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Fabrication of *Borassus* fruit lignocellulose fiber/PP composites and comparison with jute, sisal and coir fibers

P. Sudhakara[a,*], Dani. Jagadeesh[a], YiQi Wang[a], C. Venkata Prasad[a,b], A.P. Kamala Devi[c], G. Balakrishnan[a,d], B.S. Kim[e], J.I. Song[a,*]

[a] Department of Mechanical Engineering, Changwon National University, Changwon 641-773, South Korea
[b] Dielectric Material Division, Central Power Research Institute, Bengaluru 560080, India
[c] Department of Chemistry, Anna University, Chennai 600025, India
[d] Department of Mechanical Engineering, Bharath University, Chennai 600 073, India
[e] Composites Materials Group, Korea Institute of Materials Science, Changwon 642-831, South Korea

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ABSTRACT

Novel composites based on *borassus* fruit fine fiber (BFF) and polypropylene (PP) were fabricated with variable fiber composition (5, 10, 15 and 20 wt%) by injection molding. Maleated PP (MAPP) was also used as compatibilizer at 5 wt% for effective fiber–matrix adhesion. FTIR analysis confirms the evidence of a chemical bonding between the fiber and polymeric matrix through esterification in presence of MAPP. The tensile and flexural properties were found to increase with 15 and 10 wt% fiber loadings respectively, and decreased thereafter. Coir, jute and sisal fiber composites were also fabricated with 15 wt% fiber loading under the same conditions as used for BFF/PP composites. It was found that the mechanical properties of BFF (15 wt%)/PP composites were equivalent to jute/PP, sisal/PP and superior to coir/PP composites. Jute/PP and sisal/PP composites showed higher water absorption than BFF/PP and coir/PP composites. These results have demonstrated that the BFF/PP composites can also be an alternative material for composites applications.

1. Introduction

Conventional synthetic fibers, such as glass, carbon, boron and aramid have been extensively used as reinforcing agent in thermoplastic or thermosetting matrices over the last several decades (Bledzki, Mamun, & Faruk1, 2007) for many applications to improve the mechanical properties in the composites as well as reducing the overall cost. However, manufacturing of synthetic fiber composites not only consume huge energy but also their disposal at the end of the life cycle is very difficult since there is virtually no recycling option. Therefore, with increasing environmental concerns, the research on natural fiber based composites has gained momentum in the recent composite technology, because they are considered as strong candidates to replace the conventional glass fibers due to, low cost, renewable resources, degradation (Azwa, Yousif, Manalo, & Karunasena, 2013) completely by composting process and do not emit any toxic component. The abrasive nature of natural fibers is also much lower compared to that of glass-fibers, which offers advantages with respect to processing techniques and recycling (Bledzki & Gassan, 1999; Georgopoulos, Tarantili, Avgerinos, Andreopoulos, & Koukios, 2005; Tran Huu, Shinji, Nguyen, & Satoshi, 2011). Various natural fibers, such as jute (Hossain, Dewan, Hosur, & Jeelani, 2011; Ibrahim, Amr, Eid, & El-Sayed, 2010; Murshid & Tarun, 2012), sisal (Alvarez, Ruseckaite, & Va'zquez, 2006; Bourmaud & Baley, 2007), kenaf (Anuar & Zuraida, 2011; Nishino, Hirao, Kotera, Nakamae, & Inagaki, 2003), banana (Chattopadhyay, Khandal, Ramagopal, & Ghoshal, 2010; Guimarães, Wypych, Saul, Ramos, & Satyanarayana, 2010; Liu, Wua, & Zhang, 2009; Majhi, Nayak, Mohanty, & Unnikrishnan, 2010), hemp (Hu & Lim, 2007; Mohanty, Wibowo, Misra, & Drzal, 2004; Niu, Liu, Wei, Wang, & Yang, 2011), coir (Chanakan, Sarocha, Jongjit, & Joseph, 2009; Nama, Ogihara, Tung, & Kobayashi, 2011), flax (Fabunmi, Tabil, Panigrahi, & Chang, 2011; Keener, Stuart, & Brown, 2004; Oksman, Skrifvars, & Selin, 2003; Privas & Navard, 2013), bamboo (Sandeep, Veena, & Rakesh, 2010; Verma & Chariar, 2012), pineapple (Luo & Netravali, 1999), ramie (Xinqi, Liping, Haiye, Wenjun, & Wenke, 2012) have been extensively used as reinforcements within polymeric matrices by many research groups. However, with a view of effective utilization of natural sources, the search for new natural fibers is being continued in the recent years.

The properties of composites depend on the matrix, fibers and the interfacial bonding between the reinforcing fibers and the matrix, as the stress transfer between matrix and fibers determines

* Corresponding authors. Tel.: +82 55 213 3606; fax: +82 55 267 5142.
E-mail addresses: sudhakar678@yahoo.com, sudhakar678@gmail.com (P. Sudhakara), jisong@changwon.ac.kr (J.I. Song).

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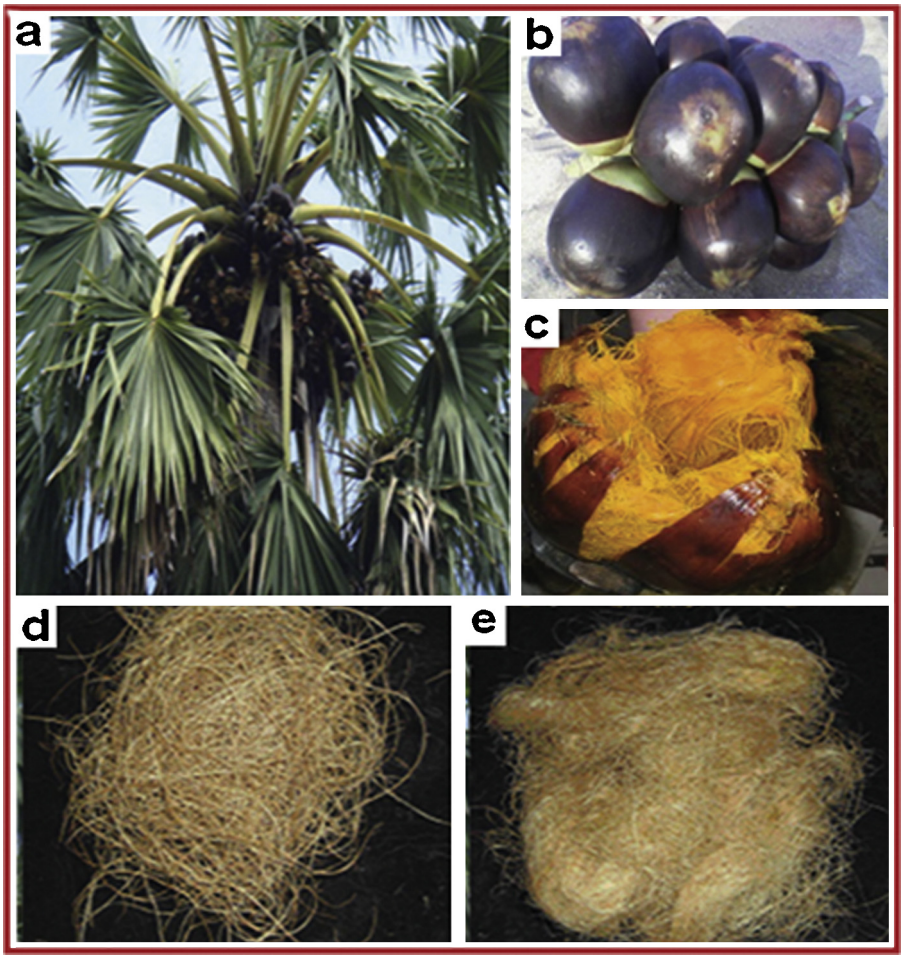
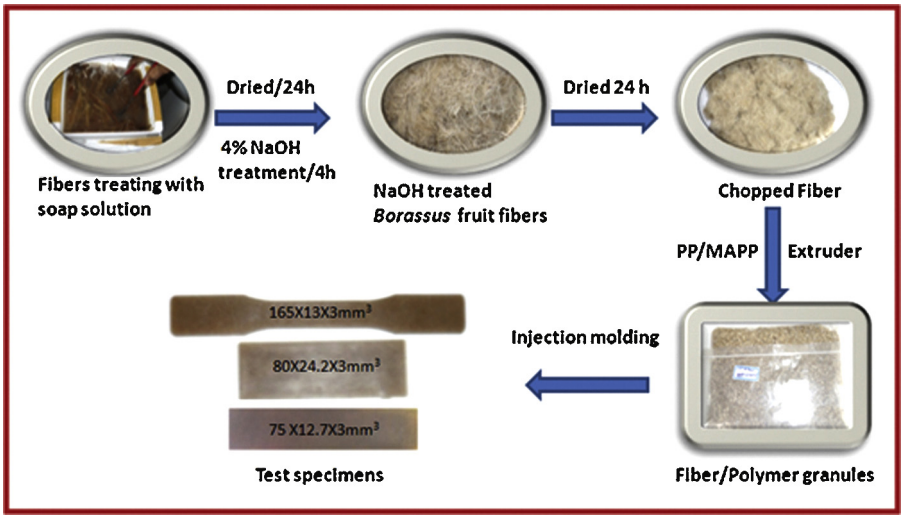


Fig. 1. (a) *Borassus* tree with fruits, (b) *Borassus* fruits, (c) fruit with fiber and pulp and seed (d) *Borassus* fruit Coarse and (e) fine fibers.

reinforcement efficiency. When natural fibers used as reinforcement in composite materials, the hydroxyl groups of natural fibers leads to poor interfacial bonding with the hydrophobic polymer matrix as well as sensitive to water absorption. Therefore, surface modification of the natural fibers is one of the largest areas of current research to improve compatibility and interfacial bond strength. The use of different types of physical treatment methods such as, corona discharge, plasma and various chemical surface treatment methods such as, alkali, acetylation, silane coupling agents, treatment with maleated polypropylene (MAPP) are well known in the literature. Chemical treatments expose more reactive groups on the fiber surface and thus facilitates efficient coupling with the matrix. According to Keener et al. (Keener et al., 2004), among coupling agents, newly developed maleated couplers demonstrate superior performance compared with other potential polyolefin coupling agents. Literature reveals that the 5 wt% of MAPP is the optimum concentration in the PP matrix. (Chattopadhyay, Khandal, Ramagopal, & Ghoshal, 2009, 2010; Keener et al., 2004; Hujuri, Chattopadhyay, Ramagopal, & Ghoshal, 2008) Surface modification of the fibers with NaOH and the addition of MAPP to the matrix lead to considerable improvement in the fiber–matrix adhesion and physico mechanical properties of the resulting composites (Chattopadhyay et al., 2010; Hujuri et al., 2008).

Borassus (Palmyra Palm) (Fig. 1) is a member of palm tree family, normally found in the tropical regions of Africa, Asia and New Guinea. The Palmyra palm has been one of the most important trees, economically useful and widely cultivated in Cambodia and India, where it is used over 800 different ways. The fruits are used as a food product either roasted or raw, and the young, jellylike seeds are also edible (Bill, 1999; Morton, 1988). These fruits contain cellulosic semisolid flush, which is reinforced by the coarse and fine fibers. A detailed study on morphology, mechanical and thermal properties of these fibers was reported in the literature (Obi Reddy, Babu Rao, & Varada Rajulu, 2009; Obi Reddy, Uma Maheswari, Shukla, Song, & Varada Rajulu, 2013) and suggested that these fibers can be utilized as reinforcement component in green composite manufacturing. It is also found that the mechanical properties the fine fibers are superior to the coarse fibers. *Borassus* fruit fibers are inexpensive, abundantly available, ecofriendly and hence it is essential to explore the potential utility of these fibers to the technical world. Polypropylene (PP) is one of the most extensively used plastics, provides advantages with regard to economy (price), ecological (recycling behavior), and technical requirements (higher thermal stability). Based on the above literature, we have made an attempt to develop the new biocomposites based on *Borassus* fruit fine fiber (BFF)/PP composites by injection molding method using 5 wt% of fiber and Maleatedpolypropylene (MAPP) as compatibilizer to investigate the effect of modification on thermal, mechanical and morphological properties (Sudhakara et al., 2013).

On the other hand, jute is the most common agricultural fiber; it is nonabrasive, exhibit moderately higher mechanical properties and abundantly available exclusively in Bangladesh, India, Thailand and in some parts of Latin America (Bledzki et al., 2007). Sisal is a highly resistant and rigid natural fiber, mainly used in applications ranging from manufacturing of ropes and yarns for ropes and carpets, to different textiles and handicrafts (Albanoa et al., 2002). Coir fiber is also an important lignocellulosic fiber obtained



Scheme 1. Schematic representation of the preparation of composite test specimens.

from coconut trees, a very cheap, and ecofriendly to the environment which grows extensively in tropical countries. Coir fibers have many advantages like low density, lower cost, availability, higher lignin content, low elastic modulus, and high elongation at break (Saw, Sarkhel, & Choudhury, 2012).

The aim of this work is to fabricate the BFF/PP composites in presence of MAPP compatibilizer and to optimize the fiber loading for BFF reinforced PP composites and compare with jute, sisal and coir fiber reinforced PP composites in terms of their, water absorption, thermal, mechanical and morphological properties.

2. Experimental

2.1. Materials

Borassus fruit fine fibers (BFF) (Fig. 1) were extracted from dried ripened fruits, as reported elsewhere (Obi Reddy et al., 2009) and used as reinforcement. Coir, jute and sisal fibers were collected from local markets. Polypropylene (PP) (injection grade) was supplied from Honam Petrochemical Corporation, South Korea. The coupling agent, Poly (propylene)-graft-maleic anhydride (MAPP) (Aldrich) and Sodium hydroxide (NaOH) (Dae-Jung Chemicals) were procured and used as received.

2.2. Fiber surface treatment

BFF, jute, sisal and coir fibers were initially washed with distilled water to remove dirts, mud, and other water-soluble impurities and dried for 24 h. The dried fibers were treated with 4% NaOH for 5 h at room temperature maintaining the liquid ratio of 1:20. The fibers were taken out and washed with distilled water until the fibers showed no residual NaOH (neutral pH) and dried in a vacuum oven at 70 °C for 24 h. The dried alkali treated and untreated fibers were chopped in the range of 5–10 mm and stored in a sealed plastic bag.

2.3. Composites fabrication

The dried short fibers, PP and MAPP (for modified composites) were melt-compounded in a co-rotating twin-screw extruder (PRISM, TSE 16TC, Thermoelectron Corporation). The temperature of the barrel sections from hopper to die was as follows 180, 185, 185, 190 and 190 °C and the screw speed was 120 rpm. Subsequently, the extrudate was pelletized using a pelletizer equipped with a set of knifes and different grids. These pellets were dried in an oven at 80 °C for at least 24 h and injection molded (WOOJIN, SELXR CO. LTD.) into standard specimens for testing the mechanical properties. The injection-molding temperature and pressure were 200 °C and 60 MPa, respectively. Various stages involved in the process of composites fabrication are shown in Scheme 1.

2.4. Characterization

2.4.1. Spectral and thermal analysis

FTIR spectra of the raw and alkali-treated BFF, pure PP, MAPP and BFF/PP composite samples were recorded in an ATR-FTIR (attenuated total reflection) spectrometer (model FT/IR-6300, JASCO, Canada). Thermogravimetric analysis (TGA) was performed using TG-DTA (SETSYS evaluation TG-DTA 24, SETARAM France) thermal analyzer in a dry nitrogen atmosphere at a heating rate of 20 °C/min with sample weight of 3–5 mg in the temperature range 35–700 °C.

2.4.2. Water absorption properties

Water absorption property of the composite specimens was carried out according to ASTM D570-98. Three specimens of each formulated composite with dimensions 80 mm × 24.6 mm × 3.2 mm were used for testing. Prior to absorption experiments, the samples were dried in an oven at 50 °C and then allowed to cool to room temperature in a desiccator until the weight (dry weight) stabilized before weighing them to the nearest 0.001 g. The specimens were then immersed in distilled water at room temperature for 24 h. The specimens were taken out from the water and all surface water was removed with a clean dry cloth and immediately weighed (wet weight) to the nearest value 0.001 g. The percentage increase in weight during water immersion was calculated using the following equation.

$$\text{Water absorption}\,(\%) = \frac{M_2 - M_1}{M_1} \times 100$$

where M_2 is the mass of the sample after immersion (g); and M_1 is the mass of the sample before immersion (g).

2.4.3. Mechanical properties

The tensile strength and modulus were measured according to ASTMD 6389 standards (165 mm × 13 mm (Narrow width) × 3 mm specimens) with a cross-head speed of 5 mm/min and the the load was 10 kN. The flexural strength and modulus of the samples were also measured according to ASTM D790-03 with a cross-head speed of 2 mm/min using three-point bending mode (specimen

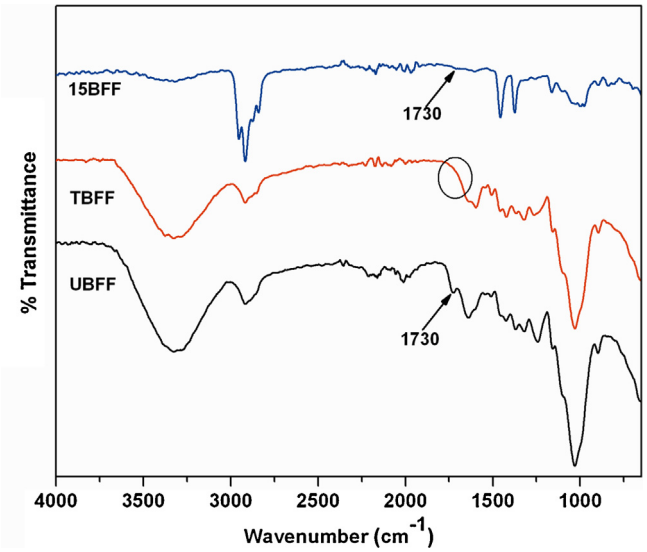


Fig. 2. ATR-FTIR spectra of untreated *Borassus* fruit fiber (UBFF), alkali treated *Borassus* fruit fiber (TBFF) and 15%BFF/PP composite with MAPP compatibilizer.

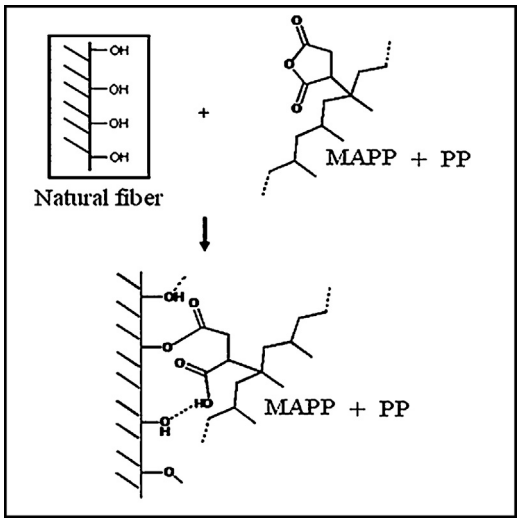


Fig. 3. Mechanism of interactions between MAPP and the hydroxyl groups on the surface of natural fibers.

dimensions of 80 mm × 24.2 mm × 3.2 mm) tests. Impact test was performed employing an Izod impact testing machine, supplied by International equipments, Mumbai, India. Rectangular strips of 75 mm × 12.7 mm × 3 mm were used as per ASTM 256-88 specifications. The impact test was carried out at room temperature and impact energy was reported in J/m. For each test, five test specimens were taken and the average value was recorded.

2.4.4. Morphology

The fracture surfaces and interfaces of the flexural and tensile tested specimens were analyzed by Scanning electron microscope (SEM; JSM-5610, Japan). The tensile and flexural fractured surface of the samples were gold coated with gold an Auto Fine sputter Coater prior to the fractographic examination.

3. Results and discussion

3.1. Borassus fruit fiber (BFF) reinforced composites

The aim of this work was to fabricate and optimize the BFF/PP composites using MAPP as compatibilizer and comparison with jute, sisal and coir fiber reinforced PP composites in terms of their, mechanical and morphological, thermal and water absorption properties.

3.1.1. FTIR analysis of modification effects on BFF fibers and BFF/PP composites

ATR-FTIR spectra of untreated, NaOH treated BFF fibers and treated BFF/PP (15% of treated BFF) composites with MAPP were recorded (Fig. 2), in order to understand the effect of alkali treatment and MAPP on fibers and composites. An absorption band ~1730 cm^{-1} corresponding to the carbonyl group of hemicellulose of untreated borassus fibers (UBFF) was disappeared for NaOH treated fibers (TBFF) (the absence of the peak position is showed with circle in Fig. 2). The similar observations were also noticed by other researchers (Chattopadhyay et al., 2010; Herrera-Franco & Valadez-Gonzalez, 2005; Liu & Dai, 2007). The disappearance of these characteristic peaks clearly indicated that the alkali treatment significantly removes hemicellulose content on fiber surface. For the NaOH treated BFF/PP composites with MAPP, a peak ~1730 cm^{-1} appears again, due to formation of covalent bonds by the formation of ester groups (Mohanty, Misra, & Hinrichsen, 2000)

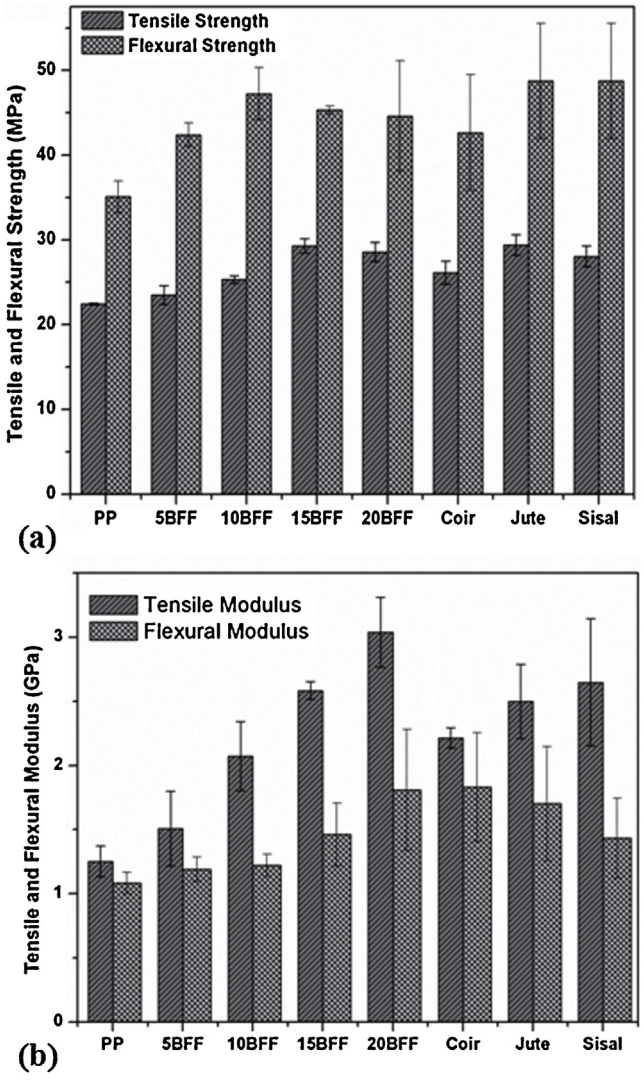


Fig. 4. (a) Tensile and (b) flexural properties of virgin PP and BFF/PP (5, 10, 15 and 20 wt% of BFF), coir (15 wt%)/PP, jute (15 wt%)/PP and sisal(15 wt%)/PP composites.

between hydroxyl groups of fiber and MAPP as shown in schematic representation of Fig. 3

3.1.2. Mechanical properties

3.1.2.1. Tensile, flexural and impact properties of BFF/PP composites. Surface modification of the fibers with NaOH and the addition of MAPP to the matrix provide considerable improvement in the fiber–matrix adhesion and physico mechanical properties of the resulting composites (Chattopadhyay et al., 2009). In our recent work it was found that the mechanical properties of MAPP modified BFF/PP composites without alkali treatment were inferior to those NaOH treated and MAPP modified composites (Sudhakara et al., 2013). Therefore, in the present study, the fibers (BFF, coir, jute and sisal) were treated with 4% NaOH for 5 h prior to composite fabrication using MAPP compatibilizer. It is essential to find out the optimum fiber loading for BFF/PP composites to achieve the enhanced properties. The tensile and impact strength is increased with increasing BFF content up to 15 wt% whereas the flexural strength is increased only up to 10 wt% of fiber loading as shown in Figs. 4 and 5 and Table 2. However the tensile and flexural

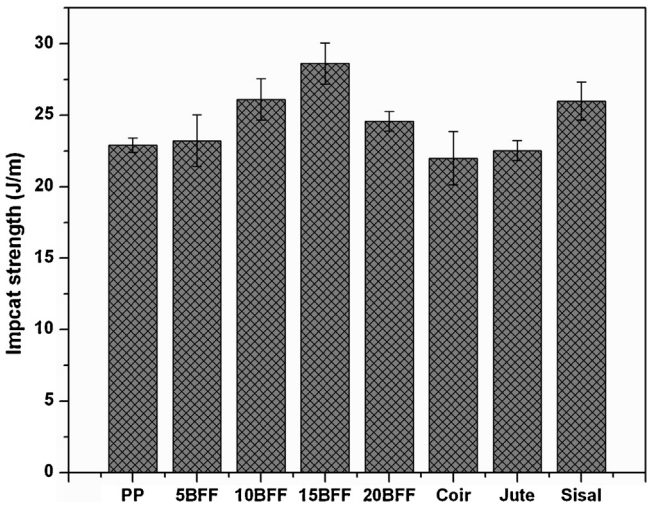


Fig. 5. Impact strength of virgin PP and BFF/PP (5, 10, 15 and 20 wt% of BFF), coir (15 wt%)/PP, jute(15 wt%)/PP and sisal(15 wt%)/PP composites.

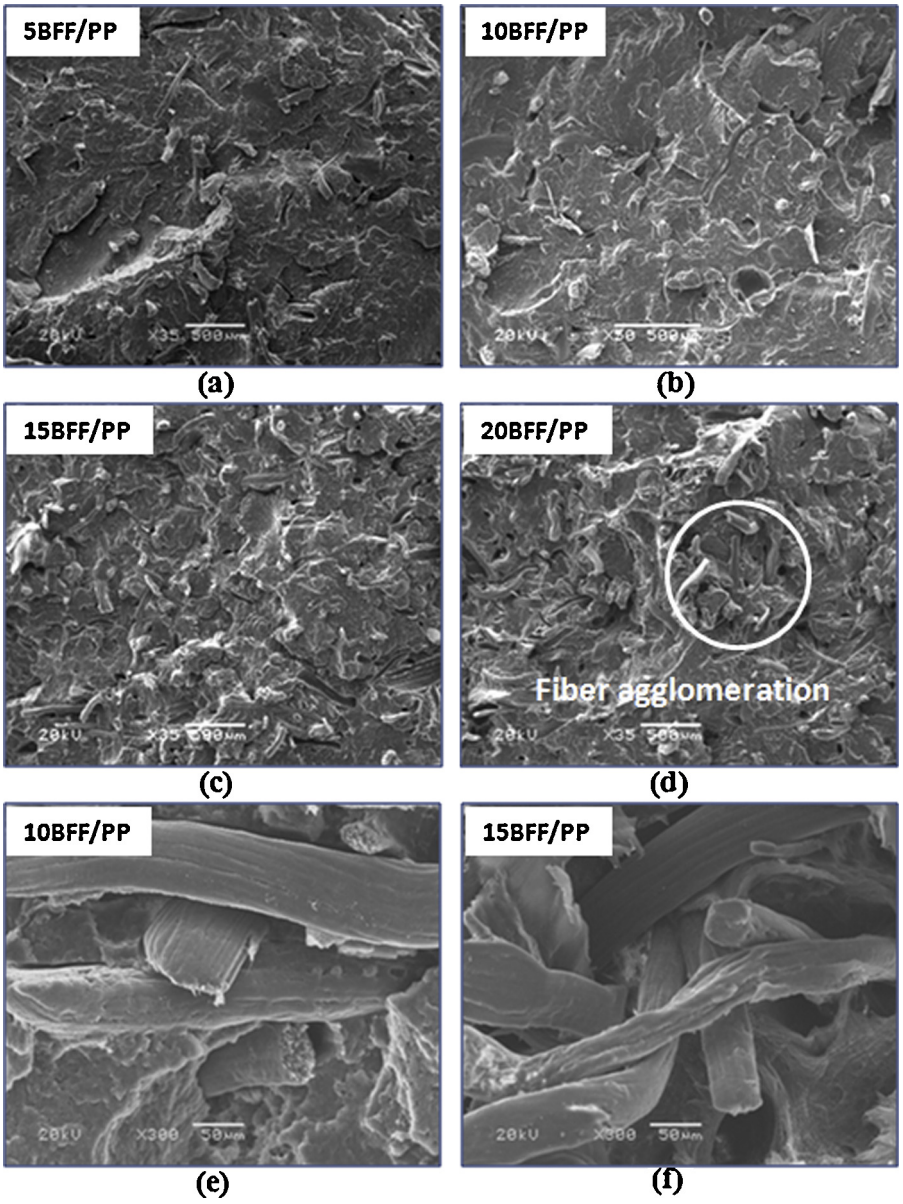


Fig. 6. SEM micrographs of the tensile fractured surfaces (5, 10, 15 and 20 wt% fiber) (a–d) and flexural fractured surfaces (10 and 15 wt% of fiber) (e–f) of BFF/PP composites.

Table 1
Comparison of the properties of *Borassus* fruit fibers with coir, jute and sisal fibers.

Properties/fibers	Cellulose (%)	Hemi-cellulose (%)	Lignin (%)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)
Borassus fruit fine fiber (BFF)	45.67	32.76	21.53	65.2	4.9	47.2
Coir	36–43	0.12–0.25	41–45	131–175	4–6	15–40
Jute	61.0–71.5	13.6–20.4	12–13	393–773	13.0–26.5	1.16–1.15
Sisal	67–78	10.0–14.2	8.0–11.0	468–640	9.4–22.0	3–7

modulus was increased with increasing fiber loading due to fiber reinforcement. The highest tensile strength of 15 wt% BFF and flexural strength of 10 wt% of BFF obtained are due to better fiber distribution in the matrix. The decrease in tensile and flexural strength is due to the agglomeration and poor dispersion of the fibers in the polymer matrix at higher fiber concentration, resulting in insufficient fiber–matrix adhesion and nonuniform transmission of the applied stresses (Chattopadhyay et al., 2009). These results are clearly explained by the SEM analysis of the tensile and flexural fractured surfaces of BFF/PP composites as shown in Fig. 6. Fig. 6(a–c) shows a uniform distribution at lower level of fiber loading and agglomerates (Fig. 6d) at higher level fiber concentration (20 wt%). It is observed from SEM micrograph of flexural fracture surfaces of 15 wt% of BFF/PP composites (Fig. 6f) that relatively excess amount of fiber lie down onto each other rather than being mixed with matrix and relatively less amount of fiber is observed at 10 wt% fiber loads. This could be the reason for lower flexural strength of 15 wt% of BFF/PP composites. Overall, it was found that 15 wt% of BFF is the optimum concentration for the fabrication of BFF/PP composites and it has an 26% increase in Impact strength, a

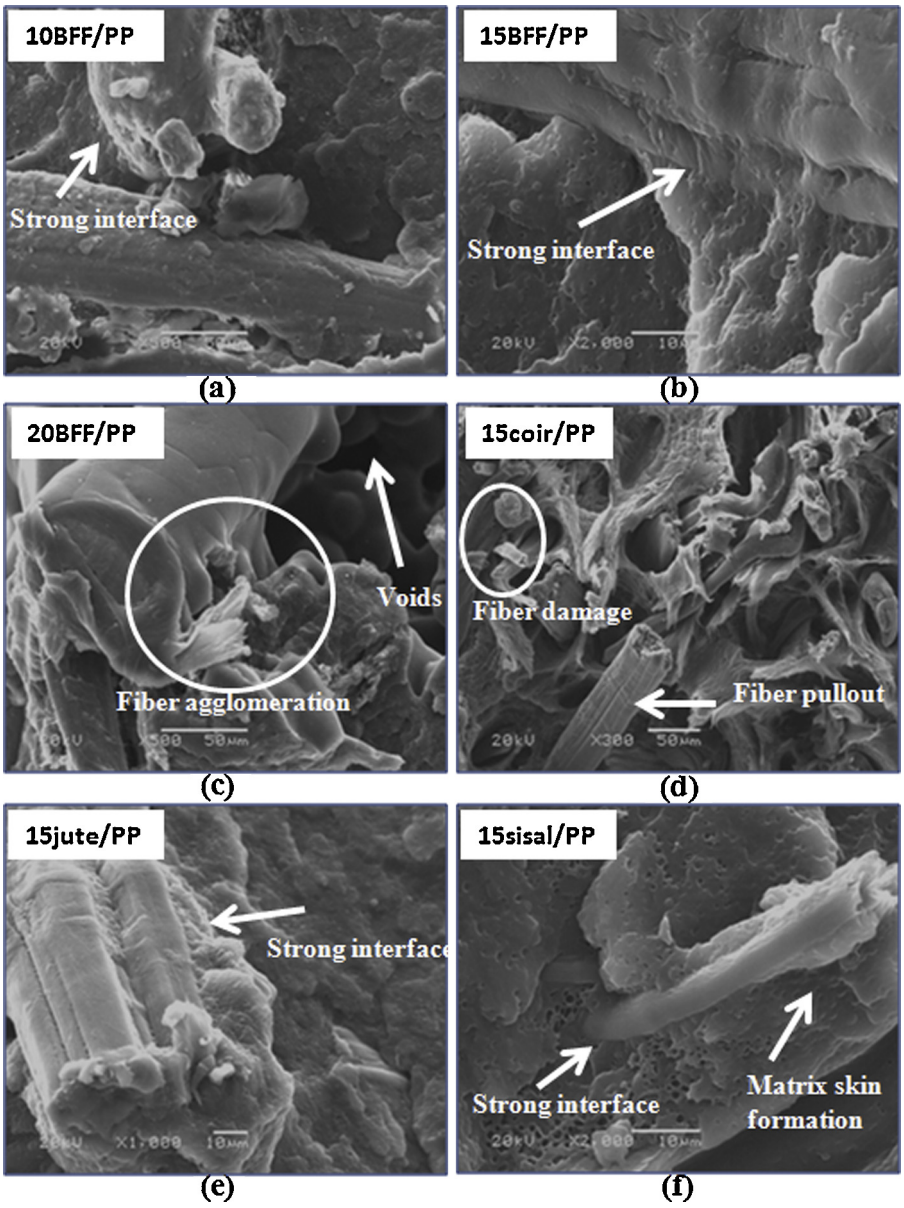


Fig. 7. SEM micrographs of the interfaces of BFF(10, 15 and 20 wt%)/PP (a–c) and coir (15 wt%)/PP, jute(15 wt%)/PP and sisal(15 wt%)/PP composites.

31% increase in tensile strength, an 102% increase in tensile modulus, a 30% increase in flexural strength and 135% increase in flexural modulus, as summarized in Table 2.

3.2. Comparison of coir, jute and sisal composites with BFF composites

3.2.1. Tensile, flexural and impact properties

The mechanical properties of BFF/PP composites were compared with coir, jute and sisal composites with BFF composites which are commercially used for many applications. The results are shown in Figs. 4 and 5 and Table 2. In the previous section, better properties were obtained for 15 wt% of BFF fiber; hence it would be reasonable to compare the properties of coir, jute and sisal fiber with the same wt%, following the same processing conditions used for BFF/PP composites. From Fig. 4(a), it is observed that the tensile strength of BFF and jute composites is almost similar and higher than that of coir and sisal composites. As for as the flexural strength is concerned, it is slightly higher for jute and sisal composites than that of BFF composites and still lower for coir composites. The tensile modulus is compared (Fig. 4(b)), and it is almost similar for BFF, Sisal composites and lower for coir and jute composites. On the other hand, the flexural modulus (Fig. 4(b)) of coir composites is higher than that of BFF, jute and sisal composites. Comparatively, coir fiber shows lower tensile and flexural strength than the rest o the composites. It may be due to more lignin content of coir fiber (Table 1) and fiber agglomeration or fiber pullouts from the matrix and damage of the fiber. This can be seen clearly from the SEM micrographs of the interface analysis of composites as shown in Fig. 7.

3.2.2. Interface morphology of composites

Fig. 7(a–f) shows the SEM micrographs of the interface analysis of MAPP modified BFF/PP, coir/PP, jute/PP and sisal/PP composites recorded at higher magnification. From the Fig. 7a, d and e, it was observed that the adhesion between fiber and matrix is strong with matrix skin formation due to the addition of MAPP for every fiber loading. The strong adhesion and fiber wetting was the result of the formation of ester linkages between MAPP moieties of PP and OH groups of cellulose (Chattopadhyay et al., 2010; Mohanty et al., 2000; Sudhakara et al., 2013) (shown in Fig. 2), could have contributed to a significant increase in mechanical properties as explained in earlier sections. The SEM micrograph of 20BFF/PP also shows good bond formation between fibers and matrix; however, poor fiber dispersion was seen with increasing fiber content, where the fibers were bunched together, and causes lower mechanical properties. As evidenced from Fig. 7d of coir/PP composites, fiber pull out from the matrix and fiber damage during fracture process causes poor mechanical properties. The fibrous structure is also deformed.

3.2.3. Thermal stability analysis

Thermogravometric analysis (TGA) provides direct information about thermal stability and degradation mechanism by measuring weight loss of sample as a function of temperature. The typical TGA curves of BFF, coir, jute and sisal/PP composites with 15 wt% of fiber are shown in Fig. 8 (Supporting information) and the corresponding weight loss and char yield are listed in Table 2 as a function of temperature. The samples were compared with 5% (First stage), 50% (second stage) weight loss and char yield at 500 °C. Temperature correspond to 5% weight loss in TGA can be viewed as a rough index of thermal stability. From Fig. 8 and Table 2, it is observed that the temperature at which the 5% weight loss of all the composites is >357 °C, which higher than that of the virgin PP (347 °C) available in the literature (Sudhakara et al., 2013). Comparatively, the thermal stability of 15BFF/PP and 15sisal/PP composites is almost

Table 2
Mechanical, thermal and water absortaron properties of BFF/PP composites and comparision with coir, jute, and sisal fiber composites.

Name of the sample	Tensile strength (MPa)	Tensile modulus (MPa)	Flexural strength (MPa)	Flexural modulus (MPa)	Impact strength J/m	TGA analysis			Water absorption (%)
						Temp. at 5 wt% loss (°C)	Temp. at 50 wt% loss (°C)	Char yield at 500 °C (%)	
PP	22.45	1.250	35.09	1.08	22.82	347	430	0	0.12
5BFF/PP	23.48	1.508	42.40	1.18	23.22	–	–	–	0.35
10BFF/PP	25.32	2.071	47.24	1.22	26.11	–	–	–	0.43
15BFF/PP	29.29	2.584	45.34	1.46	28.61	358	470	7.0	0.61
20BFF/PP	28.58	3.038	44.61	1.80	24.58	–	–	–	0.74
15coir/PP	26.14	2.21	42.67	1.83	21.99	377	470	9.0	0.52
15jute/PP	29.40	2.49	48.76	1.70	22.53	376	470	6.0	0.76
15sisal/PP	28.05	2.64	48.77	1.43	25.98	357	470	2.0	0.72

similar and lower than that of 15coir/PP and 15jute/PP composites. The first stage decomposition of all composites at 5% weight loss is ascribed to the decomposition of PP/MAPP matrix and α-cellulose followed by a major weight loss (~50%) around 470 °C, which continues beyond 500 °C (Arifuzzaman Khan, Shamsul, & Menoru, 2012; Liliana, Exequiel, Maria, & Analía Vázquez, 2006). The measured char yield of the composites at 500 °C is in the following order;

15coir/PP > 15BFF/PP > 15jute/PP > 15sisal/PP.

Comparatively, the coir and BFF composites show higher char yield than the rest of the composites. This could be due to the more amount of lignin (Table 1) present in the coir fibers. In general, lignin decomposes slowly, over a wide temperature range (200–500 °C) than cellulose and the hemicellulose components of biomass (Mihai & Cornelia, 2010). The structural complexity of lignin, high molecular weight and its insolubility make its degradation difficult in the earlier stage of decomposition.

In general, due to the removal of moisture and hemicellulose, the natural fibers show weight loss in the earlier stages up to 150 °C (Arifuzzaman Khan et al., 2012). However, the TGA results of BFF, coir, jute and sisal composites (Fig. 8) show no weight loss around 100 °C and the initial weight loss occurs only after 358 °C. This may be due to removal of amorphous impurities by alkali treatment of natural fibers, facilitates effective bonding between MAPP compatibilizer and natural fibers as shown in Fig. 3.

3.2.4. Water absorption property

The water absorption in natural fiber reinforced thermoplastic composites occurs in many ways: mainly due to the presence of lumens, microgaps between polymer chains, and hydrogen bonding sites in the natural fiber, gaps and flaws at the interfaces between fiber formed during the compounding process (Zabihzadeh, 2010). The water absorption properties of BFF, coir, jute and sisal composites are presented in Table 2. From these data, one can see that the moisture uptake increases for BFF/PP composites with increasing fiber loading due to the increase of voids and cellulose content. The water absorption nature of 15BFF/PP composites, is little higher than 15coir/PP and lower than 15jute/PP and 15sisal/PP composites in the following order.

15coir/PP < 15BFF/PP < 15jute < 15sisal/PP

Comparatively, 15BFF/PP and 15coir/PP composites show lower water absorption than 15jute/PP and 15sisal/PP composites. This could be due to the higher lignin content (given in Table 1) present in BFF and coir fibers. Lignin is usually hydrophobic in nature due to the presence of non polar hydrocarbon chains and aromatic rings, thereby reducing the water diffusion in the composites. Over all, the composites (15BFF/PP, 15coir/PP, 15jute/PP and 15sisal/PP) showed low water uptake (<1%) due to the uniform distribution of MAPP compatibilizer, provides hydrophobicity to the fibers by the esterification of the anhydride groups of MAPP with the hydroxyl groups of the natural fibers.

4. Conclusions

The present study investigates the possible opportunity to utilize *Borassus* fruit fibers as bioreinforcement in polymer composites and some of the conclusions were drawn as fallows.

- The mechanical properties of *Borassus* fruit fine fiber (BFF) and polypropylene (PP), fabricated with different fiber loading (5, 10, 15 and 20 wt%) and 5 wt% MAPP compatibilizer by injection molding suggest that the 15 wt% of BFF is the optimum concentration for composites fabrication.
- The 15BFF/PP has a 26% increase in impact strength, a 31% increase in tensile strength, a 102% increase in tensile modulus, a 30% increase in flexural strength and an 135% increase in flexural modulus when compared with pure PP matrix.
- SEM analysis of the composites infers that the poor fiber dispersion and fiber agglomeration is the main shortcoming for decreasing mechanical properties in the composites of higher fiber loading.
- It was found that the mechanical properties of BFF/PP composites are equivalent to jute/PP and sisal/PP and superior to the coir/PP composites.
- Due to the presence of more amount of lignin, the BFF and coir composites showed higher char yield at 500 °C in TGA and lower water uptake. The composites were thermally stable up to 357 °C.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.carbpol.2013.06.080.

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