

Research Article

Effect of alkalization on the properties of *Abelmoschus Manihot* lignocellulosic fibre

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Abstract

Abelmoschus manihot (AM) fibre species were treated with varied concentrations (2 - 20%) NaOH at room temperature for 1 hr and physical properties were evaluated. Chemical composition of the treated fibres showed that hemicellulose was removed to a varied extent by the alkali treatment. Tensile strength of the treated fibres, their moisture content, surface morphology (by Scanning electron microscope), crystallinity index by XRD analysis and thermal degradation (TGA) were analysed. The alkali between 2 to 15% treated fibres showed all round improvement in the properties when compared with those of untreated raw fibres.

Keywords: Chemical composition, hemicellulose, NaOH, SEM, tensile strength, TGA, XRD.

1. Introduction

Plant fibres found in abundance are renewable source materials mainly composed of cellulose, hemicellulose and lignin. Their biodegradability, low cost and reasonable performance fulfill economic interest of various industries (Pickering *et al.*, 2007; Reddy and Yang, 2005). These plant fibres are classified into categories depending on the part of the plant from which fibres are extracted. 1. Bast or Stem fibres- jute (Gassan and Bledzki, 1999), hibiscus (Singha and Thakur, 2008), hemp (Pickering *et al.*, 2007) etc., 2. Leaf fibres- sisal (Joseph *et al.*, 1996), pineapple (George *et al.*, 1998; Doraiswamy and Chellamani, 1993), coconut leaf sheath (Reddy *et al.*, 2010) etc., 3. Seed fibres - cotton, kapok (Gassan and Bledzki, 1999), fruit fibres - coir (Rout *et al.*, 2001), tamarind, borassus (Maheswari *et al.*, 2008) etc., and 4. Grass fibres- bamboo (Das and Chakraborty, 2007), napier (Reddy *et al.*, 2009) etc. Advantages of natural fibres over man-made fibres include low cost, low density, recyclability and biodegradability (Mohanty *et al.*, 2003; Baley, 2002; Van *et al.*, 2001) and their CO₂ neutral life cycle (Das and Chakraborty, 2007). These Natural fibres can replace synthetic fibres in many applications where cost and biodegradability outweigh high composite performance requirements.

Surface treatment of reinforcing fibres is normally carried out to improve their compatibility with the polymer matrix. Various fibre surface treatments like mercerization, isocyanate treatment, acrylation, permanganate treatment, acetylation, silane treatment and peroxide treatment have been carried out before

the preparation of composite which were found to result in improving composite properties (Gassan and Bledzki, 1999; Singha and Thakur, 2008; Rout *et al.*, 2001; Ray and Sarkar, 2001; Mwaikambo and Ansell, 2002). Several researchers have reported that the mechanical properties of cellulose fibres are enhanced due to alkalization, (Ray and Sarkar, 2001; Rout *et al.*, 2001). The alkali treatment also changed the chemical composition and modified the crystalline structure of natural fibres. Hence, alkali treatment seems to be useful tool to improve the properties of fibres of plant origin.

The *Abelmoschus manihot* (AM) is a flowering plant in the mallow family Malvaceae (see Fig. 1.). It is locally named as "Rann Bhendi" in Maharashtra, India. It was formerly considered a species of *Hibiscus*, but is now classified as the genus *Abelmoschus* (Thaman, 1988). This is a perennial herbaceous plant, growing up to 2 m in height. The leaves are broad and 10–40 cm in length. The flowers are 4–8 cm in diameter, with five white to yellow petals, often with a red or purple spots at the base of each petal. The fruit is a capsule, 5–20 cm long, containing many seeds. The calyx is four-lobed, and the lobes are unequal (Kiritikar and Basu, 1994). Presently this plant is widely used for its medicinal properties, and only one study on degumming of *Abelmoschus manihot* fibre (Chun-Yan Li *et al.*, 2013) has been reported yet.



Fig. 1 *Abelmoschus manihot* plant

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In the present work, an attempt has been made to investigate the properties of AM fibres and to explore its further potential to be used as textile as well as composite material. The effect of alkalization on the properties of AM fibres is studied. The characterization of the fibres by FTIR, XRD and TGA has been done and its chemical composition is estimated. The surface changes are examined using scanning electron microscope and mechanical properties of the fibres are also evaluated.

2. Experimental

2.1 Materials

The fibre was extracted from the dried stalks of the AM plant which was harvested from Wadala, (Mumbai, India). Only the outer layer of the stalk contained fibres. The AM fibres used here were without any pre-treatment or purification. The chemical reagents of analytical grade such as sodium chlorite, glacial acetic acid, sodium bisulphate, sodium hydroxide, ethanol and benzene were procured from SD Fine Chemicals Ltd., India.

2.2 Methods

2.2.1 Fibre extraction

The fibres were present in the outer layer of the stem of AM plant. They were stripped-off from the stalk manually and kept for retting in water for 15 days. The material was then removed from the water and beaten with a wooden hammer to loosen them. These fibres were then washed continuously under running water, sun dried, combed and hand brushed to get uniformly cleaned fibres.

2.2.2 Alkali treatment of fibres

The AM fibres were chopped to a length of 10cm and treated with different concentrations (2%, 5%, 10%, 15%, 20% w/v) of aqueous solutions of NaOH at room temperature for 1hr using material to liquor ratio 1:30. The fibres were then removed and washed continuously with water, neutralized with dilute acetic acid and washed again with fresh water. The fibres were there after dried at 65°C in hot air oven for 24 hr.

2.2.3 Determination of chemical composition

The chemical analysis of the fibres was carried out as per the standard procedure used by Chattopadhyay and Sarkar, (1946). The fibres were chopped and weighed. These preweighed chopped fibres were dewaxed with a mixture of benzene/ethanol taken in the ratio of 2:1 at 70°C for 3 hr. The dewaxed fibres were washed with ethanol for half an hour, dried and weighed. The dewaxed preweighed samples were boiled for 2 hr in 0.7% aqueous NaClO₂ solution (adjusted to a pH 4 using buffer solution) by

maintaining a material to liquor ratio (MLR) of 1:50. Later, they were washed with 5% aqueous sodium bisulphate solution and distilled water and dried at 105°C in a hot air oven. In this step, the lignin was removed and the weight difference after this step corresponds to the lignin content. The remaining holocellulose (hemicelluloses and α-cellulose) was treated with 17.5% aqueous sodium hydroxide solution to eliminate alkali soluble hemicellulose. The weight loss and remaining weight corresponded to the contents of hemicellulose and α-cellulose respectively. The ash content was determined by standard method of TAPPI T 211 om-02 (2002).

2.2.4 Morphological studies

The scanning electron micrographs of the fibre surface were recorded on a microscope (JEOL JSM 6380LA Akishima, Japan), from Institute of Chemical Technology. The fibre samples were sputter coated with platinum before recording the micrographs.

2.2.5 Fourier Transform Infrared spectroscopy (FTIR) analysis

The IR spectra of raw and alkali treated fibre sample was recorded using FTIR spectrophotometer (Shimadzu 8400s, Japan) using ATR sampling technique by recording 45 scans in % transmittance mode in the range of 4000-600 cm⁻¹.

2.2.6 X-ray Diffraction (XRD)

The crystallinity of raw and alkali treated AM fibres was studied using an X-ray diffractometer (Shimadzu 6100, Japan) equipped with CuK_α radiation (λ = 1.54 Å) in the 2θ range 2-50°. The experiments were performed in the reflection mode at a scan speed of 2°/min in steps of 0.02°. The crystallinity index (CrI) of the fibre was calculated according to the empirical method shown in the following equation. (Segal *et al.*, 1959)

$$\text{CrI}\% = \frac{(I_{002} - I_{am})}{I_{002}} \times 100 \quad (1)$$

where I₀₀₂ and I_{am} are the peak intensities of crystalline and amorphous materials, respectively.

2.2.7 Thermal analysis

The samples of untreated and alkali treated AM fibres were cut into small pieces and thermal gravimetric analysis (TGA) was carried out. The thermograms were recorded on Shimadzu 60H DTG machine using aluminium pan between temperature range 30-500°C under the inert atmosphere of nitrogen at a flow rate of 50ml/min.

2.2.8 Tensile properties and Moisture regain

The tensile strength of the fibres was measured according to ISO 5079; 1996 method in terms of the

breaking load, percentage elongation at breaking using Tinius Olsen tensile testing machine. A gauge length of 20 mm with a speed of 5 mm/min were used for the testing. Approximately 15 fibres were tested for their tensile properties. The moisture content of the fibre sample was measured according to ASTM standard method 2495.

3. Results and discussion

3.1 Determination of chemical composition

The results of chemical composition studies of untreated and alkali treated AM fibres shown in Table 1, reveal that the alkali treatment caused distinct change in composition of the fibre with respect to α -cellulose, hemicellulose and lignin content. Before the chemical composition was determined, the untreated and alkali treated fibres were dewaxed by extracting the chopped fibres in benzene/ethanol solvents (2:1 v/v). The percentage of extractable matter decreased as the alkali concentration increased from 2% to 20%. This might be because the alkali treatment removed most of the wax from the fibres. The hemicellulose content also distinctly decreased with increase in the concentrations of the sodium hydroxide solution which may be attributed to its relatively much more sensitive nature to the action of aqueous sodium hydroxide at room temperature than lignin or α -cellulose (Gassan and Bledzki, 1997). The hemicellulose content of the AM fibres was found to be reduced from 30% in raw fibre to 14% for AM fibres treated with 20% NaOH solution. It is well known that hemicellulose dissolves in alkali and hence, such alkali treated AM fibre showed consequent increase in relative percentage of α -cellulose and lignin. Ash content also decreased from 5% to 2% as most of the impurities such as wax, pectins, fatty substances etc. were removed during the alkali treatment.

Table 1 Chemical composition of raw and NaOH treated AM fibres

Fibres	Extractives in solvent (%)	Lignin %	Hemi-cellulose %	Cellulose %	Ash content %
Raw	5	14	30	45	5
2% NaOH	4	15	28	49	4
5% NaOH	3	17	25	52	3
10% NaOH	2.5	18	23	54	2.5
15% NaOH	2	20	19	57	2
20% NaOH	2	22	14	60	2

3.2 Mechanism of alkalization

Alkalization is based on same principle of mercerization which causes swelling of cellulosic fibre. Degree of swelling depends on the type of alkali used and it is found that Na^+ in NaOH has got a most favourable diameter, able to widen the smallest pores in between the cellulose lattice planes and penetrate

into them to a maximum extent giving highest degree of swelling. Alkali treatment results in a higher amount of swelling, leading to the formation of new Na-cellulose lattice, and the conversion of cellulose OH-groups to ONa-groups, expanding the molecular dimensions. Subsequent rinsing with water removes the linked Na-ions and converts into higher crystalline cellulose (Weyenberg *et al.*, 2006). The reaction between fibre and NaOH is shown below.

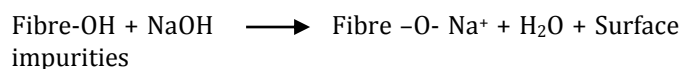


Table 2 Physical properties of the fibres

NaOH Conc.	Average length L (cm)	Average diameter D (cm)	Aspect ratio L/D
Untreated	10	0.01421	703
2%	10	0.01162	860
5%	10	0.01035	966
10%	10	0.00911	1097
15%	10	0.00853	1172
20%	10	0.00693	1443

3.3 SEM Analysis

Scanning electron micrographs of untreated and alkali treated AM fibres are shown in Fig. 2 which show surface topography of the fibre samples. The Figure indicates that with the increasing alkali concentrations, the AM fibres interior surface gets more and more exposed, ultimately leading to fibre fibrillation at higher concentrations of alkali. Fibrillation is the breaking down of the fibre bundle into small and fine fibres. All lignocellulosic fibrous materials are multicellular and every unit cell of fibre consists of small cellulose microfibrils which are surrounded and cemented together with lignin and hemicellulose. During alkali treatment of the fibres, alkali causes disruption of the fibre structure by dissolving the cementing material (hemicellulose) resulting in splitting of the fibre into finer fibres (Gassan and Bledzki, 1999). From the micrographs of the untreated and alkali treated fibres, it is seen that as the concentration of alkali increased, the fibre structure got disrupted increasingly. The wear and tear of the fibre surface takes place and the surface becomes rougher and rougher with increasing alkali concentration than that of the untreated fibre. The rough surface morphology is typical for the treated fibres due to the removal of hemicellulose and other surface impurities like wax, pectins, fatty substances (tyloses) etc. (Prasad *et al.*, 1983). Maximum extent of roughness in the surface morphology was seen in case of 15% and 20% alkali treated AM fibres. The diameter of the alkali treated fibres and raw fibre was determined on scanning electron microscope and corresponding aspect ratio (L/D) values are presented in Table 2. It was observed that the diameter decreased as the alkali concentration increased. This might be

due to the removal of hemicellulose from the fibre surface (Reddy *et al.* 2012) and better packing of the cellulosic chains.

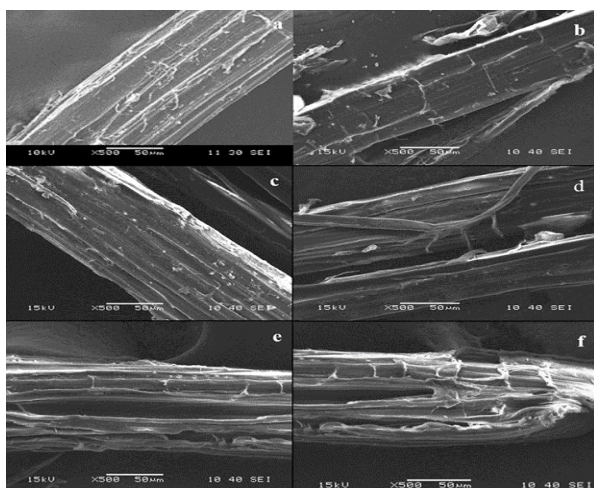


Fig. 2 a) Raw fibre b) 2% NaOH treated fibre c) 5% NaOH treated fibre d) 10% NaOH treated fibre e) 15% NaOH treated fibre f) 20% NaOH treated fibre.

3.4 FTIR analysis

FTIR spectra of untreated AM fibre and alkali treated AM fibres are shown in the Fig. 3. FTIR spectroscopy is a convenient and appropriate technique to identify the variations in the functional groups of AM fibres introduced by treatment of different concentrations of alkali. Untreated fibre and alkali treated fibre showed similar type of vibration bands of the components mainly corresponding to cellulose, hemicellulose and lignin. The untreated fibre attributed a strong absorption band in the region of 3400 to 3300 cm^{-1} assigned to the O-H stretching vibration of the OH group in cellulose molecules. The C-H stretching vibrations of methylene/methylene units of all three constituents were seen as two shoulder peaks at 2925 and 2858 cm^{-1} . A peak at 1735 cm^{-1} attributed to the C=O stretching vibration of the acetyl and uronic ester groups, from pectin, hemicelluloses, or the ester linkage of the carboxylic group of ferulic and p-coumaric acids of lignin and/or hemicellulose. (Sain and Panthapulakkal, 2006; Sun *et al.*, 2005). Another vibration at 1650 cm^{-1} aroused because of the water adsorbed OH. The peak at 1541 cm^{-1} showed aromatic skeletal vibrations of benzene ring in lignin. Similarly the peaks at 1423, 1367 and 1323 cm^{-1} present in raw fibre are associated with the bending vibrations of $-\text{CH}_2$, C-H, and O-H of cellulose (Alemdar and Sain, 2008; Nazir *et al.*, 2012). The C-O-C stretching vibration of ester groups of hemicellulose was seen between 1245-1259 cm^{-1} (Pandey, 1999) whereas asymmetrical stretching of C-O-C in the cellulose and hemicellulose at 1157 cm^{-1} was observed. Another peak at 1236 cm^{-1} indicates C-O-C Aryl-alkyl ether. Another group of bands in the region 1100-950 cm^{-1} .

Table 3 Possible assignment of frequencies (cm^{-1}) of functional groups in untreated and NaOH treated fibres

Untreated	2% NaOH	5% NaOH	10% NaOH	15% NaOH	20% NaOH	Possible assignment of functional groups
3390	3324	3373	3357	3332	3336	O-H stretching of α -cellulose
2930	2922	2910	2929	2925	2922	C-H stretching
2858	2856	2857	2857	2856	2856	CH_2 Symmetric Stretching (cellulose & hemicellulose)
1735	---	---	---	---	---	C=O (stretching of carbonyl ester) (Hemicellulose)
1650	1648	1648	1649	1648	1648	Adsorbed OH water
1541	1541	1541	1540	1540	1540	Aromatic skeletal vibrations of benzene ring in lignin.
1423	1422	1422	1421	1421	1420	CH_2 bending
1367	1367	1368	1367	1368	1363	C-H symmetrical deformation
1323	1318	1318	1317	1317	1317	O-H in plane bending
1255	---	---	---	---	---	C-O Stretching of acetyl (hemicellulose)
1236	1235	1236	1234	1234	1235	C-O-C Aryl-alkyl ether
1158	1157	1157	1157	1157	1155	C-O-C asymmetrical stretching (cellulose & hemicellulose)
1026	1029	1027	1029	1027	1020	C-O stretch/C-C stretch
896	896	894	893	894	894	β - glucosidic linkage

observed is mainly due to C-O/C-C stretching in cellulose and hemicellulose. (Higgins *et al.*, 1961). The peak observed at 896 cm^{-1} indicates the presence of the β -glucosidic linkages between the monosaccharides.

After the alkali treatment of the fibres, drastic changes were observed in the FTIR spectra. The examination of the spectra showed appearance of 1541 cm^{-1} peak, indicating the lignin component being intact in alkali treated fibres. The band near 1735 cm^{-1} is due to C=O stretching frequency of acetyl and carboxyl groups in 4-O-methylglucuronoxylan component of hemicellulose in the fibre. The intensity of this band is reduced on alkaline treatment and finally the disappearance of these characteristic stretching vibrations clearly indicated significant removal of the hemicellulose on alkaline treatment. Further the reduction of the peak between 1245-1259 cm^{-1} of hemicellulose appeared as the alkali concentration increased, which confirmed removal of hemicellulose. This implies that hemicellulose is easily removed by alkalization compared to lignin. From these results it is clear that several reactions take place during alkalization. The possible assignments of functional groups are shown in the Table 3.

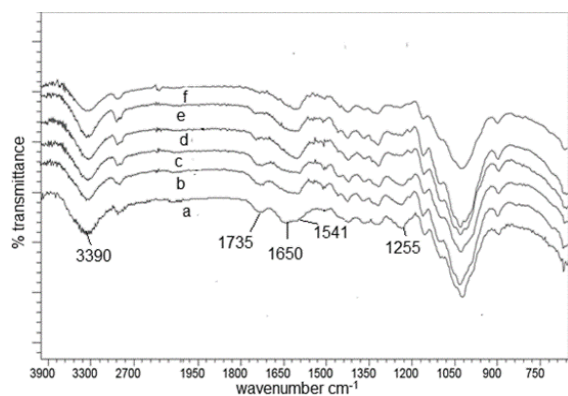


Fig. 3 a) FTIR spectra of untreated AM fibre b) FTIR spectra of 2% NaOH treated AM fibre c) FTIR spectra of 5% NaOH treated AM fibre d) FTIR spectra of 10% NaOH treated AM fibre e) FTIR spectra of 15% NaOH treated AM fibre f) FTIR spectra of 20% NaOH treated AM fibre

3.5 XRD analysis

The X-ray diffraction patterns of untreated and alkali treated AM fibres are shown in the Fig. 4. The diffractogram showed two reflections, corresponding to 2θ values of around 16° and 22° , respectively. Among these, the low angle reflection (16°) was of low intensity, representing $I_{(am)}$ of amorphous material and the other reflection (22°) had higher intensity, and it represented $I_{(002)}$ of crystalline material in cellulosic fibre. The degree of crystallinity (CrI%) was calculated using Eq (1) described in experimental part of this paper. It was seen that the degree of crystallinity of alkali treated AM fibres increased as the concentration of alkali increased upto 15% (refer Table. 4). This might be because of the removal of hemicellulose which results in close packing of cellulosic chains (Table. 4). However at 20% alkali concentration, it was observed that the crystallinity of the fibre decreased indicating there by degradation of cellulose structure. Similar type of behaviour was also observed in hemp, sisal, kapok, jute and bamboo fibres by other authors. (Das and Chakraborty, 2008; Leonard *et al.*, 2002).

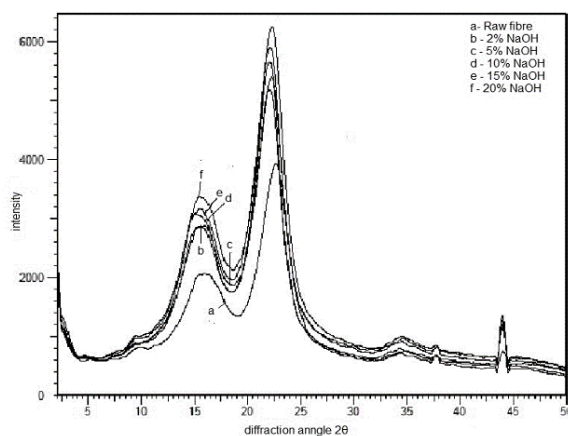


Fig.4 XRD diffraction pattern of raw and NaOH treated fibres

Table 4 Crystallinity Index of raw and NaOH treated AM fibres

Sample	$I_{(am)}$ at 2θ 15.5°	$I_{(002)}$ at 2θ 22°	CrI %
Raw AM	415	1124	63
2% NaOH	605	1742	65
5% NaOH	655	1980	67
10% NaOH	615	1974	69
15% NaOH	530	1886	72
20% NaOH	667	1963	66

3.6 Thermogravimetric analysis

The thermograms of untreated and alkali treated AM fibre are shown in Fig. 5 and it can be observed that the thermal degradation of AM fibres exhibited three - step process. (Yang *et al.*, 2007). This behaviour is attributed to the differences in the chemical structures of different components of wood fibres which decompose at different temperature. AM fibre being lignocellulosic material is a composite structure of different types of components wax, pectin, and hemicelluloses in it and they degrade near 180°C , cellulose at around 300°C , and lignin at around 400°C (Johar *et al.*, 2012). Fig. 6 shows the first, second and third stages of degradation in the temperature ranges of $50-125^\circ\text{C}$, $220-300^\circ\text{C}$ and $300 - 400^\circ\text{C}$, respectively. The first decomposition temperature range of $50- 125^\circ\text{C}$ corresponded to the evaporation of moisture. The alkali treated fibres presented a slightly lower moisture content than that of the untreated fibres, which might be due to reduction of free hydroxyl groups. The second decomposition step of raw fibres in the temperature range of $220 - 300^\circ\text{C}$ indicated the loss of hemicellulose and some part of the lignin. The third decomposition step corresponded to the decomposition of cellulose in the range of $300 - 400^\circ\text{C}$. Similar observation was also made in the case of many natural fibres (Reddy *et al.*, 2009; Rajulu *et al.*, 2002). The decomposition temperatures, percentage degradations and char content of untreated and alkali treated fibres showed remarkable differences. These values are presented in Table 5. It was observed that the residual char left at 500°C increased considerably from 23% to 28% in the case of all the treated fibres (Table. 5). A similar observation was reported by Saha *et al.*; (1991) who explained that alkali treatment reduced the hemicellulose content to a considerable extent, giving rise to a lignin-cellulose complex, thereby making the product more stable than the raw sample, and this was reflected in the increased amount of residual char.

This might be caused by an increased rate of formation of free radicals that are stabilized by condensed carbon ring formations in the char. (Hinojosa *et al.*, 1973; Austen *et al.*, 1958; Milsch *et al.*, 1968). The thermal stability of the fibres treated with 20% alkali solution fibres decreased as compared to 15 % alkali treatment. The char content also decreased to 27.5%. This is in support of the earlier observation in

other properties of the fibres treated with 20% alkali solution indicating the degradation of cellulose taking place at this extreme concentration of alkali studied.

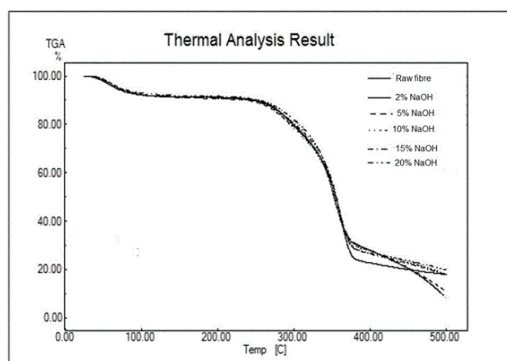


Fig.5 TGA analysis of raw and NaOH treated fibre

Table 5 Results of TGA analysis of raw and NaOH treated AM fibres

Fibres	Peak temperature °C	Degradation %	Residue at 500 °C Char content, %
Raw AM	81.15	8.40	23.11
	270.10	3.71	
	362.50	64.79	
2% NaOH	79.30	8.34	28.31
	281.10	3.48	
	365.90	59.87	
5% NaOH	78.35	8.24	28.41
	268.70	3.80	
	369.20	59.55	
10% NaOH	73.24	8.23	28.52
	270.60	4.12	
	366.60	59.13	
15% NaOH	69.130	7.98	28.70
	268.00	3.55	
	371.70	59.77	
20% NaOH	65.40	7.62	27.54
	281.50	3.38	
	368.20	61.47	

3.7 Tensile properties and Moisture content

The tensile properties of untreated and alkali treated AM fibres given in Table. 6 indicate that concentration of alkali had positive dependence on the tensile strength and elongation, %. The tensile strength was found to be maximum for 15% alkali treated AM fibre. This increase in the tensile strength might be because of the removal of hemicellulose during alkali treatment causing increase in the crystallinity. The alkali sensitive bonds were ruptured during the treatment due to which the hemicellulose got removed and thus the fibre became more homogeneous resulting in the enhanced level of stress transfer between cells. (Mukherjee et al., 1993). In untreated fibre, the strain remains intact in the cellulose chains because of presence of hemicellulose in the fibre structure which keeps the cellulose chains dissociated

from each another. Hemicellulose acts as the barrier because of which the chains are in the state of strain. When this barrier of hemicellulose is removed, new H-bonds are formed between the cellulose chains which result in close packing of cellulose chains (Varma et al. 1984).The graphical representation of the tensile strength and elongation properties is shown in Fig. 6. As observed here, the alkali treatment upto 15% increased the packing density due to removal of hemicellulose and other impurities leading to increase in the tensile strength. However, 20% alkali treated sample showed decrease in tensile strength which is attributed to the degradation of cellulose at such high concentrations of alkali. Moisture content of the alkali treated fibres also decreased as compared to the raw fibre as the alkali treated fibres showed reduction of free hydroxyl groups as well as increase in crystallinity there by reducing amorphous content of fibre. This result supports TGA analysis results discussed earlier.

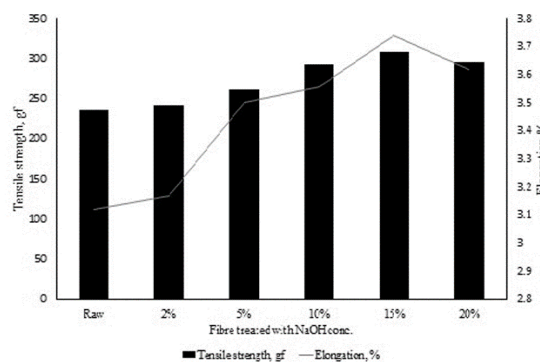


Fig.6 Relation between alkali concentration and Tensile strength and Elongation properties

Table 6 Tensile properties and moisture content of raw and NaOH treated fibre

Fibres	Tensile strength gf	Elongation %	Moisture content %
Raw	236.3	3.12	8.4
2% NaOH	241.2	3.17	8.3
5 %NaOH	262.2	3.5	8.2
10%NaOH	293.1	3.56	8.1
15% NaOH	308.6	3.74	7.9
20% NaOH	295.5	3.62	7.6

Conclusion

The AM fibres treated with different concentrations of NaOH showed distinct enhancement in their properties when compared to those of raw AM fibre. The chemical composition showed that the hemicellulose content decreased with increase in alkali concentration. This was due to ability of alkali to dissolves the hemicellulose. Surface morphology of the fibres became rougher due to removal of hemicellulose as a result of treatment with increase in alkali

concentration. Further FTIR study confirmed the removal of hemicellulose as the functional groups indicating the presence of hemicellulose were either absent or the peak intensities gradually decreased as the alkali concentration increased.

These results were further supported by the XRD analysis showing increase in the crystallinity upto 15% NaOH treated samples. Beyond that at 20% concentration the cellulose degradation took place showing decrease in the crystallinity of alkali treated AM fibre. TGA analysis also showed that the thermal stability slightly being increased as compared to that of raw fibre. It was observed that the residual char content increased in case of increase in alkali concentration till 15%. However, beyond that it decreased at 20% possibly due to cellulose degradation. Similarly tensile properties were also enhanced till 15% and then decreased at 20% concentration. It was observed that the AM fibre which was treated with 15% alkali was most suitable for further applications as it had over all enhanced properties.

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