

A review on natural areca fibre reinforced polymer composite materials

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Abstract

Natural fibres, nowadays, have become the matter of discussion in the research field amongst various scientists to inculcate it in the formation of composites instead of production of composites using synthetic fibres like glass, carbon and aramid. This is due to various advantages associated with natural fibres like eco-friendly, low cost, availability in abundance and its bio-degradability. Lots of work has been carried out in the production of natural fibre reinforced polymer composites, using natural fibres like jute, hemp, cotton, sisal, kenaf, bagasse, areca, abaca, bamboo etc. and their properties have been studied. Here is an attempt made on the literature survey of areca fibre reinforced polymer composites where different properties of areca fibres, its maturity level, surface treatment effect on properties of fibres, composite formation with different matrices, its mechanical properties, thermal and acoustic properties related to different composites has been highlighted.

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1. Introduction

Basically, composite is defined as the material consisting of binder which is a continuous phase and the fibrous filler as reinforcement which is the discontinuous phase. Matrix present in the polymer composites supports the reinforcement and helps to stay it in proper position and orientation. Ductility is more and hardness is less for the polymeric resin and this resin is responsible for the toughness of composites. Reinforcement is harder than matrix and it is embedded into matrix. Reinforcement is the load carrying material and it strengthens the composites by imparting its properties into the matrix.

Composites can be classified based on matrix and based on the reinforcement. Based on matrix, there are three types; metal matrix composites, ceramic matrix composites and polymer matrix composites. It is very simple to manufacture the polymer matrix composites than metal matrix and ceramic matrix composites

because polymer processing does not require high temperature and pressure and the types of equipment needed for composite fabrications are simple. Polymer matrix composites are further classified into thermoplastic, thermoplastic elastomeric and thermoset polymer composites. Based on the shape of reinforcement, the composite classification can be made as particulate composites, fibrous composites and laminate composites. Fibrous composites are subdivided into short fibre (discontinuous) reinforced and long fibre (continuous) reinforced polymer composites. Based on the occurrence of fibres, again fibrous composites can be classified into natural fibre reinforced composites and synthetic fibre reinforced composites.

Over past several years, lots of work has been done in the field of development of natural fibre reinforced polymer composites; where the focus is more on cellulose based fibres which is naturally available, is incorporated into the polymer matrix to form bio-composites [1]. These cellulose fibres have properties like high strength, specific stiffness, availability, light weight, non-hazardousness, renewability, non-

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abrasiveness, which reduces wear in processing equipment, and biodegradability [2-5]. Whereas the synthetic fibres such as Kevlar, carbon, glass, etc. even though have got very high strength and stiffness [6], but the problems associated with them like biodegradability, recyclability, initial processing cost, health hazards made to find an alternative source for the production of composites. Hence these composites with high strength could be extensively used in marine applications, constructive industry, transport and automotive industry, etc. [7-9]. The comparative properties of the natural fibres with conventional man-made fibres are presented in Table 1.

Natural fibre is characterized by its fineness, adaptability and good aspect ratio [10]. Agro-waste fibres can be referred to as lignocellulosic and they possess appropriate superior properties suitable to be used as fibre reinforcement in polymer composites [11]. As a result of this many such fibres like sisal [12], jute [13], abaca [14], soybean [15], oil palm [16], hemp [17], flax [18], bamboo [19], henequen [20] etc. are been used as reinforcement in designing polymer composites which have been well recognized. Lots of research work has been carried out, till the date, where different naturally occurring fibres were considered for the manufacture of polymer composites. An attempt has been made to brief up an idea about the same.

1.1. Survey on natural fibre composites

Mwaikambo et al. (1999) [21] studied the effect of chemical treatment on the properties of hemp, sisal, jute and kapok fibres for composite reinforcement. It showed that mercerization would change the surface

topography and their crystallographic structure. The interfacial bonding between the matrix and the fibre would be more effective due to chemical treatment which brings better mechanical properties to the composites prepared.

Han-Seung Yang et al. (2004) [22] revealed the morphological study and mechanical properties related to rice husk flour filled polypropylene composites. The tensile strength was conducted according to the ASTM D638-99 standard. The tensile strength decreased with increasing fibre loading; however, the tensile modulus showed improvement with increasing trend. The composites showed maximum properties at 40% fibre loading.

Herrera-Franco et al. (2005) [23] investigated the composite formed by the coupling of short henequen fibres and polyethylene matrix. The fibres were subjected to alkali and silane treatment. The tensile strength and the flexural strength were found out according to the ASTM standards D638 and D790 respectively. It was reported that the silane treatment changed the adhesion between the fibre and the matrix. The mechanical properties increased for treated fibre composites compared to untreated fibre composites and the maximum effect was seen on the fibre matrix interface shear strength.

Fibres were in three ways to form the composite; particle size, short fibre (3 mm size) and long fibre (6 mm size). The composite was prepared using the compression moulding machine (SANTECH INDIA Ltd).

It was observed that the mechanical properties of urea-formaldehyde resin were much lower as compared to the fibre reinforced composite.

Table 1. Comparative properties of natural fibres with conventional manmade fibres [6].

Name of the fibres	Density (g/cm ³)	Tensile Strength (MPa)	Young's modulus (GPa)	Specific Strength (GPa/g/cm ³)	Specific modulus (GPa/g/cm ³)	Elongation at break (%)
Jute	1.3-1.4	393-773	13-26.5	0.3-0.5	10-18.3	1.16-1.5
Flax	1.50	345-1100	27.6	0.2-0.7	18.4	2.7-3.2
Hemp	1.14	690	30-60	0.6	26.3-52.6	1.6
Sisal	1.45	468-640	9.4-22.0	0.3-0.4	6.4-15.2	3-7
PAIF	1.52	413-1627	34.5-82.51	0.3-1.1	22.7-54.3	1.6
Cotton	1.5-1.6	287-800	5.5-12.6	0.2-0.5	3.7-7.8	7.0-8.0
E-glass	2.5	2000-3500	70	0.8-1.4	28	2.5
S-glass	2.5	4570	86	1.8	34.4	2.8
Aramid	1.4	3000-3150	63-67	2.1-2.2	45-47.8	3.3-3.7

All the inclusions showed the best result with good mechanical properties and proved the fibre to be a promising material.

The effect of surface treatment and fibre loading on the bagasse fibre reinforced unsaturated polyester composites were studied by Vilay et al. (2008) [25]. The fibres were subjected to NaOH and acrylic acid treatment and then different mechanical properties were studied for the composites prepared from the treated fibres. The tensile strength and the flexural strength were calculated according to the standards ASTM D3039 and ASTM D790-98 respectively. The results revealed that the surface modifications improved the fibre-matrix interaction which was justified by SEM analysis; FESEM Leo Supra 35VP, thereby increasing the mechanical properties of the chemically treated bagasse fibre-polyester composites.

Mahmoodul Haq et al. (2008) [26] studied the hybrid bio-based composites from blends of unsaturated polyester and soybean oil reinforced with Nano clay and natural fibres (industrial hemp). The tensile strength and the impact strength were carried out according to the standards ASTM D638 and ASTM D256 respectively. The coefficient of thermal expansion was found using TMA 2940 analyser. The studies showed that because of addition of bio-resin, stiffness and tensile stress reduced; however, there was increase in the impact strength and ductility. The coefficient of thermal expansion and the moisture absorption increased with increasing bio-resin content and decreased with the addition of Nano-clay. These hybrid composites made up with respective combination can give desired properties which can be used in applications like transportation and housing structural materials.

The study was done on pine needle reinforced resorcinol-formaldehyde composites by Thakur and Amar Singh (2010) [27]. The composites were prepared by taking pine needles in three different forms like powder (200 μ), short fibres (3 mm) and long fibres (6 mm). The composites were then subjected to the mechanical testing like tensile strength test, flexural strength test and wear test according to the standards ASTM D3039, ASTM D790 and DUCOM-TR-20L, respectively. The addition of pine needles into the composite material increased the mechanical properties to a significant level. In tensile strength determination, the composite with powder pine needle could bear maximum load of 531.47 N than short (471.8 N) and long fibres (426.0 N). Even during flexural strength determination, the

highest load bearing capacity was for the composite with the powder form of fibre (191.48 N) followed by short fibres (131.53 N) and then long fibres (107.25 N). Thus it revealed that the pine needle, in the form of powder showed better result compared to short and long fibre. Pine needles used as reinforcement in the formation of composite with different resins was investigated by A. S. Singha et al. (2011) [28]. The composites were prepared using compression moulding machine (SANTECH INDIA LTD.) at different fibre loading of 10, 20, 30, 40 and 50% with varying concentration of resins. It was recorded that the mechanical properties were maximum for the composites with urea-formaldehyde at concentration ratio 1.0:2.5 (tensile strength: 106.125N; compressive strength: 987N; flexural strength: 48.18N) and when urea-resorcinol-formaldehyde was used as the resin for composite preparation, the maximum mechanical behaviour was seen when the resin was in the concentration ratio 1.0:1.0:2.5 (tensile strength: 555.75N; compressive strength: 987N; flexural strength: 63.24N). The properties increased with increasing fibre loading which was supported by thermal analysis and SEM analysis.

Mohd. Zuhri et al. (2010) [29] investigated the mechanical properties of short random oil palm empty fruit bunch (OPEFB) fibre reinforced epoxy composites. The OPEFB were chopped into 10 mm to 20 mm fibre length using grinder model Retsch. Composites were prepared with different fibre loading (5, 10, 15 and 20 vol.%) and were subjected to mechanical testing. Results revealed that the mechanical properties decreased with increasing fibre percentage in the composites. The tensile strength and the flexural strength was recorded maximum to the composites with 5 vol.% fibre loading. The tensile strength was found to be 30 MPa and Young's modulus was recorded to be around 1430 MPa for the same.

M. Saiful Islam et al. (2011) [30] studied the effect of treatment of benzene diazonium salt on the five different tropical light hardwood species. The wood samples used were jelutong, terbulan, batai, rubber wood and pulai. It was recorded that the mechanical properties of the treated fibres were comparatively higher than the untreated ones. The thermal stability of treated fibres was very high, which was attributed to the fact of formation of 2,6-diazocellulose compound because of the reaction with benzene diazonium salt which was confirmed by FTIR. The scanning electron micrographs of untreated samples of all the wood showed number of void spaces and agglomeration of

fibre in the wood surface whereas after treatment, the diazonium salt filled the void spaces and aligns the uneven fibres which provided a smoother surface texture which enhanced the morphological properties. The pseudo stem banana fibre reinforced epoxy composite was studied by Maleque and Sapuan (2007) [31]. The comparison was done with epoxy and banana reinforced epoxy composite. The tensile strength was calculated according to ASTM D638 and the flexural test was carried out according to BS EN ISO 14125. It revealed that all the mechanical properties showed tremendous rise in banana reinforced composites compared to only epoxy resin without fibre. The tensile strength for the epoxy resin was reported as 23.98 MPa and for the composite, it was found to be 45.57 MPa. The flexural strength and the flexural modulus for epoxy resin and the composite was found to be 53.38 MPa and 73.58 MPa and 1563.2 MPa and 1834.6 MPa respectively. Similarly, the impact strength was found to be 4.92 kJ/m² and 6.95 kJ/m² for epoxy resin and the fibre composite, respectively. Tensile strength increased by 90% and the impact strength increased by 40%. Study was done on banana fibre-polypropylene composites by Sherey Annie Paul et al. (2008) [32], where the investigation has been done on effect of fibre loading and chemical treatment on thermo-physical properties. The surface of the fibres was modified using chemicals like NaOH (2 and 10%), benzoyl chloride, KMnO₄ and silane treatment. At different fibre loadings the composites were prepared using chemically treated fibres. It was reported that the thermal conductivity and thermal diffusivity decreased with increasing fibre loading; however, the surface modifications increased the thermo-physical properties, where the benzoyl chloride treated fibre composite showed the maximum effect. Also the concentration of alkali used for the treatment played a vital role, where the fibres treated with 10% NaOH showed better result compared to 2% alkali treated fibres.

Ahad et al. (2009) [33] studied the effect of chemical treatment on the surface of banana and coir fibres. The fibres were treated with 5, 10 and 15% NaOH and the surface has been analysed by SEM imaging. It was reported that the treated surface fibres remove all the impurities and the surface becomes rough. As a result of this there could be interlocking between matrix and fibre providing better mechanical strength. Boopalan et al. (2013) [34] studied the mechanical properties of jute and banana fibre reinforced epoxy hybrid composites. The composites were prepared with

different fibre loading of jute and banana concentrations 100/0, 75/25, 50/50, 25/75 and 0/100 respectively by hand-lay-up technique followed by compression moulding technique. The composites were subjected to different mechanical testing like tensile testing by following ASTM D638-03, flexural strength as per ASTM D790 and impact strength by following ASTM D256. It was observed that the mechanical and the thermal properties increased with increasing concentration of banana fibre in the composite. 17% increase in tensile strength, 4.3% increase in flexural strength and 35.5% increase in impact strength was seen in composite with 50/50 concentration of fibres, above which the mechanical properties showed decreasing trend.

Arthanarieswaram et al. (2014) [35] studied the effect of incorporation of glass fibre in the hybrid epoxy composites formed by the combination of banana and sisal fibres. The composites were subjected to different mechanical testing as per the ASTM standards. The tensile strength, flexural strength and the impact strength were calculated according to ASTM D3039, ASTM D790 and ASTM D4812, respectively. It was observed that the tensile strength increased at 3-layer glass fibre hybrid composite whereas the flexural property enhanced on banana-sisal fibre with two layered glass fibre.

Ample studies on composites made by reinforcing natural fibres such as bamboo [36], abaca [37-39], coir [40-41], flax [42], hemp [43-45], jute [46-50], kenaf [51-52] and sisal [53-57] have shown that lignocellulosic fibres have the prospective to be a successful reinforcement in thermoplastic and thermosetting materials. Thus even the areca fibre which is abundantly available in nature, serves as a promising material in production of composites, which can be widely used in various applications. A short literature survey on work done using areca fibre till the date has been summarized further to get an idea of potential in using the areca fibre as the reinforcement in the formation of polymer composites.

2. Areca fibres

Areca belongs to the species *Areca catechu* Linnaeus under the family palmecea which is originated in the Malaya peninsula, East India. Areca trees yields commercially important products like nuts, fibre and oil. The husk of the areca is a hard fibrous material covering the endosperm and it constitutes about 60-80% of the total weight and volume of the areca fruit. The physical properties of the areca fibres are mentioned in Table 2.

Table 2. Physical properties [58].

Diameter (mm)	Length of the fibre (mm)				Density (g/cm ³)
	Short	Medium	Long	Average	
0.285- 0.89	18-29	30-38	39-46	29-38	1.05- 1.25

The areca fibre is composed of cellulose with varying proportions of hemicelluloses, lignin, pectin and protopectin. The chemical composition of areca and other natural fibres is presented in the Table 3. The hemicelluloses content of Areca fibre is much greater than any other fibres.

The strength of natural fibre reinforced composites is very low compared to synthetic fibre reinforced composites. This is due to the inaptness between the fibre and the polymer matrix. Natural fibres absorb water from the environment which deforms the surface of the composites by swelling and creating voids. The deformation lowers the strength of composites and thereby increases the mass of composites. Lignocellulosic change dimensions with changing moisture content because the cell wall polymers contain hydroxyl and other oxygen containing groups which attracts moisture through hydrogen bonding. The hemicellulose is mainly responsible for moisture absorption, moisture swells the cell wall, and the fibre expands until the cell wall is saturated with water. Above this saturation point, moisture exists as free water in the void structure and does not contribute for further expansion. This hygroscopicity can create challenges both in composite fabrication and in the performance of the end product. Natural fibres absorb less moisture in the final composites since they are at least partially encapsulated by the polymer matrix. However, even small quantities of absorbed moisture can affect performance.

Table 3. Chemical composition [58].

	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Ash (%)	Pectin (%)	Wax (%)
Jute	61-71.5	13.6-20.4	12-13	-	0.2	0.5
Flax	71-78.5	18.6-20.6	2.2	1.5	2.2	1.7
Hemp	70.2-74.4	17.9-22.4	3.7-5.7	2.6	0.9	0.8
Kenaf	31-39	15-19	21.5	4.7	-	-
Sisal	67-78	10-14.2	8-11	-	10.0	2.0
PALF	70-82	-	5-12	-	-	-
Cotton	82.7	5.7	-	-	-	0.6
Coir	36-43	0.15-0.25	41-45	-	3-4	-
Areca	-	35-64.8	13-24.8	4.4	-	-

2.2. Advantages of areca fibres

Areca fibres are the natural fibres which are available in abundant amount. Areca Catechu Linnaeus shell is a rigid fibrous material. The physical characteristics and the chemical composition of areca fibres are easily accessible. The comparison of various properties of areca fibres with other natural fibres is given in Table 4. The tensile strength of areca fibres ranges from 147 - 322 Mpa which is higher when compared to other fibres like coconut fibre (95 - 230 Mpa) and palm fibre (80 - 248 Mpa). Hemicellulose is mainly responsible for moisture absorption which could create problem in the performance of composites prepared from it. The amount of these hemicelluloses are 13 - 15.42% in the areca fibres which is less when compared to that in other fibres like flax (18.6 - 20.6%), kenaf (20.3%), jute (14 - 20%) and abaca (20 - 25%). Hence the comparison of various properties of areca fibres with other fibres shows that out of all the natural fibres, areca fibres serves to be a promising material in incorporating it in composite formation.

Areca fibres can be produced at low cost and hence makes it a better product for low-wage countries. They play a better role compared to the synthetic fibres in incorporating it as the reinforcement in the production of composites as the fibres itself are biodegradable. These fibres have good thermal and acoustic insulating properties. Areca fibres are light weight compared to other synthetic fibres and are eco-friendly, non-toxic and sustainable which further provides the waste management solution.

Table 4. Comparison of various properties of areca fibres with other natural fibres.

Fibre	Chemical properties					Physical properties			Mechanical properties		
	Cellulose (wt.%)	Hemi Cellulose (wt.%)	Lignin (wt.%)	Wax (wt.%)	Moisture (wt.%)	Diameter (μm)	Density (g/cm^3)	Length (mm)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation (%)
Areca fibre	57.35-58.21	13-15.42	23.17-24.16	0.12	7.32	396-476	0.7-0.8	10-60	147-322	1.124-3.155	10.23-13.15
Coconut fibre	32-43.8	0.15-20	40-45	-	8	100-460	1.15-1.46	20-150	95-230	2.8-6	15-51.4
Palm fibre	60-65	-	21-29	-	-	150-500	0.7-1.55	-	80-248	0.5-3.2	17-25
Cotton	82.7	5.7	-	-	-	10-20	1.5-1.6	15-56	287-800	5.5-12.6	7-8
Bagasse	55.2	16.8	25.3	-	8.8	10-34	1.25	0.8-2.8	290	17	1
Bamboo	26-43	30	21-31	-	8.9	14	0.6-1.1	2.7	140-230	11-17	-
Flax	71	18.6-20.6	2.2	1.5	7	10-25	1.5	10-65	345-1035	27.6	2.7-3.2
Kenaf	72	20.3	9	-	-	1.4-11	-	12-36	930	53	1.6
Jute	61-71	14-20	12-13	0.5	12	25-200	1.3	0.8-6	393-773	26.5	1.5-1.8
Abaca	56-63	20-25	7-9	3	15	-	1.5	-	400	12	3-10
E-glass	-	-	-	-	-	8-15	2.5	-	2000-3500	70	2.5
Carbon	-	-	-	-	-	5-100	1.7	-	2400-4000	230-400	1.4-1.8
Aramid	-	-	-	-	-	15	1.4	-	3000-3150	63-67	3.3-3.7
S-glass	-	-	-	-	-	-	2.5	-	4570	86	2.8

3. Literature review on areca fibres

3.1. Effect of fibre maturity on areca fibres

The effect of fibre maturity and its potential in various applications was studied by Yusriah et al. 2012 [59], where the mechanical properties were evaluated for raw, ripe and dried betel nut husk fibres. The chemical composition is reported according to Table 5.

Table 5. The chemical composition of areca fibre

Composition	Average amount (%)
Alpha cellulose	53.20
Hemicellulose	32.98
Lignin	7.20
Fat and wax	0.64
Ash	1.05
Other materials	3.12

It was reported that with the increase in the maturity level, the fibre length decreased however the density increased from raw to ripe and then to dried fibres (5.7, 5.5 and 4.9 cm fibre length with the density of 0.19, 0.34 and 0.38 g/cm^3 , respectively). Water uptake behaviour was high for raw fibre (bigger lumen size encourages in absorbing more water content), less for ripe fibre (lumen size is reduced compared to the raw betel nut husk fibre) and the least for the dried fibres (due to compact size, prevents water penetration into the fibre) which is shown in Figure 1. The tensile properties of the fibres were studied using Instron 5566 machine with a gauge length of 20 mm. The ripe betel nut husk fibre showed highest tensile strength and elongation at break, but there is no significant difference in these properties of raw and dried fibres. Dried fibres possess greater Young's modulus compared to the raw and ripe fibres. The stress v/s strain curve is shown in Figure 2. Thus it was concluded that based on the application, the selection of fibres and their maturity level could be considered.

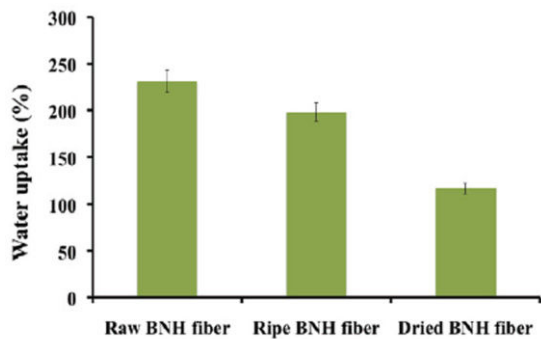


Fig. 1. Water absorption of raw, ripe and dried BNH.

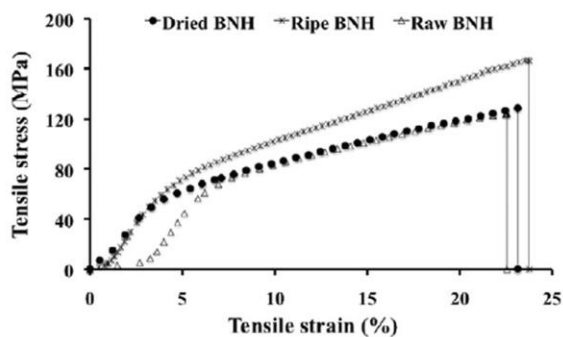


Fig. 2. Stress-strain curve of raw, ripe and dried BNH fibre.

3.2. Effect of different treatment on areca fibres

Padmaraj et al. (2010) [60] studied the effect of different treatment media on the breaking strength of long areca nut fibres. The fibres were extracted from soaked areca leaves, and the dried fibres were treated with three different solutions; sugar solution, jaggery and wheat flour solutions which can be disposed of safely, easily and are eco-friendly. Fibres were treated with above mentioned solutions each with different concentrations of 70, 80, 90 and 100% w/v respectively. It showed that the strength of fibres treated with sugar solution, jaggery solution and wheat flour solution increased by 34%, 31% and 51% respectively when compared to strength of untreated fibres. Compared to three medias, wheat flour treated fibre resulted in maximum strength (55 N).

Dhanalakshmi et al. (2012) [61] studied the effect of esterification on moisture absorption of single areca fibre. The presence of hydrophilic group is responsible for moisture absorption and thereby reducing the life of the polymer composite prepared from the fibre. As a result of this, an attempt was made where fibres were treated with alkali; 20% NaOH followed by 5% acrylic acid and thereby it was exposed to various source of water such as pond water, river water, sea

water and bore water. From the Figure 3, it was observed that the moisture absorption for untreated fibres was very high (60%) compared to alkali treated fibres (40%), followed by acrylic acid treated fibres (30%).

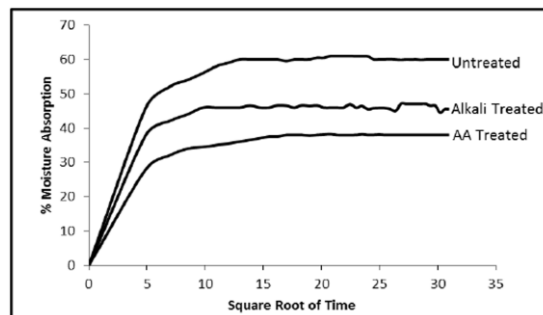


Fig. 3. Comparison of moisture absorption of untreated, alkali treated acrylic acid treated areca fibres in sea water.

Areca fibres absorbed more moisture in bore water and less in sea water. Hence it proved that the surface modification of the fibres by introducing hydrophobic group can reduce the water absorption capacity of the fibres and can produce better polymer composites.

Further in 2015, the investigation on physical characterization of natural lignocellulosic single areca fibres was carried out [62]. The fibres were treated with different chemicals like 6% NaOH, 0.5% KMnO₄, benzoyl chloride, 5% acrylic acid and acetic anhydride. Surface modifications took place due to various chemical treatments. The thermal stability of these chemically modified fibres was studied by using a STA 409 PL Luxx instrument. In accordance with other studies on natural lignocellulosic fibres, the TGA curve of untreated and all chemically treated areca fibres also showed three weight loss steps and their decomposition occurred in two main stages and shown in Figure 4. The initial weight loss, observed around room temperature (RT) to first stage degradation temperature is attributed to the vaporization of moisture and decomposition of volatile extractives from the fibres. Above this temperature, it can be observed that the thermal stability is gradually decreasing and the degradation of untreated and all chemically treated areca fibres occurs. The first stage degradation temperature range is associated to the thermal depolymerisation of hemicelluloses, pectin and cleavage of glycosidic linkages of cellulose and lignin.

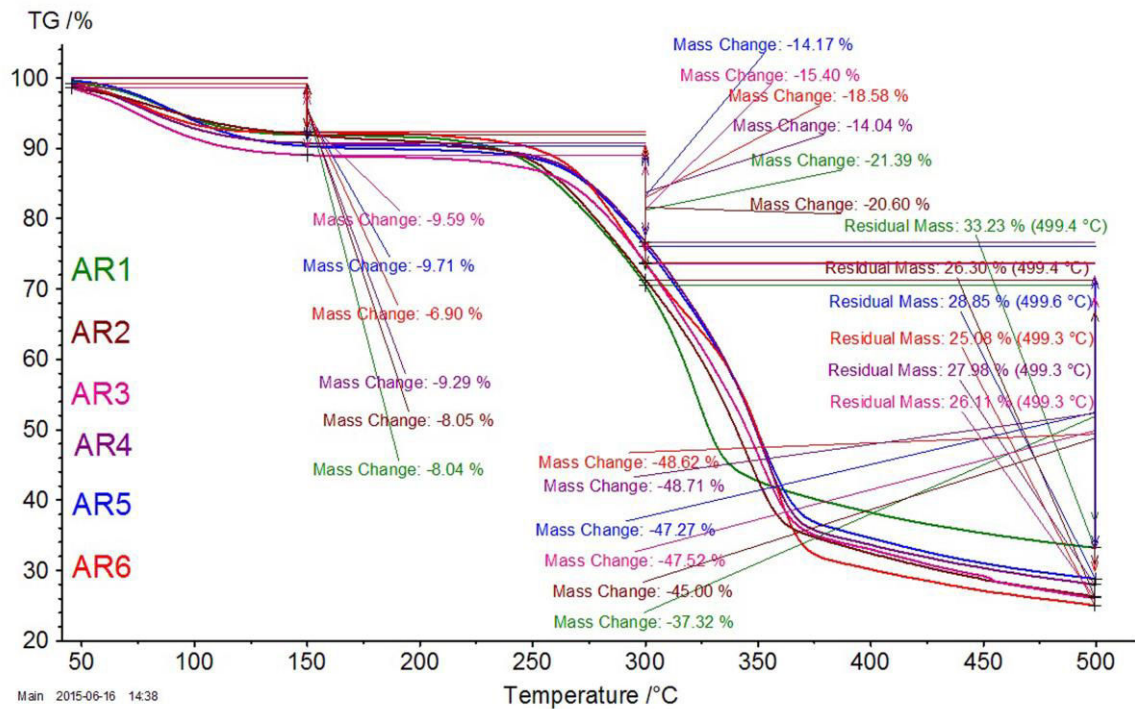


Fig. 4. TGA of Untreated and chemically treated areca fibres.

The second stage degradation temperature range corresponds to the degradation of α -cellulose and lignin present in the fibre. The weight loss, observed after second stage degradation temperature up to 500 °C is due to the degradation of lignin. Generally, the decomposition of lignin, owing to its complex structure containing aromatic rings with various branches occurs slowly within the whole temperature range up to 500 °C. In an inert atmosphere, the final products of degradation of areca fibres consist of carbonaceous residues and possible undegraded fillers. These results are confirmed by DTG curve of untreated and all chemically treated areca fibres wherein the maximum decomposition rates for weight losses are represented and shown in Figure 5. The small first peak corresponds to evaporation of moisture from areca fibres and the second peak observed confirms the maximum decomposition rates for weight losses of cellulose present in the untreated and chemically treated areca fibres. The TGA results of untreated and chemically treated areca fibres from Table 6 revealed that the untreated, alkali treated, permanganate treated, benzoyl chloride treated, acrylic acid treated and acetic anhydride treated areca fibres

are stable until around 241.5, 250.8, 259.0, 257.0, 252.0 and 251.0 °C respectively. The DTG results of untreated and chemically treated areca fibres from Table 7 revealed that the temperature of maximum decomposition for untreated, alkali treated, potassium permanganate treated, benzoyl chloride treated, acrylic acid treated and acetic anhydride treated areca fibres are 322, 346.0, 350.4, 350.7, 351.1 and 355.3 °C respectively. Studies revealed that the thermal stability of chemically treated fibres were higher when compared to the untreated areca fibres. Treated and untreated fibres were then subjected to X-ray diffraction studies on X-Ray Diffract meter using $\text{Cu-K}\alpha$ radiation.

It showed that the chemical treatment reduced the crystallinity of the fibres to some extent as a result of which the tensile strength of chemically treated fibres were comparatively lesser than the untreated fibres (untreated-116.93 N/mm², 6% alkali treated-100.13 N/mm², 0.5% KMnO_4 treated-108.02 N/mm², benzoyl chloride treated-110.34 N/mm², 5% acrylic acid treated-112.42 N/mm² and acetic anhydride treated-108.68 N/mm²).

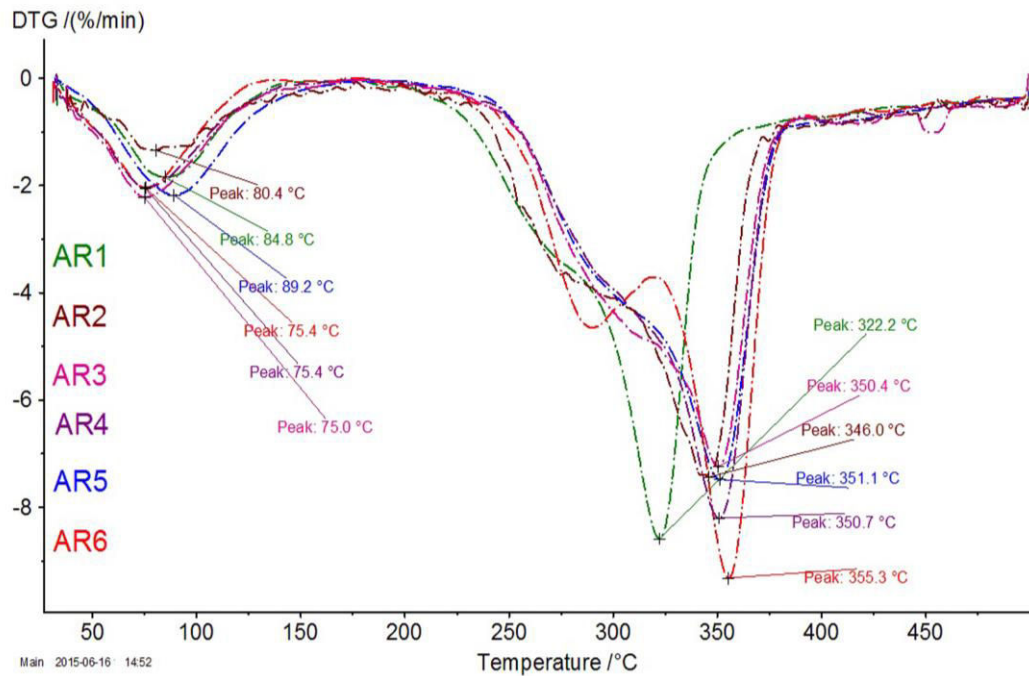


Fig. 5. DTG of Untreated and chemically treated areca fibres.

Table 6. TGA results of untreated and chemically treated areca fibres.

Areca Fibres	1 st stage degradation in TGA curve		2 nd stage degradation in TGA curve		Decomposition temperature, °C in TGA curve at		Weight loss of areca fibres, % in TGA curve at			Residual mass % at 500 °C
	Temp. range, T ₁ (°C)	Weight loss (%)	Temp. range, T ₂ (°C)	Weight loss (%)	25% weight loss	50% weight loss	150 °C	300 °C	500 °C	
Untreated (AR1)	241.5 to 297.0	17.13	297.0 to 353.0	29.54	289.5	328.5	8.04	21.39	37.32	33.23
NaOH treated (AR2)	250.8 to 306.0	19.16	306.0 to 384.0	35.00	291.0	340.0	8.05	20.60	45.00	26.30
KMnO ₄ treated (AR3)	259.0 to 332.5	28.47	332.5 to 382.5	23.21	297.0	345.0	9.59	15.40	47.52	26.11
Benzoyl chloride treated (AR4)	257.0 to 319.5	19.95	319.5 to 371.0	32.00	304.0	349.0	9.29	14.04	48.71	27.98
Acrylic acid treated (AR5)	252.0 to 309.5	16.27	309.5 to 380.0	35.83	302.5	349.5	9.71	14.17	47.27	28.85
Acetic anhydride treated (AR6)	251.0 to 320.0	24.11	320.0 to 369.0	932.00	297.0	349.5	6.90	18.58	48.62	25.08

Exploring the morphological, physical, mechanical, chemical and thermal characterization of areca fruit husk fibre was carried out using the instruments like Perkin Elmer Spectrum RXI-FTIR spectrometer, CARL ZEISS SMART scanning electron microscope, P-analytical Xpert PRO MPD Diffractometer, Jupiter

simultaneous thermogravimetric analyser were used for the respective determination by Binoj et al. in year 2016 [63]. It was confirmed that the areca fibres discarded from tobacco industrial waste had high cellulose (57.35 wt.%) and less wax (0.12 wt.%) with rough surface and better strength and bonding.

Table 7. DTG results of untreated and chemically treated areca fibres.

Areca Fibres	Decomposition temperature, °C in DTG curve at	
	First Peak	Second Peak
Untreated (AR1)	84.8	322.2
NaOH treated (AR2)	80.4	346.0
KMnO ₄ treated (AR3)	75.0	350.4
Benzoyl chloride treated (AR4)	75.4	350.7
Acrylic acid treated (AR5)	89.2	351.1
Acetic anhydride treated (AR6)	75.4	355.3

Also lower density (0.78 g/cm³) and moderate tensile strength makes it fit for light weight applications. The mechanical properties of the areca fibres are listed in Table 8.

Table 8. Mechanical properties of areca fibres.

Gauge length (mm)	Tensile Strength (MPa)	Young's modulus (GPa)	Strain to failure (%)	Diameter (mm)
10	147.923 ± 32	1.124 ± 0.86	13.15 ± 1.31	0.476 ± 0.013
	20	196.544 ± 41	1.596 ± 1.13	12.31 ± 2.52
30		259.363 ± 54	2.273 ± 1.87	11.41 ± 3.63
	40	322.829 ± 67	3.155 ± 2.31	10.23 ± 2.75

3.3. Areca fibre reinforced natural rubber composites

Investigation was done on tensile behaviour of the natural areca fibre reinforced rubber composites by Dhanalakshmi et al. (2014) [64]. Composite was prepared with 60% fibre loading using heat press machine at different temperatures like 130, 140, 150 and 160°C. The tensile behaviour of the composites, prepared at different temperature was studied according to ASTM D3039 standards. It was found that there was no considerable difference in tensile strength among four samples. Hence the compounding temperature 130°C was recommended for considerations. At 130°C, composites were prepared with different fibre loadings of 40, 50, 60 and 70%. The tensile strength was found to be 87.24, 112.28, 126.48 and 108.32 MPa, respectively. The tensile strength increased with increasing fibre loading. At 60% it was found to be maximum because of better fibre distribution in matrix, less fibre fractures and effective transfer of load from matrix to fibre. At 70%

the decreased result was due to lesser amount of matrix material, because of which it leads to ineffective transfer of stress from matrix to reinforced fibre. Hence, it was told that the composites of 60 % fibre loading are suggestible.

The effect of chemical treatments on tensile strength of areca fibre reinforced natural rubber composites was further carried out by Dhanalakshmi et al. in year (2015) [65]. The composite was prepared with fibre loading 40, 50, 60 and 70% fibre loading at 130°C. The alkali 6% NaOH treated areca fibres were then treated with different chemicals like potassium permanganate, benzoyl chloride and acrylic acid. The composites were prepared with chemically treated fibres and different fibre loading of 40, 50, 60 and 70% respectively. The tensile strength was found out according to the ASTM D3039 standards. It showed that the tensile strength was maximum at 60% fibre loading in untreated as well as chemically treated areca fibre reinforced natural rubber composites.

The tensile strength of areca-natural rubber composite with different fibre loadings are shown in the Figure 6. The tensile strength of untreated, alkali, KMnO₄, Benzoyl chloride and acrylic acid treated fibre composite was found to be 126.48, 130.82, 134.56, 138.52 and 140.82 MPa respectively. Thus, out of all chemical treatments, the composite prepared with acrylic acid treated areca fibres showed highest tensile strength at 60% fibre loading. This is because most of the hemicelluloses and lignin are removed and there is a replacement of hydroxyl group by hydrophobic ester groups in areca fibres.

3.4. Areca fibre reinforced polyester composites

Lai et al. [66] in year 2008 studied the properties of woven kenaf and betel palm reinforced unsaturated polyester composites. The tensile test was carried out using ASTM D3822-01 and the flexural test was carried out using Instron 3366 according to ASTM D790. It revealed that the cellulose content is more in case of kenaf fibres compared to betel palm fibres. As a result of this the untreated kenaf fibres showed high tensile strength (117.9 MPa) compared to that of betel palm fibres (31.6 MPa). The NaOH treatment on 7 vol.% betel palm and kenaf polyester composites showed improvement in flexural properties (flexural strength and flexural modulus) compared with untreated fibre composites. But the strength of kenaf fibre composites is comparatively more than the betel palm fibre composites.

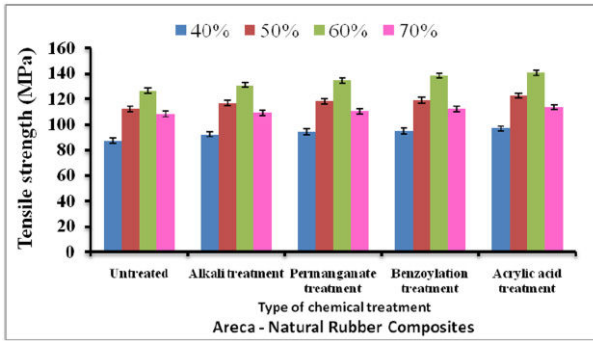


Fig. 6. The tensile strength of areca-natural rubber composite with different fibre loading.

Jayamani et al. in 2014 [67] investigated the effect of fibre surface treatment on mechanical, acoustical and thermal properties of betel nut fibre polyester composites. The composites were prepared at different fibre compositions (5, 10, 15 and 20%). The tensile strength was carried out according to the ASTM D638 standards. It was seen that the tensile strength and the yield strength of the composites increased with increasing fibre percentage till 15% fibre loading. But when it was 20% fibre loading, the mechanical properties decreased which was due to the over presence of the fibre in the material that contributed in initiating the crack which caused non-uniform stress transform due to fibre agglomeration within the matrix.

Whereas alkali (5% NaOH) treated composites showed better result compared to untreated composites and the best result was seen at 10% fibre

loading (Figure 7). The sound absorption properties of the composites were carried out according to ASTM E1050-10. It was reported that the sound absorption co-efficient (α) was high for 20% fibre composites (0.27). Whereas it was least for 5% fibre loading (ranging from 0.03 to 0.20). Effect of betelnut fibre content on sound absorption coefficients is given in Figure 8. Also the sound absorption co-efficient was found for 20% fibre loaded composites with three different thickness of 2, 4 and 6 mm. It revealed that the sound absorption co-efficient increases with increasing thickness of the composite and it reached to the maximum of 0.42 at 6000Hz (Figure 9). The thermal stability of the untreated and alkali treated composites were studied by Thermogravimetric analysis. Both showed two step decomposition processes with temperature range between 30 to 900 °C (Figure 10). Treated fibre composites showed better thermal stability compared to untreated fibre composites and this could be justified by improved fibre-matrix interactions, which generally, generate additional intermolecular bonding between fibre and matrix.

Hazarika et al. [68] in 2015, carried out the investigation on areca fibre reinforced polyester composites based on different fibre length with different fibre loading. Four different fibre lengths were considered, 10, 20, 30 and 40 mm, with four different fibre loadings, 10, 20, 30 and 40%, for each fibre length samples.

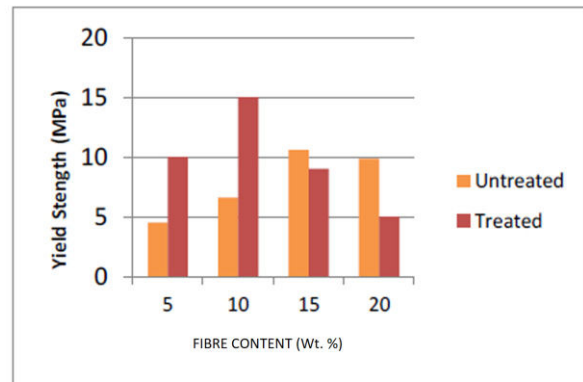
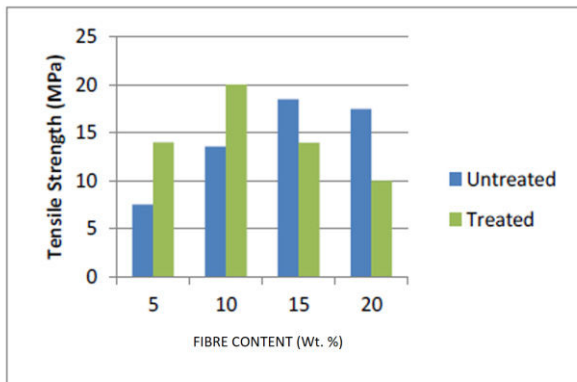


Fig. 7. Variation of tensile (left) and yield (right) strength of composites with fibre content and fibre treatment.

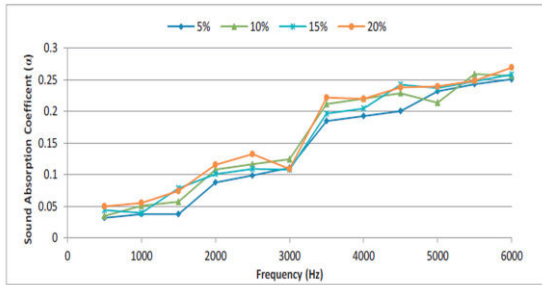


Fig. 8. Effects of betelnut fibre content on sound absorption coefficients of the composites.

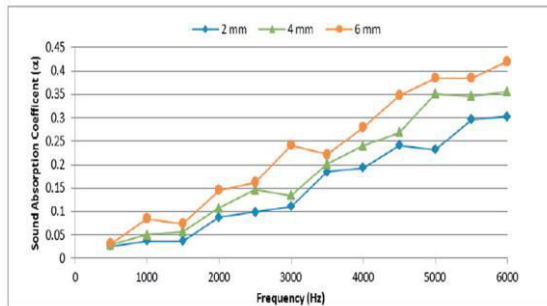


Fig. 9. Effect of thickness of composites with 20% betelnut fibre on sound absorption coefficients.

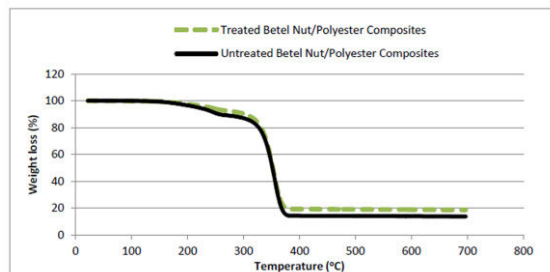


Fig. 10. TGA curves of polyester composites reinforced with treated and untreated betelnut fibre.

The tensile strength, the flexural strength and the impact strength testing was done by following ASTM D-638, ASTM D-790 and ASTM D256 standards, respectively. It was observed that out of four different fibre length composites, the one with 10 mm fibre length (alkali treated) showed maximum mechanical properties. This could be due to short fibre end interaction with the matrix. The composites with increasing fibre loading (from 10-30%) showed increasing trend in the mechanical properties like tensile strength, flexural strength and impact strength but when the fibre loading was 40%, the mechanical properties decreased. The maximum mechanical

properties at 30% fibre loading is because at this stage the fibres get maximum level of orientation and mixed homogeneously within the matrix and actively participate in stress transfer. At low levels of fibre loading (< 30%), the orientation of fibres was poor. At higher level of fibre content (> 30%), agglomeration of fibres within the matrix takes place, which produced non-uniform stress transfer capacity. The water absorption test was carried out as per ASTM D570, for different fibre loaded polyester composites and it was observed that the water absorption capacity increased with increasing fibre content. This was attributed to the fact that the cellulose content increases with increasing fibre content which contributes to the increasing water absorption.

3.5. Areca fibre reinforced polycaprolactone composites

Dey et al. in 2013 [69] studied the surface treatment of areca nut fibre using silane and gamma irradiation and its polycaprolactone based composites. The composite was prepared with 50% fibre loading and its mechanical properties were determined. Tensile strength, tensile modulus, bending strength, bending modulus and impact strength of the composites were found to be 32 MPa, 685 MPa, 45 MPa, 820 MPa and 15 kJ/m², respectively. Surface treatment of fibres was done preparing six different formulations (F1–F6) using vinyl trimethoxysilane (1–6 wt.%), methanol (97–92%) and photo initiator radocur (2%) and these samples were exposed to gamma radiations of various doses 250–1000 krad. It was reported that the areca fibre with 4% silane and at 500 krad dose of gamma radiation showed good mechanical properties. Namely, tensile strength, tensile modulus, bending strength, bending modulus and impact strength of the composite were found to be 43 MPa, 1015 MPa, 64 MPa, 1423 MPa and 20 kJ/m², respectively. The treated and the untreated polymer composites were subjected to degradation test for 6 weeks in soil media and it was found that treated composite retained much of its original strength compared to untreated composite.

3.6. Areca fibre reinforced corn starch composites

Bio-degradable composite using areca nut frond fibres were studied by Padmaraj et al. (2013) [70]. Initially the extracted, purified fibres were subjected to tensile strength test according to ASTM D638-03 and it

showed the tensile strength of 29.47 N (Figure 11). The alkaline solution used for the surface treatment of natural fibre was 1N sodium carbonate solution. The treated fibres showed the tensile strength of 38.96 N (Figure 12). The composite was prepared using treated areca nut frond fibre with renewable, biodegradable and non-toxic starch, glycerol, vinegar and water. Composite materials were tested for tensile strength according to ASTM D3039. It was observed that the tensile strength of chemically treated areca composites showed the tensile strength of 45.29 N which was considerably high (Figure 13). This result reflected that the areca fibres can be reinforced with suitable polymers which can be helpful for small load carrying applications.

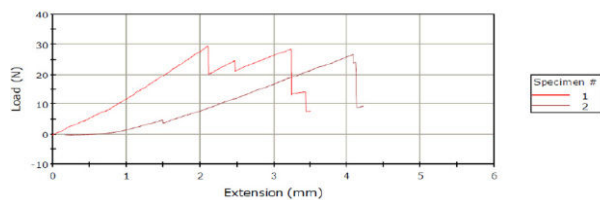


Fig. 11. Load vs. Extension curve for untreated fibre.

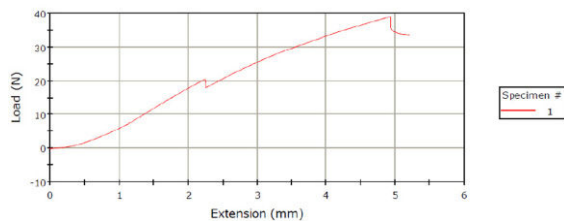


Fig. 12. Load vs. Extension curve for Sodium carbonate treated fibre.

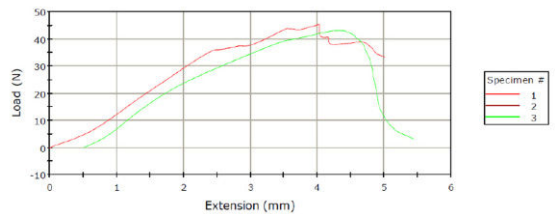


Fig. 13. Load vs. Extension curves for areca fibre composite.

Studies on the flexural behaviour of areca frond fibre reinforced composite by Srinivas et al. in 2014 [71] showed following results. The fibres were treated with 1N sodium carbonate solution and the composite was prepared with different composition of base material (corn starch powder, vinegar and water), binders (methyl cellulose and resorcinol) and plasticizer (glycerol). The composite was subjected to flexural

strength test and it revealed that plasticizer has maximum effect on flexural strength of biodegradable composites. Maximum flexural strength obtained was 16.97 MPa at the combination of base material, 170 g, binder, 10 g and plasticizer, 5 g (Figure 14). Further, the studies on tensile behaviour of areca-starch composite was carried out in 2016 [72] according to ASTM D3039 by taking base materials [corn starch (20-30 g), water (40-80 g), vinegar (5-10 g)], binder [cellulose acetate (5-10 g), agarose (5-10 g)] and plasticizer [glycerol (10-20 g)] at different compositions. The best result was shown by the composite having the composition starch (20 g), water (80 g), vinegar (10 g), cellulose (10 g), agarose (10 g) and glycerol (10 g) which showed the maximum tensile strength of 38.92 MPa compared to other composites prepared. The plasticizer here plays a major role in determining the strength of the composite. It was reported that the delta value for glycerol is 6.89 whereas for starch, water, vinegar, cellulose acetate, it's found to be 1.86, 5.99, 3.48 and 3.16, respectively. It's less for agarose (0.16). Hence it was concluded that the plasticizer (glycerol) had the highest significance while the binder (agarose) had the least importance in the manufacture of biodegradable composites.

3.7. Areca fibre reinforced polypropylene composites

Masudul Hassan et al. (2010) [73] investigated the physico-mechanical properties of betel nut and seaweed polypropylene (pp) composites. The composite was prepared by compounding with extrusion and hot press machine. Different composites were prepared with combination of different proportion of betel nut (Bn) fibre and pp and betel nut, seaweed and polypropylene. The areca fibre composites prepared (3, 5, 10, 20 and 30%) showed increasing tensile strength (ASTM D-53455) and elongation at break with increasing concentration of areca fibre up to 10% fibre loading and then gradually it decreased. This may be due to lack of stress transfer from pp matrix to betel nut fibre. The bending strength (ASTM D-53452) and the impact strength (ASTM D-53433) also increased with increasing fibre loading up to 10% and then it decreased; is due to high fibre content at higher fibre loading which could cause crack initiation and hence potential composite failure occurs. The tensile and bending modulus showed the increasing trend with increasing fibre loading from 3 to 30 %. This is due to high stiffness of areca short fibrils composition.

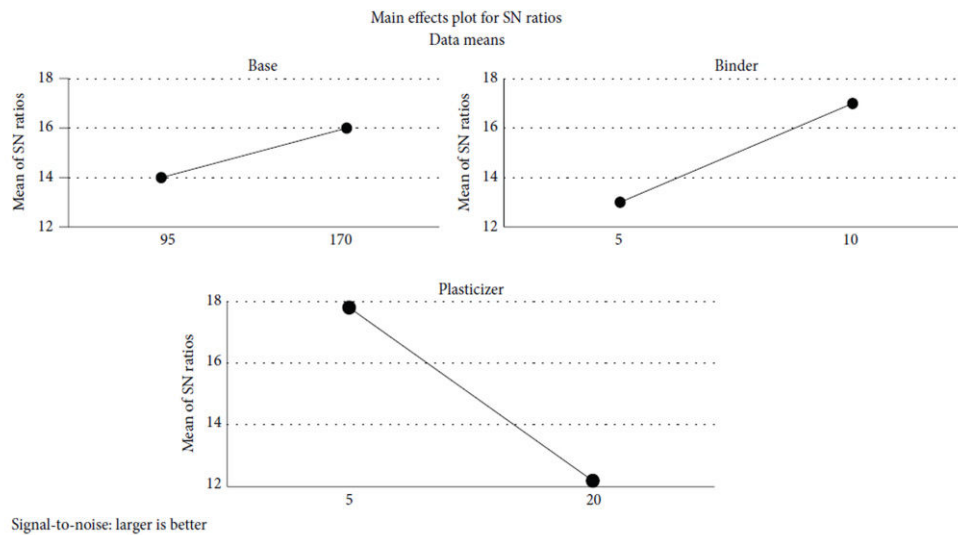


Fig. 14. Effect of base, binder and plasticizer on flexural strength of areca frond fibre.

The areca hybrid composites were prepared with seaweed and it was seen that all the mechanical properties showed improvement in hybrid when compared to Bn-pp composites. Water absorption test was calculated according to ASTM D5229/D 5229M-92, which revealed that water absorption is the highest for seaweed-pp composite, whereas it is less for Bn-seaweed polypropylene composites. Water absorption increases with the increasing fibre content which owes to the increasing cellulose content. The lowest water uptake indicates that more of the OH group of cellulose present in fibres are been blocked by the polypropylene matrix. Weathering effect and soil degradation test also showed best result for Bn-seaweed-pp composite when compared to Bn-pp and seaweed-pp composites.

Performance of hybrid jute/betel nut fibre reinforced polypropylene composites were further investigated by Masudul Hassan et al. in 2011 [74]. The fibre was alkali treated with 5 % caustic soda and was used for the compounding of composites using extruder and a hot-press machine. Jute-pp composites were prepared with different fibre loading of 3, 5, 10, 20 and 30%. It was observed that the mechanical properties like tensile strength (ASTM D 53455), elongation at break, bending strength (ASTM D 53452) and impact strength (ASTM D 53433) increased with increasing fibre content and the performance was maximum at 10% fibre loading; after which the mechanical properties decreased. This is due to lack of stress transfer from the pp matrix to jute filler, presence of too many filler ends in the composite at higher concentration, which could cause crack initiation and

hence potential composite failure. Jute-betel nut fibre-pp hybrid composite was prepared and was subjected for mechanical property determination. The mechanical properties of hybrid composites increased significantly compared to jute-pp composites. Treated fibre composites showed better results compared to untreated fibre composites, including for water absorption which was calculated according to the ASTM D5229/D 5229M-92.

The effect of surface treatment on betel nut fibre reinforced polypropylene composites was studied by Chakrabarty et al. in 2012 [75]. The composite was prepared with increasing fibre loading (0, 10, 20, 30 and 40%) and was subjected to mechanical testing. It was seen that the mechanical properties increased with increasing fibre content and showed maximum result at 30% fibre loading (tensile strength-27 MPa, elongation at break-51 %, bending strength-55 N/mm², impact strength - 1.6 Kj/mm²). Two different fibres composite were prepared; the composite prepared with the fibre which is detergent washed, and the composite prepared out of fibres which is alkali treated (20% NaOH) and was subjected for testing. It was observed that the result for detergent washed fibre composite (treatment improved fibre surface adhesive characteristics by removing natural and artificial impurities) and alkali treated fibre composite (treatment improves the adhesive characteristics of the fibre surface by removing the inorganic impurities thereby producing a rough surface topography) was more compared to untreated areca-polypropylene composites. Water absorption test calculated according to ASTM D 5229 revealed that the water intake

increased with increasing fibre loading which can be attributed to the fact that the cellulose content increases with increasing fibre content. Also the water intake is less for detergent washed fibre composite and the least for alkali treated fibre composite.

Siddika and Sharif in year 2015 [76] studied the processing and characterization of areca and waste nylon fibre reinforced hybrid polypropylene composites. The composite was prepared with fibre loading of 10% (areca: nylon – 1:1 ratio) with different layers of fibre (2 layered, 3 layered and 4 layered fibre composite) and was subjected to mechanical testing. Tensile strength increased with an increase in the number of fibre layers. As the fibre layer increases, fibres become uniformly dispersed into the matrix. Tensile strength, Young's modulus, flexural strength, flexural modulus increased with increase in the fibre layers (Figures 15 - 18).

SEM analysis was carried out and the micrographs were taken at the magnification of 100 and 200 revealed the reason for better mechanical properties of 4 layered fibre composite (4 layered fibre composite has better dispersion of filler into the matrix) compared to 3 and 2 layered fibre composite.

Thermogravimetric analysis (TGA) measures the amount and rate of change in the mass of a sample as a function of temperature/time in a controlled atmosphere. Maximum decomposition rates for weight losses of components present in composites are shown by DTG curve. TGA-DTG is specifically useful for the study of polymeric materials including thermoplastics, thermosets, elastomers, composites, films, fibres, coatings and paints. The TGA was carried out in the universal V4.2E TA instruments. The TGA curves of 3 layered (3L) and 4 layered (4L) 10 wt.% areca and waste nylon fibre reinforced polypropylene (PP) composites are shown in Figures 19 and 20. In both cases, the obtained TGA curves represent one-stage decomposition and therefore represent the thermal stability limit of the composite. From Figure 19, it can be seen that in case of 3 layered fibres reinforced composite, thermal degradation starts at around 260 °C and the thermal decomposition starting temperature does not differ much in case of 4 layered fibre reinforced composite without slight enhancement. The decomposition temperature corresponding to 25, 50 and 75% weight loss of 3L 10 wt.% areca waste nylon fibre (areca: nylon=1:1) reinforced PP composite and 4L 10 wt.% areca waste nylon fibre (areca: nylon=1:1) reinforced PP composites shows that there is no much difference in thermal degradation temperature.

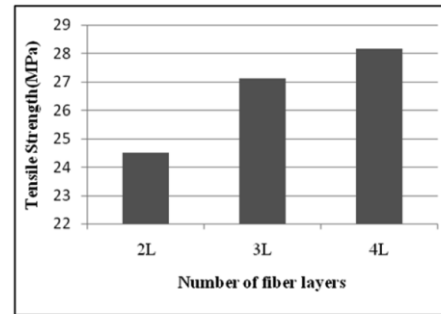


Fig. 15. Variation of tensile strength with number of areca/nylon fibre layers.

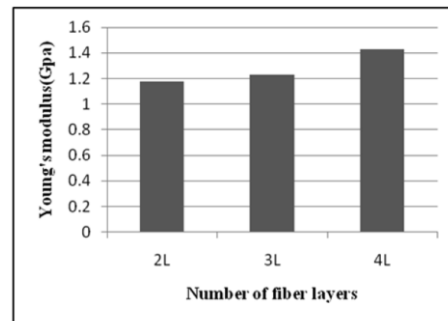


Fig. 16. Variation of Young's modulus with areca/nylon fibre layers.

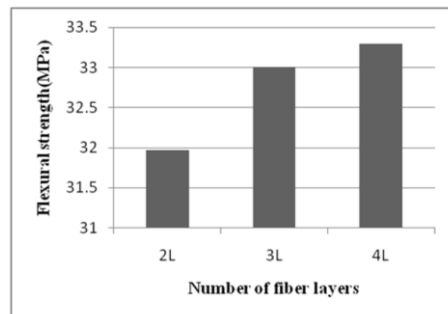


Fig. 17. Variation of Flexural Strength with number of areca/nylon fibre layers.

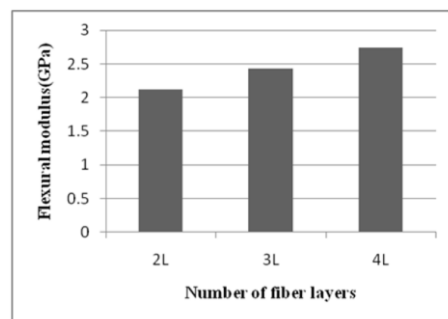


Fig. 18. Variation of flexural modulus with areca/nylon fibre layers.

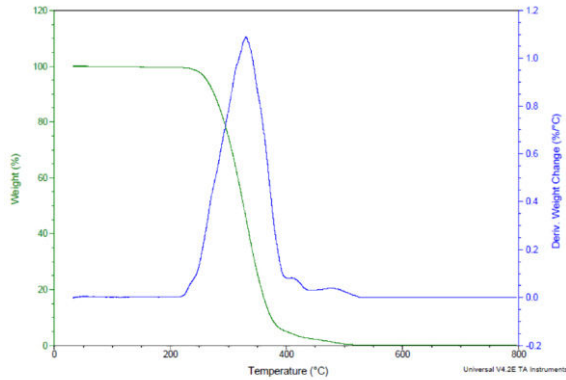


Fig. 19. TGA of 3L 10 wt.% areca-nylon-PP composite.

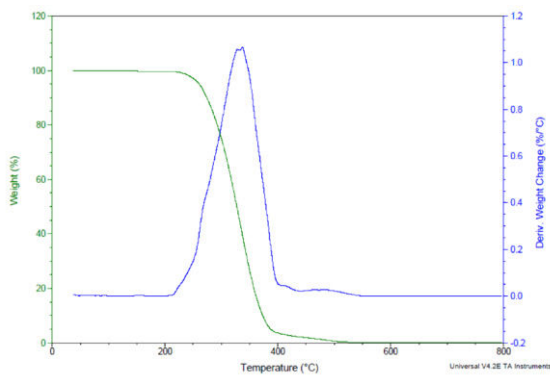


Fig. 20. TGA of 4L 10 wt.% areca-nylon-PP composite.

The maximum decomposition rates for weight losses of 3L 10 wt.% areca waste nylon fibre (areca: nylon=1:1) reinforced PP composite and 4L 10 wt.% areca waste nylon fibre (areca: nylon=1:1) reinforced PP composites are represented by DTG curve. Pure polypropylene starts to decompose at around 350 °C. From this, it can be concluded that both the composites have lower thermal stability than pure polypropylene and this occurs due to the presence of less thermally stable fibres. However, around 2.5% residual products remains in 4 layered fibre reinforced composite, the amount is slightly higher in case of 3 layered fibre reinforced composites.

Mechanical and thermal properties of areca leaf sheath fibre reinforced polypropylene composite (Figure 21) was studied by Poddar et al. (2016) [77]. The studies revealed that 10% fibre loaded composites showed maximum mechanical properties when compared to 5, 15, 20 and 25% fibre loaded composites. The tensile strength (DIN 53455) and bending strength (DIN 53452) for 10% fibre loaded polypropylene composite was found to be 28.7 MPa (Figure 22) and 46.9 MPa (Figure 23) respectively.



Fig. 21. Image of the areca fibre polypropylene composite.

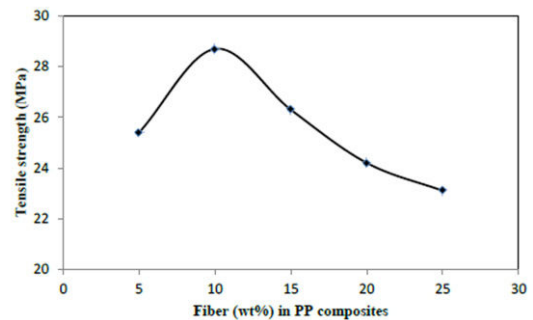


Fig. 22. Tensile strength of polypropylene composite at different fibre loading.

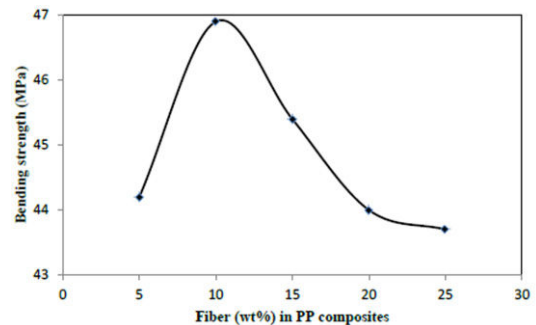


Fig. 23. Bending strength of polypropylene composite at different fibre loading.

Water uptake increased due to increasing fibre loading is due to increasing cellulose with increasing fibre percentage in the composite (Figure 24). SEM images for 10% fibre loading and 25% fibre loading composites are shown in the Figures 25 and 26. This indicates the better fibre-matrix adhesion responsible for higher mechanical properties in 10% fibre loaded composite where as in 25% fibre loaded composite, there exists gap between the fibre and the matrix, which in turn is responsible for its lower mechanical properties.

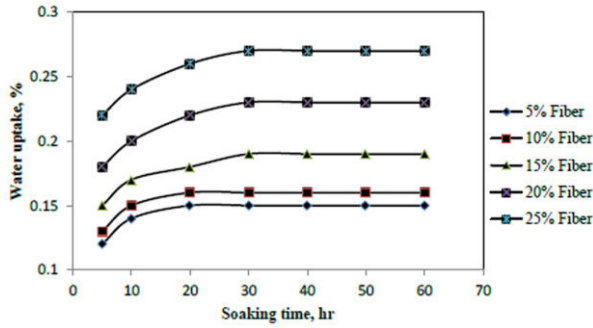


Fig. 24. Water uptake behaviour of polypropylene composites.

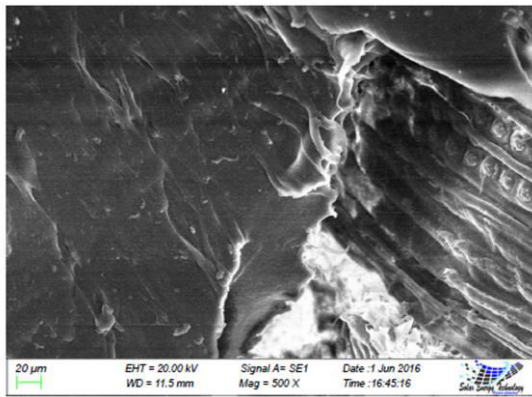


Fig. 25. SEM of 10% fibre loading polypropylene composite.

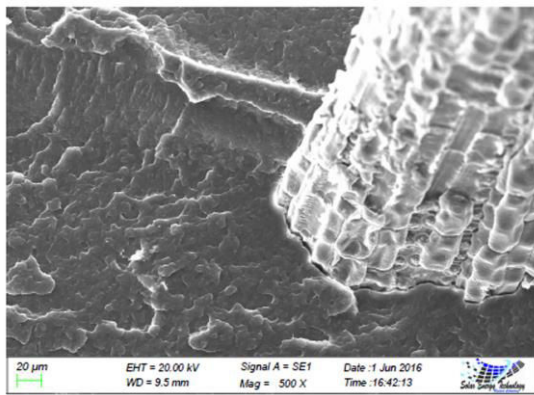


Fig. 26. SEM of 25% fibre loading polypropylene composite.

3.8. Areca fibre reinforced phenol formaldehyde composites

The work was done on areca reinforced polymer composite in comparison with coir-polymer composite by Swamy et al. in 2004 [78]. Initially the strength of the fibres was determined and it was found that the maximum tensile strength and Young’s modulus for areca fibre was found to be 85 - 101.85

MPa and 1100 - 1240 MPa, respectively, which was much less compared to the coir (tensile strength - 110 to 138 MPa, and Young’s modulus - 2560 to 3520 MPa). The areca fibres were treated with 5, 10, 15, 20 and 25% NaOH and were subjected to tensile strength testing. It was observed that the tensile strength was maximum for fibres treated with 15% NaOH (Figure 27).

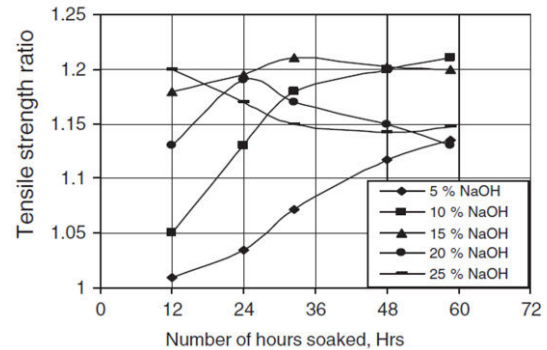


Fig. 27. Variation of tensile strength ratio of NaOH treated to natural areca fibre.

The areca fibres were then treated with 15% NaOH and composites were prepared with 1000 g of areca fibre and varying percentage of phenol-formaldehyde (100, 200, 300, 400 and 500 g). It was observed that the tensile property was maximum for composite with 1000 g areca fibre and 400 g of resin and it was observed to be 0.2488 MPa. The maximum bending load was found to be 223.6 N for areca-polymer composites for 200 g phenol-formaldehyde composition (Figures 28 and 29). The areca composites showed very good resistance to water absorption compared to wood-based particle boards and the biodegradability of these areca-composites is also at a slower rate.

Mohan Kumar in the year 2008 [79] added on to the work in studying the areca-phenol formaldehyde composites. The strength of areca fibres was found to be 101.85 MPa and the alkali treated fibre composite (15 % NaOH for 28-32 h) showed maximum tensile strength of 123.36 MPa. The strength of maize fibre is higher than areca fibre and is 152 MPa. The composite plates were prepared with areca 1000 g, 140 g of maize stalk short fibre and varying proportions of phenol formaldehyde (100, 200, 300, 400 and 500 g). For the composite with phenol formaldehyde 400 g; PF400, showed maximum tensile strength of 0.248 MPa and the composite with phenol formaldehyde 200 g; PF200 showed maximum bending stress of 10.01 MPa.

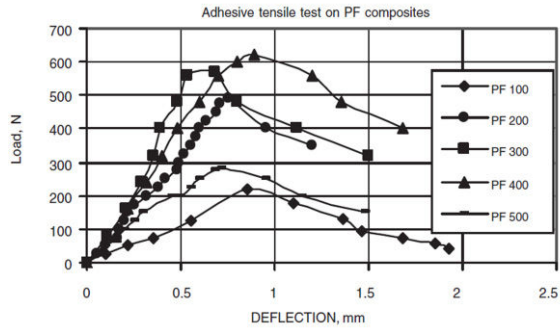


Fig. 28. The load-deflection curves for areca-PF composite plate at different phenol-formaldehyde proportions of 100 g to 500 g, corresponding to PF 100 to PF 500.

The mechanical behaviour of areca fibre and maize powder hybrid composites were studied by Kishan et al. in 2014 [80]. The composites were prepared with different proportions of areca and maize fibres and were subjected for mechanical property testing. The tensile strength and the flexural strength was found using the standards IS 2380 (part 3)-1977 and IS 2380 (part 4)-1977 respectively. It was reported that, the composite with 700 g areca and 300 g maize with 200 mL phenol formaldehyde showed highest tensile property and its Young's modulus was seen to be 77.72 MPa.

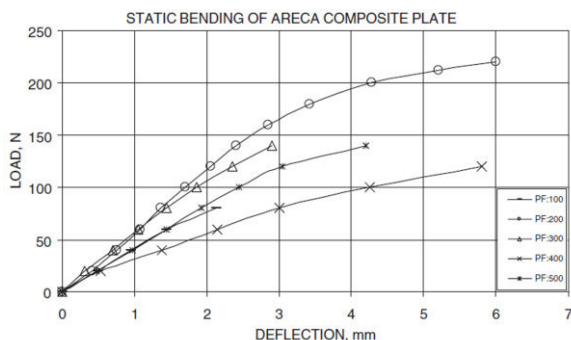


Fig. 29. Bending test curve for the composites plate at different phenol-formaldehyde proportions of 100 g to 500g corresponding to PF 100 to PF 500.

Now the phenol formaldehyde concentration was increased to 300 mL and again the tensile strength was found to be highest for areca (700 g) and maize (300 g) composite and it was recorded to be 135 MPa. Then the composite was prepared with 400 mL phenol-formaldehyde and the composite with 700 g of areca and 300 g of maize showed highest tensile strength (125.2 MPa). Flexural strength for 500 g areca and 500 g maize composite was found to be maximum. The maximum bending load for 200, 300

and 400 mL of phenol formaldehyde concentration was observed to be 0.753, 0.951 and 1.054 kN, respectively.

The study was made on areca fibre and wood powder reinforced phenol formaldehyde composites in year 2015 by Prem Kumar et al [81]. The areca fibre and the wood powder were mixed in different proportions like 800 g and 200 g, 700 g and 300 g, 600 g and 400 g and 500 g and 500 g respectively each with 200, 300, 400 and 500 mL of phenol-formaldehyde resin. These composites were subjected to different mechanical testing. According to IS 2380 (part B)-1977 for tensile testing and IS 2380 (part 4)-1977 for bending testing. Composite plate of 300 mL resin showed maximum tensile strength (Young's modulus for the same 700 g of areca and 300 g of wood powder - 91.59 MPa), 400 mL PF showed maximum bending stress (600 g areca and 400 g of wood powder - 0.854 kN maximum load) and composite with 500 mL plate (500 g of areca and wood powder) showed maximum moisture absorption resistance. The moisture content decreased with the increase in phenol-formaldehyde content.

3.9. Areca fibre reinforced urea formaldehyde composites

Bharath et al. [82] studied the adhesive tensile and moisture absorption characteristics of natural fibre reinforced urea formaldehyde composites in year 2009. The areca fibre and the maize fibre were taken in different proportions and the composites were prepared with different urea-formaldehyde concentration with the help of hydraulic hot press at 150 °C and 100 bar pressure. These composites were subjected to testing according to ASTM standards. The maximum tensile strength was seen for the composites with weight fraction ratio 7:3 of areca fibres to maize powder and the moisture absorption resistance was proved to be good for the composites with weight fraction ratio 4:1 of areca fibres to maize powder. Swelling behaviour of hybrid natural fibre reinforced UF composites were studied further in 2012 [83]. The areca fibres were subjected to alkali treatment (5% NaOH) and then the composites were prepared with different fractions of areca fibre and maize powder like 900 g of areca and 100 g of maize, 800 g of areca and 200 g of maize and so on up to 400 g areca and 600 g maize powder with 100, 200, 300 and 400 mL each of urea formaldehyde resin using hot hydraulic press. It was reported that the thickness increased with decreasing areca fibre proportion and

increasing maize percentage. It was maximum for 900 g areca fibre and 100 g maize powder composites. For 100 mL UF it was 94 mm, 57 mm for 200 mL UF, 23 mm for 400 mL UF. But for 300 mL UF composites, the maximum thickness was seen for 600 g areca and 400 g maize powder (42 mm). Also it has been reported that the water absorbed by these hybrid composites is lesser than the wood based composites.

3.10. Areca fibre reinforced urea formaldehyde, melamine urea formaldehyde and epoxy resin polymer composites

Srinivasa et al. [84, 85] investigated the static bending and impact behaviour of areca fibre composites. The areca fibres were initially treated with 10% KOH. With different fibre loading (50 and 60%), the composites were prepared using both treated and untreated fibres with the resins like urea formaldehyde (UF), melamine urea formaldehyde (MUF) and epoxy resins respectively. It was observed that the composite prepared from untreated fibres had lesser mechanical properties compared to the alkali treated fibre composite. The flexural strength for treated UF60 is maximum (27.36 MPa) compared to other composites and for untreated UF50 it is minimum (15.12 MPa). For MUF composites the flexural strength further increased compared to UF composites. This was because of the fact that the addition of melamine to urea formaldehyde increases the bonding strength, thereby increasing the flexural strength. The composite prepared with epoxy resin showed still better results with increasing fibre loading. When fibre proportion raised from 50 to 60 %, for treated fibre composite, the flexural strength increased from 63.36 to 84.87 MPa and for untreated fibre composite from 40.32 to 46.64 MPa. The load vs displacement curve for flexural behaviour of areca fibres reinforced urea formaldehyde composites, melamine urea formaldehyde composites and epoxy composites are given in Figures 30, 31 and 32, respectively. Out of these three resins, it was observed that the better results are obtained with epoxy resin composites because the interfacial bonding strength between fibre and matrix is found to be more in epoxy compared to formaldehyde groups due to improved adhesion and enhanced polar interactions at fibre-matrix interface.

The flexural strength of areca composites and impact energy absorbed by the composite are shown in Figures 33 and 34, respectively. Similar behaviour was observed with respect to the impact resistance testing which was later verified by SEM analysis.

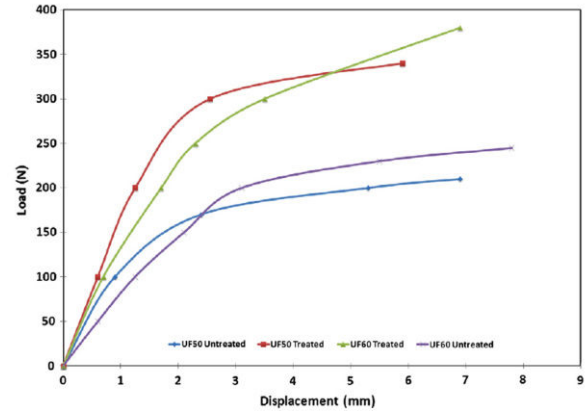


Fig. 30. Flexural behaviour of areca-urea formaldehyde composite.

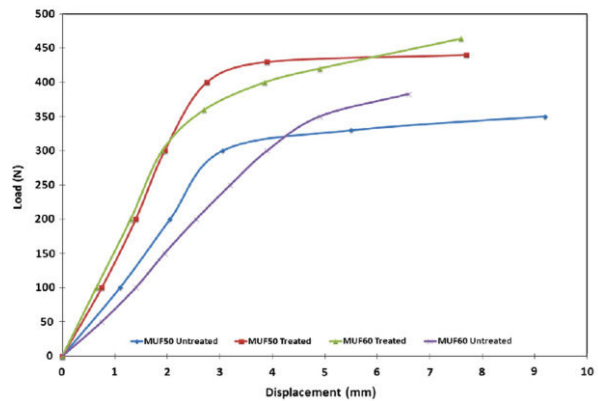


Fig. 31. Flexural behaviour of areca-melamine urea formaldehyde composite.

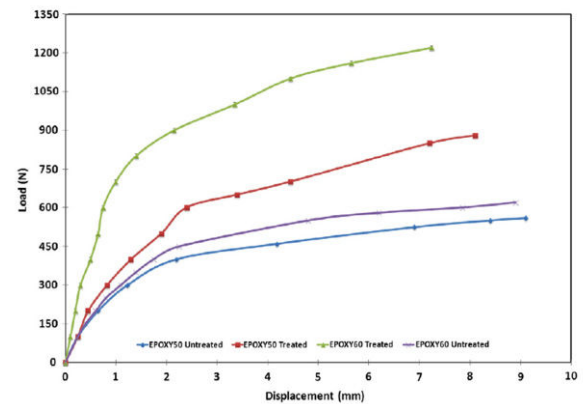


Fig. 32. Flexural behaviour of areca fibres reinforced epoxy composites.

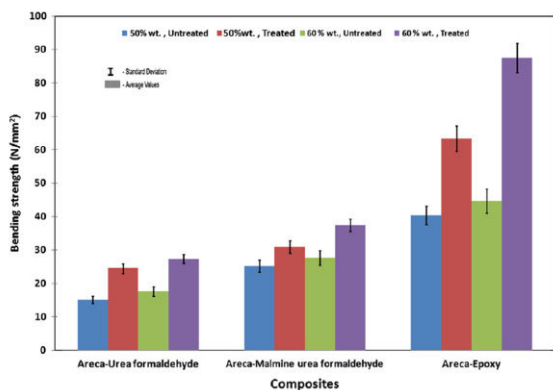


Fig. 33. Flexural strength of areca composites with treated and untreated fibres at different fibre loading.

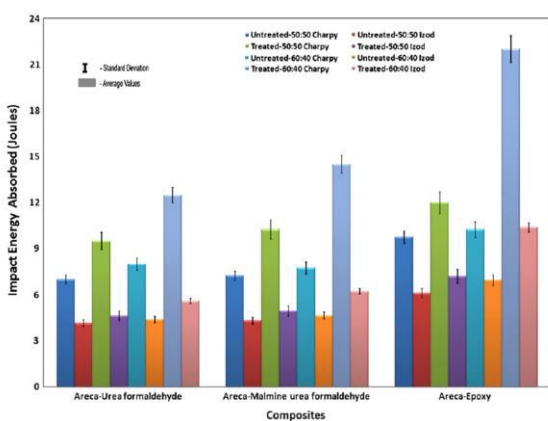


Fig. 34. Impact energy absorbed by areca composites (Charpy and Izod method).

3.11. Areca fibre reinforced epoxy composites

Study on 3-point bending analysis of untreated natural areca fibre reinforced epoxy composite was reported by Chethan et al. in 2016 [86]. The composite was prepared with 70% epoxy resin and 30% fibre loading and was subjected to flexural strength analysis according to ASTM D-7264 method. The flexural strength and modulus for 30 mm fibre length was found to be maximum; 50.34 and 42.62 N/mm², respectively.

The study of impact and hardness properties of areca fibre reinforced epoxy composites were carried out by Srinivasa et al. in the year 2011 [87] for which the fibres were alkali treated with 10% KOH and then the composite was prepared with 50 and 60% fibre loading. The composites were subjected to impact test and hardness testing according to ASTM D 256 and ASTM D 785 respectively. It was reported that the impact strength of the alkali treated fibre composites

increased with curing time at a greater degree when compared to fibre volume in the composite. The hardness test revealed that the fibres that increase in the moduli of composites, increases the hardness of the composite.

In 2015, Sunil et al. [88] investigated the preparation and characterization of short areca leaf fibre reinforced epoxy and vinyl ester composites. The respective composites were prepared with different fibre loadings and the composites were subjected to different mechanical testing according to ASTM standards. The maximum compressive strength of 49.80 and 135.83 MPa was found in epoxy and vinyl ester composites at 10 and 16 wt.%, respectively. Comparatively, vinyl ester composites showed better result when compared to epoxy composites at all the fibre loadings. The erosive wear test result as per ASTM G76 of epoxy and vinyl ester composites at 90° and 75° nozzle angle was determined. The percentage loss in weight at 90° nozzle angle was found to be lower compared to 75° nozzle angle for both the composites. Minimum percentage weight loss at 90° nozzle angle for epoxy and vinyl ester composite was at 18 and 10 wt.% (0.0068 and 0.0012, respectively) and the minimum percentage weight loss at 75° nozzle angle was at 16 wt.% for epoxy composite (0.0300) and 12 wt.% for vinyl ester composite (0.0365). The density of vinyl ester composites was found to be lower than that of the epoxy composites and the water absorption studies revealed that it increased with increasing fibre content in both the composites but the comparative study showed that the water absorption rate is lower in epoxy composites when compared to vinyl ester composites at all the fibre loadings.

Padmaraj et al. in 2016 [89] studied on natural fibre epoxy hybrid composites. Areca fibres were treated with 1 N NaOH and banana fibres were treated with 5% NaOH. Laminate preparation was done by taking a layer of epoxy resin followed by areca layer, a layer of resin, banana fibre layer and again a layer of epoxy resin. Five different samples were considered and were subjected for mechanical testing according to ASTM standards. ASTM standard used for tensile strength, flexural strength, hardness and Impact strength were D3039, D780, ISO (6507-1) and D256 respectively. Maximum tensile strength was found to be 26.48 MPa (Figures 35 and 36), Young's modulus was reported as 1145 MPa, bending maximum load capacity was 135 N (Figures 37 and 38). The results obtained revealed good mechanical properties for hybrid composites.

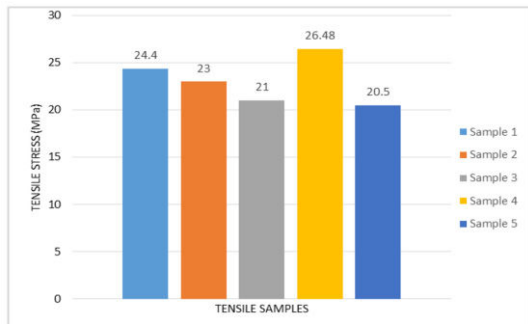


Fig. 35. Tensile strength of the areca-banana hybrid samples.

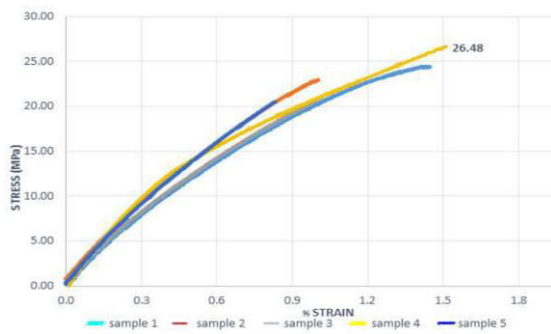


Fig. 36. Stress vs. strain for tensile strength of the areca-banana fibre composite.

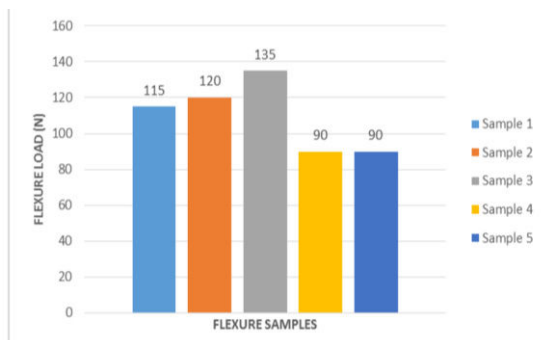


Fig. 37. Flexure strength of the areca-banana hybrid samples.

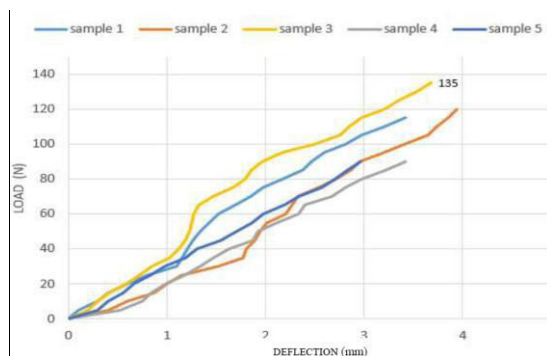


Fig. 38. Load vs. deflection for bending sample.

In 2016, mechanical behaviour of areca fibre reinforced epoxy composites was studied by Vinayaraj and Ashok [90]. The areca fibres were alkali treated with 10% NaOH. The composite was prepared with different fibre loading of 0, 5, 10 and 15% and the composites were subjected to mechanical testing. It was observed that the tensile strength gradually increased with increasing fibre content (tensile strength for fibre loadings of 0, 5, 10 and 15% was found to be 16.95, 22.58, 26.21 and 37.89 MPa, respectively). Flexural strength (flexural strength for fibre loadings of 0, 5, 10 and 15 % was found to be 17.68, 52.4, 54.12 and 86.62 MPa, respectively) and the impact strength (impact strength for fibre loadings of 0, 5, 10 and 15% was found to be 8.01, 8.30, 12.76 and 14.46, respectively) showed the same result as that of the tensile strength. The hardness test also showed that the hardness increases with increasing fibre content.

4. Conclusions

Polymer composites play a major role nowadays, where it has got wide applications in various field. There has been a growing interest in utilizing fibre reinforced polymer composite materials. Hence, the effort has been made to produce advantageous polymer composites. But as there are problems related to synthetic fibres like its availability, biodegradability, initial production cost, recyclability, health hazards, etc., the focus is more on natural fibre reinforced polymer composites. Researchers are targeting on finding different naturally available fibres, studying its physical and chemical properties, its feasibility in combining with the resins and formation of composites. Several works were done on different natural polymer composites using fibres like jute, bagasse, flax, hemp, cotton, coir, sisal, kenaf, hemp, abaca and many more. But the work done on the areca fibre composites is limited in spite of its abundant availability and high potential in using it as the reinforcement in the composite formation. The applications of the areca composites have been dramatically increasing for low cost construction, packing materials, sports equipment, marine structures, etc. Further research is still required to extend their application range, including on the moisture resistance and fire retardance. This was an attempt made to get an idea about the work done on areca fibre composite with their respective properties and strength in composite formation, so as to get an idea about how it could be further inculcated in

composite formation with advanced application. Overall, growth of natural areca fibre composite materials uptake continues at a rapid rate and there would appear to be a very positive future ahead for their applications.

References

- [1] M.N. Islam, M.R. Rahman, M.M. Haque, *Composites Part A*. 41 (2010) 192.
- [2] A.K. Bledzki, J. Gassan, *Prog. Polym. Sci.* 24 (1999) 221.
- [3] A.R. Sanadi, D.F. Caulfield, R.M. Rowell, *Ind. Eng. Chem. Res.* 34 (1995) 1889.
- [4] A.K. Bledzki, O. Faruk, *Composites Part A*. 37 (2006) 1358.
- [5] L.M. Matuana, C.B. Park, J.J. Balatinecz, *Polym. Eng. Sci.* 38 (1998) 1862.
- [6] M.M. Kabir, H. Hwang, K.T. Lau, F. Cardona, *Composites Part B*. 43 (2012) 2883.
- [7] A.K. Kaw, *Mechanics of Composite Materials*, Taylor & Francis, New York, 1997.
- [8] J.M.L. Reis, *Constr. Build. Mater.* 20 (2006) 497.
- [9] Z. Li, X. Wang, L. Wang, *Composites Part A*. 37(3) (2006) 497.
- [10] M.M. Kabir, H. Wang, K.T. Lau, F. Cardona, *Composites Part B*. 43 (2012) 2883.
- [11] K.G. Satyanarayana, K.K. Ravikumar, K. Sukumaran, P.S. Mukherjee, S.G.K. Pillai, A.K. Kulakarni, *J. Mater. Sci.* 21(1) (1986) 51.
- [12] V.P. Cyras, C. Vallo, J.M. Kenny, A. Vazquez, *J. Compos. Mater.* 38 (2004) 1387.
- [13] Y. Seki, *Mater. Sci. Eng. A*. 508 (2009) 247.
- [14] P. Ramadevi, S. Dhanalakshmi, B. Bennehalli, C.V. Srinivasa, *Bioresour.* 7(3) (2012) 3515.
- [15] K. Adekunle, D. Akesson, M. Skrifvars, *J. Appl. Polym. Sci.* 116 (2010) 1759.
- [16] M. S. Sreekala, M.G. Kumaran, S. Joseph, M. Jacob, *Appl. Compos. Mater* 7 (2000) 295.
- [17] L.Y. Mwaikambo, N. Tucker, A.J. Clark, *Macromol. Mater. Eng.* 292 (2007) 993.
- [18] B. Wang, S. Panigrahi, L. Tabil, W. Crerar, J. Reinf. Plast. Compos. 26 (2007) 447.
- [19] S. Jain, R. Kumar, U.C. Jindal, *J. Mater. Sci.* 27 (1992) 4598.
- [20] M.N. Cazaurang-Martinez, P.J. Herrero-Franco, P.I. Gonzalez-Chi, M. Vega, *J. Appl. Polym. Sci.* 43 (1991) 749.
- [21] L.Y. Mwaikambo, M.P. Ansell, 2nd International Wood and Natural Fibre Composites, 1999.
- [22] H.S. Yang, H.J. Kim, J. Son, H.J. Park, B.J. Lee, T.S. Hwang, *Compos. Struct.* 63 (2004) 305.
- [23] P.J.H. Franco, A.V. Gonzalez, *Composites Part B*, 36 (2005) 597.
- [24] A.S. Singha, V.K. Thakur, *Bull. Mater. Sci.* 31 (2008) 791.
- [25] V. Vilay, M. Mariatti, R. Mat Taib, M. Todo, *Compos. Sci. Technol.* 68 (2008) 631.
- [26] M. Haq, R. Burgueno, A.K. Mohanty, M. Misra, *Compos. Sci. Technol.* 68 (2008) 3344.
- [27] V.K. Thakur, A.S. Singha, *Iran. Polym. J.* 19 (2010) 3.
- [28] A.S. Singha, B.S. Kaith, I. Kaur, A.J. Khanna, *J. Chem.* 8 (2011) 1478.
- [29] M. Yusoff, M. Salit, N. Ismail, R. Wirawan, *Sains Malays.* 39 (2010) 87.
- [30] M. Islam, S. Hamdan, M. Rahman, I. Jusoh, A. Ahmed, M. Idrus, *Bioresour. Technol.* 6 (2011) 737.
- [31] M.A. Maleque, F.Y. Belal, S.M. Sapaun, *Arab. J. Sci. Eng.* 32 (2007) 359.
- [32] S.A. Paul, A. Boudenne, L. Ibos, Y. Candau, K. Joseph, S. Thomas, *Composites Part A*. 39 (2008) 1582.
- [33] N.A. Ahad, N. Parimin, N. Mahmed, S.S. Ibrahim, K. Nizzam, Y.M. Ho, *J. Nucl. Technol.* 6 (2009) 155.
- [34] M. Boopalan, M. Niranjanaa, M.J. Umapathy, *Composites Part B*. 51 (2013) 54.
- [35] V.P. Arthanarieswaran, A. Kumaravel, M. Kathirselvam, *Mater. Des.* 64 (2014) 194.
- [36] A.K. Ray, S. Mondak, S.K. Das, *J. Mater. Sci.* 40 (2009) 5249.
- [37] P. Ramadevi, S. Dhanalakshmi, R.P. Ranganagowda, B. Bennehalli, P. Badyankal, C.V. Srinivasa, *Cienc. Tecnol. Mater.* 26 (2014) 142.
- [38] P. Ramadevi, S. Dhanalakshmi, R.P. Ranganagowda, B. Bennehalli, C.V. Srinivasa, *J. King Saud. Univ. Eng. Sci.* 29 (2017) 289.
- [39] B. Bennehalli, C.V. Srinivasa P. Ramadevi, S. Dhanalakshmi, *Handbook of composites from renewable materials*, Volume 6, Chapter 13, Wiley, 2017, pp 353.
- [40] W. Wang, G. Huang, *Mater. Des.* 30 (2009) 2741.
- [41] A. Chanakan, C. Sarocha, H. Jonjit, K. Joseph, *Composites Part B*. 40 (2009) 633.
- [42] E.B. Harmida, V.I. Mega, *Composites Part A*. 38 (2007) 1387.
- [43] A. Etaati, S. Pather, Z. Fang, H. Wang, *Composites Part B*. 62 (2014) 19.
- [44] D.G. Hepworth, R.N. Hobson, D.M. Bruce, J.W. Farrent, *Composites Part A*. 31 (200) 1279.
- [45] P. Pantamanatsopa, W. Ariyawiriyanan, T. Meekeaw, R. Suthamaong, K. Arrub, H. Energy. *Procedia. Hamada*, 56 (2014) 641.
- [46] P.A. Kumar, S. Chakraborty, M. Ray, *Chem. Eng. J.* 141 (2008) 130.
- [47] J. Jawaid, H.P.S.A. Khalil, A. Abu Bakar, P.N. Khanam, *Mater. Des.* 32 (2011) 1014.

- [48] D. Ray, B.K. Sarkar, A.K. Rana, N.R. Bose, *Composites Part A*. 32 (2001) 119.
- [49] M.A. Khan, M.H. Hassan, L.T. Drzal, *Composites Part A*. 36 (2005) 71.
- [50] D. Ray, B.K. Sarkar, A.K. Rana, N.R. Bose, *Composites Part A*. 33 (2002) 233.
- [51] R. Mahjoub, J.M. Yatim, A.R.M. Sam, M. Raftari, *Mater. Des.* 64 (2014) 640.
- [52] Y.A. El-Shekeil, S.M. Sapuan, M. Jawaid, O.M. Al-Shuja, *Mater. Des.* 58 (2014) 130.
- [53] M.A. Martin, L.A. Forato, L.H.C. Mattoso, L.A. Colnago, *Carbohydr. Polym.* 64 (2006) 127.
- [54] A. Belaadi, A. Bezazi, M. Bourchak, F. Scarpa, C. Zhu, *Composites Part B*. 67 (2014) 481.
- [55] P.A. Sreekumar, S.P. Thomas, J.M. Saiter, K. Joseph, G. Unnikrishnan, *Composites Part A*. 40 (2009) 1777.
- [56] A. Vera, A. Vazquez, *Composites Part A*. 37 (2007) 1672.
- [57] N. Vekateshwaran, A. Elayaperumal, A. Alavudeen, M. Thiruchitrabalam, *Mater. Des.* 32 (2011) 4017.
- [58] C.V. Srinivasa, B. Bennehalli, M.G. Kenchappa, R.P. Gowda, *Bioresor.* 5 (2010) 1846.
- [59] L. Yusriah, S.M. Sapuan, E.S. Zainudin, M. Mariatti, *Procedia. Chem.* 4 (2012) 87.
- [60] N.H. Padmaraj, M.K. Viajy, R. Pai, S. Shenoy, Krishnamoorthy, National Conference on Trends in Mechanical Engineering 2010.
- [61] S. Dhanalakshmi, P. Ramadevi, B. Basavaraju, S.C. Venkateshappa, *Int. J. Agr. Sci.* 4 (2012) 227.
- [62] S. Dhanalakshmi, P. Ramadevi, B. Basavaraju, S.C. Venkateshappa, *Cienc. Technol. Mater.* 27 (2015) 121.
- [63] J.S. Binoj, R. Edwin Raj, V.S. Sreenivasan, G.R. Thusnavis, *J. Bionic. Eng.* 13 (2016) 156.
- [64] S. Dhanalakshmi, P. Ramadevi, R.P. Ranganagowda, B. Pramod, B. Basavaraju, *Chem. Sci. Rev. Lett.* 3(12) (2014) 957.
- [65] S. Dhanalakshmi, P. Ramadevi, B. Basavaraju, *J. Apl. Chem.* 8 (2015) 43.
- [66] W.L. Lai, M. Mariatti, M. Jani, *Polym. Plast. Tecnol. Eng.* 47 (2008) 1193.
- [67] E. Jayamani, S. Hamdan, M.R. Rahman, M. Khusairy, *Proc. Eng.* 97 (2014) 545.
- [68] S.B. Hazarika, S.U. Choudhury, S.S. Panja, S.K. Dolui, B.C. Ray, *J. Sci. Ind. Res.* 74 (2015) 589.
- [69] K. Dey, S. Ganguly, R.A. Khan, M.A. Khan, *J. Compos. Biodegrade. Polym.* 1 (2013) 1.
- [70] N.H. Padmaraj, M.V. Kini, B.R. Pai, B.S. Shenoy, *Proc. Eng.* 64 (2013) 966.
- [71] S.S. Heckadka, M.V. Kini, R.P. Ballambat, S.S. Beloor, S.R. Udipi, U.A. Kini, *Int. J. Manuf. Eng.* 2014.
- [72] S.S. Heckadka, S.Y. Nayak, S.R. Vikas, M.V. Kini, N.H. Padmaraj, *Indain J. Sci. Technol.* 9(35) 2016 .
- [73] M.M. Hassan, M.H. Wagner, H.U. Zaman, M.A. Khan, *J. Nat. Fibres.* 7 (2010) 165.
- [74] M.M. Hassan, M.H. Wagner, H.U. Zaman, M.A. Khan, *J. Adhes. Sci. Technol.* 25 (2011) 615.
- [75] J. Chakrabarty, M.M. Hassan, M.A. Khan, *J. Polym. Environ.* 20 (2012) 501.
- [76] S. Siddika, A. Sharif, *Int. J. Inno. Sci. Res.* 19 (2015) 319.
- [77] P. Poddar, M.S. Islam, S. Sultana, H.P. Nur, A.M.S. Chowdhury, *J. Mat. Sci. Eng.* 5 (2016).
- [78] R.P. Swamy, G.C. Mohan, Y. Vrushabendrappa, *J. Reinf. Plast. Compos.* 23 (2004) 1373.
- [79] G.C.M. Kumar, *Proceedings of the World Congress on Engineering* 2 (2008).
- [80] K. Naik, R.P. Swamy, *Int. J. Eng. Res. Appl.* 4 (2014) 185.
- [81] P. Naik, V. Kumar, S. Kumar, K.R. Srinivasa, *Am. J. Mat. Sci.* 5(3C) (2015) 140.
- [82] K.N. Bharath, R.P. Swamy, *Int. J. Recent Trends Eng.* 1 (2009) 60.
- [83] K.N. Bharath, R.P. Swamy, *J. Purity, Util. React. Environ.* 1 (2012) 517.
- [84] C.V. Srinivasa, A. Arifulla, N. Goutham, T. Santosh, H.J. Jeetendra, R.B. Ravikumar, S.G. Anil, D.G. Kumar, J. Ashish, *Mater. Des.* 32 (2011) 2469.
- [85] C.V. Srinivasa, K.N. Bharath, *International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering* 7 (2013) 240.
- [86] M.R. Chethan, S.G. Gopala Krishna, R. Chennakeshava, M. Majunath, *Int. J. Eng. Technol. Manag. Appl. Sci.* 3 (2016) 412.
- [87] C.V. Srinivasa, K.N. Bharath, *J. Mater. Environ. Sci.* 2(4) (2011) 351.
- [88] S. Kumar, S.G. Gopalakrishna, H.R. shivakumar, K.S. Rai, *IJARSE.* 4(1) (2015) 1635.
- [89] N.H. Padmaraj, A. Suresh, V. Nayak, O. Anand, E.J.D. Pavan, *IJCEM* 3 (2016) 24.
- [90] K.G. Vinayraj, B.C. Ashok, *Int. J. Mech. Ind. Technol.* 4 (2016) 66.