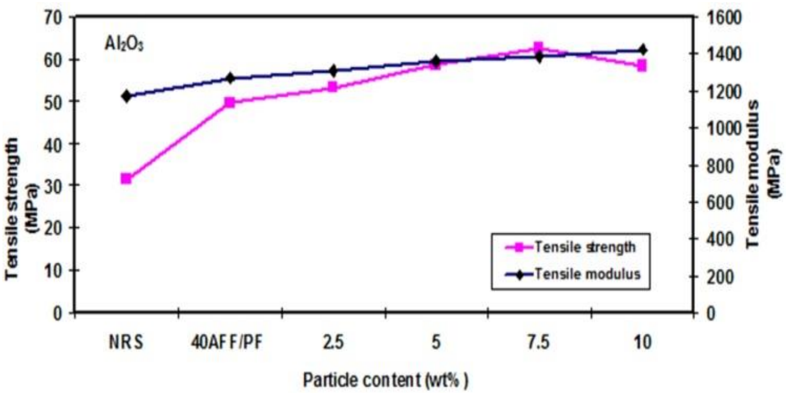

Fig.3. Variation of tensile properties of AFF/Al_2O_3/PF composite according to the particle content

Figure 4 shows SiC in all weight fractions which have obviously improved the tensile abilities of AFF/PF composite. The tensile strength improved by the inclusion of the SiC particle up to 7.5 wt% and then decreased as shown in Fig. 4. Tensile abilities of AFF/PF composite is improved from 49.7 MPa to 71.9 MPa for the composite specimen having the SiC particulate of 7.5 wt% and then decreased from 71.9 MPa to 65.8 MPa for the composite specimen having the SiC particulate of 10 wt%. Therefore, composite specimen having the particulate of 7.5 wt% indicates the maximum tensile strength value. Improvements of 44.67 % and 128.98 % were achieved in tensile strength when compared to virgin AFF/PF composite and neat resin sample. As it is shown in Figure 4, the tensile modulus of AFF/SiC/PF composite specimen is considerably improved. Here also, the tensile modulus improved linearly with the inclusion of SiC particulate contents. The tensile ability of AFF/PF composite specimen with the 7.5 wt% of SiC particle is 15.04% higher than the AFF/PF composite having the 7.5 wt% of Al_2O_3. Besides, the tensile modulus of AFF/SiC/PF composite at 10 wt% is 5.25% higher than AFF/Al_2O_3/PF composite at 10 wt%.

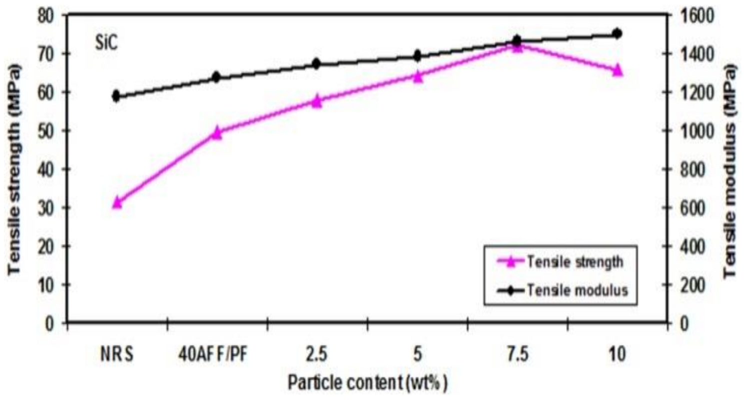

Fig.4. Variations of tensile properties of AFF/SiC/PF composite according to the particle content

Flexural Properties: The influence of particulate content on the flexural properties of AFF/PF composites is shown in table 4. The Al_2O_3 and SiC particulates are added to the PF composite with the AFF of 40 wt% as filler with different weight fraction. It can be revealed that the flexural abilities were distinctly increased with the inclusion of Al_2O_3 and SiC grains in AFF/PF composite specimen. It is also revealed from Table 4 that composites having the

SiC particulates showed the superior flexural abilities when match up with the composite having the Al_2O_3 particles. In both cases, 7.5 wt% of particulate composites show better flexural abilities when match up with the others. Composite having the 7.5 wt% of Al_2O_3 shows the flexural strength 81.7 MPa which is 26.47% higher than virgin AFF/PF composite specimen. When contrast with the zero fiber stuffing sample, an improvement of 122.01% was obtained. The flexural modulus of the composites having the Al_2O_3 particles also increased linearly from 2.5 wt% to 10 wt%.

In Table 4, it is also shown that when the content of SiC particle higher the flexural ability of the composites, first, improved up to 7.5 wt% and then decreases. The maximum flexural ability is observed when the SiC particle content is 7.5 wt%. When the SiC particle content increased, then flexural modulus increase linearly up to the particle content of 10 wt%. The flexural strength AFF/SiC/PF composite at 7.5 wt% is 5.14% higher than AFF/Al_2O_3/PF composite at 7.55 wt%. Moreover, the flexural modulus of AFF/PF composite with the 10 wt% of SiC particle is 3.98 % higher than the AFF/PF composite having the 10 wt% of Al_2O_3.

Table 4. Variations of flexural properties of AFF/ Al_2O_3/PF and AFF/SiC/PF composite

Particles content (wt%)	**Al_2O_3**		**SiC**	
	Flexural strength (MPa)	**Flexural modulus (MPa)**	**Flexural strength (MPa)**	**Flexural modulus (MPa)**
NRS	36.8	1214.7	36.8	1214.7
40AFF/PF	64.6	1356.6	64.6	1356.6
2.5	69.5	1382.4	73.5	1397.3
5	74.1	1427.9	79.7	1441.9
7.5	81.7	1486.5	85.9	1498.2
10	76.7	1412.3	80.1	1468.5

From above mentioned and discussed Figures and Table 4, it is observed that by increasing micro particles (Al_2O_3 and SiC) up to 7.5 wt%, the tensile and flexural ability of virgin AFF/PF composite are improved but with further addition of particles the strength values were decreased. The predictable reason is that the improved weight percentages of particles in the composites act as a barrier in transferring stress from the fiber to the matrix or from the matrix to the fiber. Besides the barrier, the bonding surface area also increased due to the higher particulate content (beyond 7.5 wt%) which leads to the reduced attachment strength between the particulate and the matrix. Due to the lesser bonding capacity, the applied load may not effectively be transferred from one point to another point which resulting in reduction of the ability of the composite. Therefore, the optimal particle content for AFF/PF composite is found to be 7.5 wt%. The tensile and flexural properties of AFF/PF composite specimen prepared with SiC particles were significantly enhanced when compared with the composites prepared with Al_2O_3 particles.

Influence of Particle Size on the Mechanical Properties

In the second stage, it was found that the SiC particle filled AFF/PF composites specimen exhibited the maximum range of mechanical abilities compared to Al_2O_3 filled AFF/PF composites specimens. Besides, AFF/SiC/PF composite with the SiC particle of 7.5 wt% exhibited the improved mechanical properties contrast to others. Therefore, the AFF/PF composite filled with 7.5 wt% of SiC is taken to third stage study, i.e., the impact of grain size on the mechanical abilities of AFF/SiC/PF composite.

Tensile Properties: Tensile properties versus SiC particle size are indicated in Fig. 5. It is revealed that the impact of SiC grain size on the tensile abilities of the AFF/SiC/PF composites is significant. It is revealed that the 5SiC/AFF/PF composite specimen achieved the superior tensile abilities compared to others. When comparing the tensile abilities of the 5SiC/AFF/PF composite with virgin AFF/PF composite, it is revealed that tensile ability increases from 49.7 to 81.6 MPa and tensile modulus is improved from 1271.7 to 1549.7 MPa. Moreover, when comparing the 10SiC/AFF/PF and 15SiC/AFF/PF composites, the tensile ability increases from about 49.7 to 78.3 MPa and 49.7 to 74.8 MPa, respectively as well as the tensile modulus was increased from about 1271.7 MPa to 1501.2 MPa and 1271.7 MPa to 1468.6 MPa respectively. This may indicate that the composites could be bonded well by such 5SiC particles. Here, the tensile ability of 5SiC/AFF/PF composite specimen is 64.19% and 9.09% improved than the unfilled AFF/PF composite and 15SiC/AFF/PF composite, respectively. As seen in Fig. 5, with increasing particle size, the tensile properties are decreased. This indicates that in composite specimens with a bigger size of SiC particles, the tensile properties are decreased. Moreover, the maximum tensile modulus was also obtained at 5SiC/AFF/PF composite.

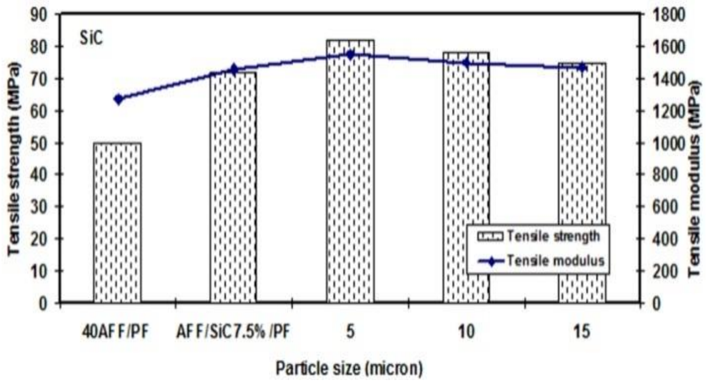

Fig. 5. Variations of tensile properties of AFF/SiC7.5%/PF composite according to the particle size

Flexural properties: Table 5 indicates the outputs of the flexural abilities of AFF/SiC/PF composite specimens prepared with different size of SiC particles. As it may be seen, the effects of reinforcement of SiC particles with different sizes in AFF/SiC/PF composite materials are readily apparent. As seen in Table 5, with increasing particle size, the flexural properties are decreased like in tensile properties. It can also be observed from Table 5 that the 5SiC/AFF/PF composite specimen revealed the improved flexural abilities compared to the others. As seen in Table 5, the 5SiC reinforced composite specimen indicated improved flexural ability and flexural modulus in comparison with a virgin AFF/PF composite and 10SiC and also a 15SiC filled AFF/PF composite. In the case of 5SiC reinforced composites, the flexural strength is increased from 64.6 to 97.5 MPa when compared with virgin AFF/PF composite and the flexural modulus is also increased from 1356.6 to 1601.8 MPa. Besides, when comparing the 15SiC/AFF/PF composite, the flexural strength increases from about 64.6 to 90.4 MPa and tensile modulus is improved from 1356.6 to 1521.9 MPa. This improvement indicates the better interfacial fastening between the AFF and PF resin matrix by the inclusion of SiC particles with the size of 5 µm. The main reason is that due to the strong bonding ability the strength values of the composite specimens increased as well as the applied load is transferred effectively from particles to the fiber through the matrix, which results in the increase of mechanical properties of the composite specimens. On the other hand, when the size of the particles exceeds the required size, then the surface zone of the particles increases in the composite. Therefore, the interfacial fastening between the particle and the matrix decreases as well as the applied load cannot be effectively transferred from one point to another point, which resulting in the reduction of mechanical abilities of the composite. Another reason is that when increasing the size of the particles beyond 5 µm, the particles disturb the matrix continuity which creates the poor adhesion ability between the particles, the matrix and the fiber. Finally, it can be concluded that adding any inorganic particles could increase the mechanical abilities of natural fiber reinforced polymer composites.

Table 5. impact of SiC particle size on the mechanical properties of AFF/SiC7.5%/PF composite

Particles Size (micron)	**SiC**	
	Flexural strength (MPa)	**Flexural modulus (MPa)**
40AFF/PF	64.6	1356.6
AFF/SiC7.5%/PF	85.9	1498.2
5	97.5	1601.8
10	94.8	1565.3
15	90.4	1521.9

CONCLUSIONS

A detailed study on the mechanical abilities of AFF/PF composite packed with Al_2O_3 and SiC particles was carried out based on the fiber content, particle content and particle size and their results are presented here. AFF/PF composite was characterized based on the fiber weight percentage and found that composite with the fiber stuffing of 40 wt% showed the extreme strength and modulus values related to the other fiber weight percentage composites. The mechanical properties of AFF/PF composite were evaluated at four different weight fractions of Al_2O_3 and SiC particle. From this study, the optimal particle content for AFF/PF composite specimen is formed to be 7.5 wt%. It is also identified that the tensile and flexural properties of AFF/PF composite prepared with SiC particles are significantly enhanced than that of Al_2O_3 particles. The mechanical properties of AFF/SiC7.5%/PF composite were evaluated based on the size (5, 10 and 15 µm) of the SiC particles. It is found that the AFF/SiC7.5%/PF composites reinforced with the SiC particles with the size of the 5 µm show the better results than the other size of the particles.

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