Influence of alkali treatment on the physical properties of jute fibre

Ranajit Kumar Nag[1*], Andy Long[2] and Michael J Clifford[3]

Abstract

It is well known that jute is a ligno-cellulosic fibre and it contains nearly 65% cellulose. Second and third major component of jute fibre are hemicellulose and lignin (around 12% each). Lignin is a natural adhesive and essential component of jute fibre. Jute fibre cell is very small in length (2.5-4 mm) which is called 'jute ultimate' and the fibre length is similar to the plant length. Lignin joins ultimates to form long jute fibre. Thus without lignin jute fibre loses textile properties. However cellulose possess superior physical properties than that of hemicellulose and lignin and hence researchers are trying to reduce hemicellulose and lignin to increase cellulose portion that would increase the physical properties of jute. Alkali treatment is a popular process to reduce those components. Realizing the fact, the influence of alkali treatment with and without tension is studied in this work to understand the effect on the physical properties of jute fibre.

***Keywords**: Jute fibre, alkali, tension, tensile strength, tensile modulus*

1. Introduction

Cellulose is the chief element of jute fibre (Mwaikambo, 2006) and it has very good mechanical properties (Nishino, Takano and Nakamae, 1995). However low tensile properties of jute fibres (with respect to cellulose) e.g. 7.2 (Pickering, 2008) – 38.9 (Sayeed, Rawal, Onal and Karaduman, 2014) GPa tensile modulus and 187 (Pickering, 2008) – 800 (Ramesh, Palanikumar and Reddy, 2013) MPa tensile strength were observed by many researchers. Various natural defects observed by Hossain, Islam, Van Vuure and Ignaas, (2012 and 2013) including processing faults and the chemical composition play a major role to reduce the tensile properties. For example hemicellulose, the second major component of jute fibre (Mwaikambo, 2006) possesses 5-8 GPa tensile modulus and the third important component lignin has 2.5-3.7 GPa tensile modulus and 25-75 MPa tensile strength (Gibson, 2012)

[1] *Department of Textile Engineering, BGMEA University of Fashion & Technology (BUFT), Dhaka, Bangladesh*
[2] *Northumbria University, Newcastle upon Tyne NE1 8ST, UK*
[3] *The University of Nottingham, Nottingham, NG7 2Rd, UK*
[*] ***Corresponding author email:*** *nag.ranajit@buft.edu.bd*
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which are much lower than the properties of cellulose. Hence it is expected that removal of hemicellulose and lignin will improve the tensile properties of cellulosic fibres (Zhang, Fei, Yu, Cheng and Wang, 2013). Thus the intention of this work is to remove hemicellulose and lignin to understand the effect on the properties of jute fibres. Alkali treatment is a well-established technique to remove hemicellulose, lignin, pectin, wax and other oily substances of plant fibres (Mwaikambo and Ansell, 2001, Sever et.al. 2012, Ndazi, Nyahumwa and Tesha, 2008) and is practiced here.

2. Materials and Methods

2.1 Materials

Tossa jute yarn is used in this experimental work as fibre separation and treating yarn under tension is easier for yarn than raw jute fibre. Moreover comparing the properties of fibre from same material seems more logical. Laboratory grade NaOH (> 97%) from Sigma-Aldrich at pellet form is used for alkali treatment. > 99.7% acetic acid from Sigma-Aldrich is used to neutralize the alkali solution after treatment.

2.2 Preparation of yarn for alkali treatment.

Loose yarns (Fig. 1(A)) dipped in alkali solution are described as alkali treated yarn without tension. Alkali treatment of jute yarn with tension is performed by wrapping it on a glass fibre composites board (similar to Fig. 1(B)) in a single ply. A single ply of yarn is preferred to ease the reaction of alkali.

(A)

(B)

Fig. 1 (A) Yarn at loose condition before dipping and (B) yarn wrapped on glass fibre composite board.

2.3 Alkali treatment

1% and 5% NaOH solution (by weight) is made with tap water. Different yarn samples are dipped in these solutions separately at loose condition and using tension for 20 minutes at room temperature. Yarns are then neutralized by adding acetic acid, washed several times, squeezed gently (for loose fibre) and dried in an oven at $105^{O}C$ (Khan, Khan and Islam, 2013) for one hour keeping extraction fan on. Fibres are then conditioned for 48 hours at room temperature before preparing for testing.

2.4 Single fibre preparation for tensile test

Yarns are untwisted to separate fibres for tensile testing. Separation of fibres from yarns is performed using tweezers. This operation is performed carefully to avoid the fibre damage.

To facilitate the tensile testing of single jute fibres, a fibre is attached to a rectangular paper frame. The dimension of the paper frame is 35x20 mm. Inside the frame a rectangular hole is cut. The dimension of the hole is 25x10 mm. Each individual fibre is attached on a separate paper frame (Fig. 2) with araldite and is allowed to dry.

Zeiss optical microscope is used to determine the diameter of single fibre. Measuring fibre diameter at several places and taking the mean as the fibre diameter is an established method. However in this work the thinnest width of the fibre is taken as the fibre diameter and the cross-section is considered circular. The logic behind considering the thinnest diameter is, anything breaks at the weakest point and most of the cases thinnest point is the weakest point.

(A) (B)

Fig. 2 (A) Rectangular paper template and (B) fibre attached on the frame.

2.5 Single fibre tensile test

Tensile testing of single fibres is performed according to BS ISO 11566:1996 using a Hounsfield Series-S machine (Software-QMAT) with a cross head speed of 1 mm min^{-1}, gauge length 25 mm and a 5N load cell. Fibre gripping in this machine is performed by screw mounting jaws as shown in Fig. 3. At least 25 specimens are tested to obtain the mean value.

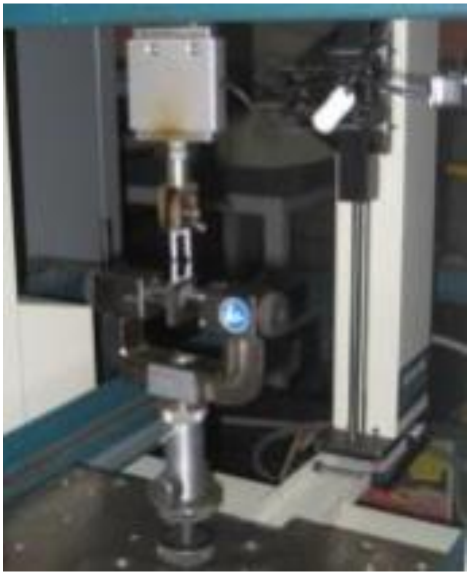

Fig. 3 Fibre testing on Hounsfield Series-S machine

3. Results and Discussion

Fibre diameter studied in this chapter (Table 1 and Fig. 4) do not show any significant differences ($P<0.05$). Tensile moduli of raw and alkali treated jute fibres do not show any specific trend or relation and no significant ($P<0.05$) differences (Table 1 and Fig. 5) are observed. Large values of standard deviations are noted here due to the inherently variable properties of jute fibre.

Table 1 Tensile property of fibers

Type of fibre	Fibre dia. (µm)	Standard deviation	Tensile modulus (GPa)	Standard deviation	Tensile strength (MPa)	Standard deviation	Strain at failure (%)	Standard deviation
Raw	32	8	45.4	16.3	1108	403	2.03	0.46
1% NaOH no tension	35	8	41.6	17.8	1050	442	2.09	0.52
1% NaOH with tension	33	9	44.6	14.8	973	445	1.92	0.62
5% NaOH no tension	32	9	43.5	16.2	932	378	1.95	0.52
5% NaOH with tension	29	7	46.2	20.1	953	406	2.29	0.68

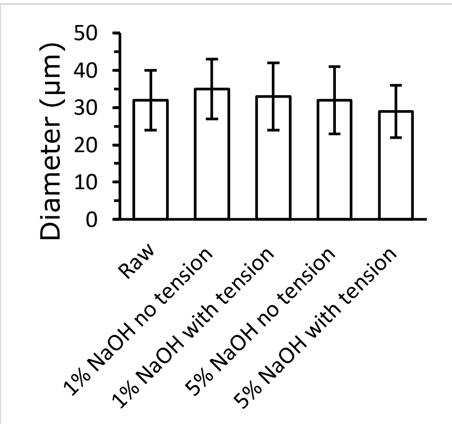

Fig. 4 Diameter of fibres (error bars indicate standard deviation)

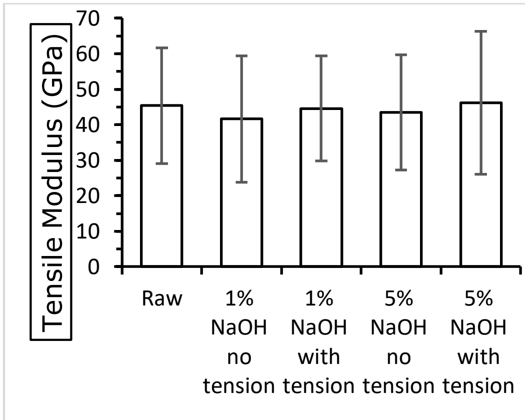

Fig. 5 Tensile moduli of fibres (error bars indicate standard deviation)

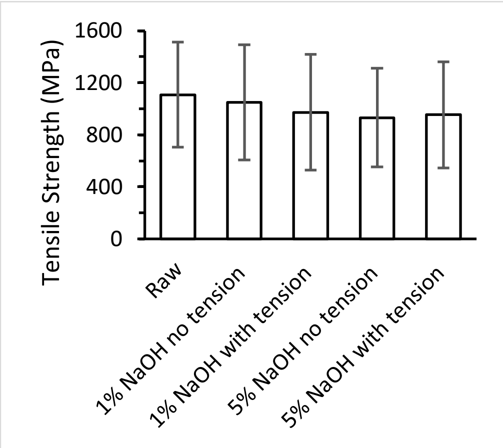

Fig. 6 Tensile strength of fibres (error bars indicate standard deviation)

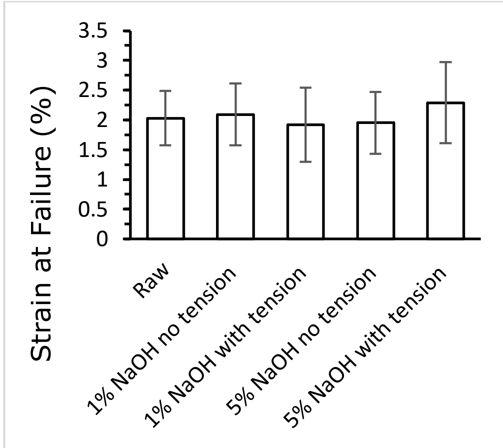

Fig. 7 Strain at failure of fibres (error bars indicate standard deviation)

Tensile strength of raw and alkali treated fibres present no significant ($P<0.05$) differences (Table 1 and Fig. 6). Scattered results are obtained for strain at failure of single jute fibres (Table 1 and Fig. 7) and the variations are not statistically significant ($P<0.05$). Fibre test results indicate that the chemical treatment as well as the treatment conditions studied in this research work do not affect the diameter and tensile properties of jute fibre.

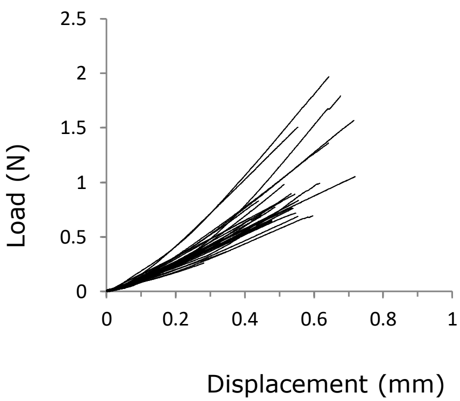

Fig. 8 Force displacement curves of single

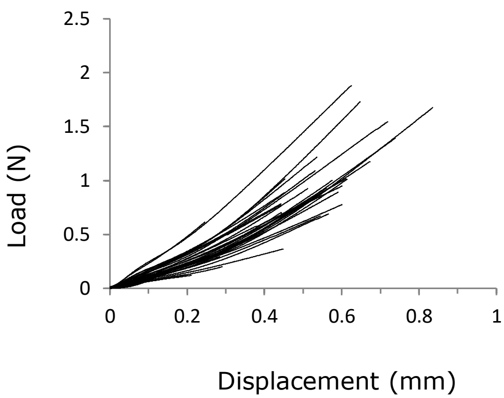

Fig. 9 Force displacement curves of single

jute fibres extracted from unsized raw yarn

jute fibres extracted from 1% NaOH treated yarn without tension

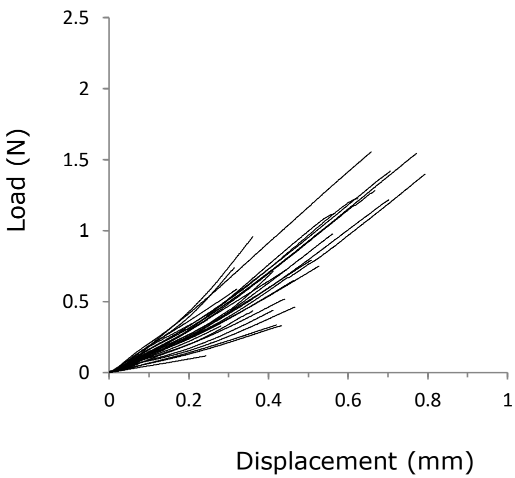

Fig. 10 Force displacement curves of single jute fibres extracted from 1% NaOH treated yarn with tension

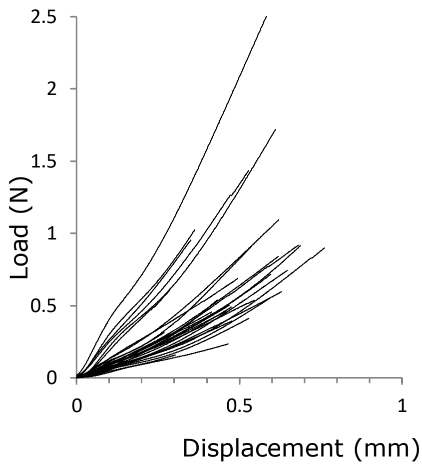

Fig. 11 Force displacement curves of single jute fibres extracted from 5% NaOH treated yarn without tension

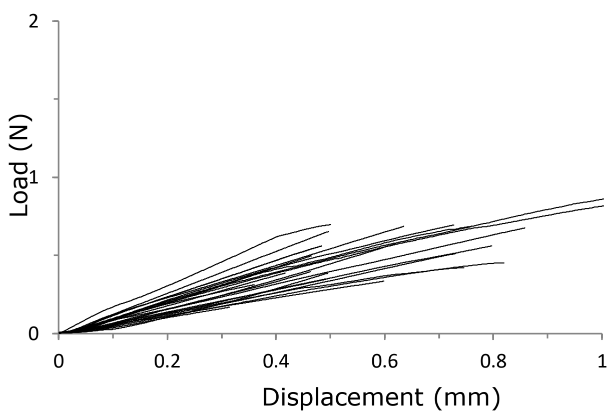

Fig. 12 Force displacement curves of single jute fibres extracted from 5% NaOH treated yarn with tension

Force-displacement curves of single jute fibres are presented in Fig. 8 to Fig. 12. The majority of force-displacement curves of textile fibres show an upward curvature after a small initial linear portion.

However, the nature of force-displacement curves of jute fibres tested in this study is different from that of other common textile fibres such as cotton (Wakelyn et. Al. 2010 and Hearle, 2002) and flax (Lu, 2014). The force-displacement curves of common textile fibres has an initial elastic region, a yield point and quasi-linear plastic region. However the force-displacement curves of most of the jute fibres obtained in this research show initially a very small linear region and then the slope of the curves increases presenting stiffer behaviour with increasing load. The initial linear region observed here is very small, nearly 0.2% of total extension and possibly this region is due to extension of hemicellulose and lignin. In this region the curves show a low gradient as these are low modulus materials (Mwaikambo, 2006). With increasing load fibres show an increase in tensile modulus due to untwisting of cellulose microfibrils, which remain helical with respect to the longitudinal axis of fibres (Thomas and Pothan, 2008 and Kozlowski, 2012). Untwisting and stretching of microfibrils occurs simulataneously and continues up to fibre failure.

However the characteristics of single fibres extracted from 5% NaOH treated yarn with tension showed a quasi-linear froce-displacement curve and this behaviour may be due to inherent variability of jute fibres.

4. Conclusions

Diameter of single fibres does not change due to alkali treatments performed in this chapter. The alkali treatment of jute fibre studied here does not affect the tensile properties irrespective of the alkali concentration as well as the condition of the treatment. Force-displacement curves of single jute fibres show an upward bending after initial linear portion revealing that with increasing load the stiffness of fibres increases and the alkali treatment does not affect the behaviour of the curves. However force-displacement curves of fibres treated in 5% NaOH solution behave differently and the cause may be the natural variability.

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