A study on processing of jute and cotton by underwater shock wave treatment and its characteristics

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Fiber quality is very important for all the steps of the textile processing and during the last decade underwater shock wave has been utilized for metal, wood, food processing and medical applications, therefore, this research paper will demonstrate underwater shock wave as a surface treatment of natural fibers, such as jute and cotton in form of yarn and to report characteristic properties of the treated fibers. The underwater shock wave is generated by the explosion of the detonation fuse in the water tank.The process of bubble generation and expansion inside the water results in the formation of shock wave. Natural fibers were exposed to shock wave treatment depending on the different pressures and detonation fuse separation distance. After shock-loading, fibers were selected for physico-mechanical and physico-chemical tests such as Scanning Electron Microscopy (SEM) analysis, breaking strength, moisture behavior, permeability and wicking test. The maximum effect with improved moisture content, permeability and wicking properties were observed from 100MPa.The treated fiber showed high performance necessary for use in woven and non woven purpose.

Keywords: Natural Fibers, Underwater Shock Wave, Surface Morphology, Moisture Content, Wicking, Permeability.

1. Introduction

Studies on the use of natural fibers as the replacement of artificial fibers in textile area have recently increased and opened up further industrial possibilities. Natural fibers have the low cost, biodegradability and comfort for wearing. Many kinds of functional finishes and treatments are increasingly utilized in the textile industries. The aim of all these innovations is to create more attractive finishes and treatments and produce fibers which are more comfortable to use for final products with a view to attract consumers. Such treatment to realize comfort can be categorized into physical-based technology and chemical-based technology. Physical-based or mechanical treatments are considered in modifying or processing of fiber surface properties.

Recently, a few studies have been published and devoted to fibrous materials treatment by underwater plasma, DC glow discharge, underwater capillary electric discharge (1-3). But underwater shock wave produced by explosion has been applied to various kinds of metals, woods, foods and medical applications is a new development . Some publications dealt with wood focusing on the engineering aspect of improvement of permeability, dryability and fire resistance properties. (4 -7).

In the present work, underwater shock wave treatment, a new mechanical-based technology, has been applied to processing of natural fibers by inducing micro cracks or micro roughness on the fiber surface to get their high performance properties.

To achieve this goal, shock treated natural fibers were allowed to analyze different physical characteristics. Shock treated jute and cotton yarn with improved physical properties will facilitate yarn dyeing or production of quality fabrics.

2. Materials

Industrial Jute (Corchorus olitorius) and cotton were collected from the local market of Tangail district, Bangladesh, and used for this investigation. Corchorus capsularies (Bengal White Jute), Chorchorus olitorius (Tosaa Jute) are the common species, which are widely cultivated in Bangladesh and India.

Electric detonator and detonating fuse (5mm diameter, 10g/m PETN with detonation velocity of 7000m/s) were supplied by **Asahi Kasei Chemicals (Japan)** and **Nippon Kayaku Co. Ltd (Japan)**, respectively. Methylene blue was supplied by **Wako Pure Chemical Industries Ltd., (Japan).**

3. Experimental section

3.1. Underwater explosion shock testing

The underwater shock wave loading assembly for treatment of natural fiber (jute and cotton) is schematically presented in Fig.1. Fibers samples, which were treated with the underwater shock wave, were cut into 40cm length and had mass of 10g, were put into unipac vacuum packed. These bags were put into lamizip–clear and double vacuum packed. Bags with specimen were hung with a specimen holder made of iron rod.

At the position of Dh (mm) above the upper surface of the specimen, a detonating fuse was placed parallel to the length of the specimen. The positions of the detonating fuse (Dh) were set 100, 65, 50, 45, 34 and 27 mm, which indicated the incident shock strength as 100, 150, 184, 200, 250 and 300 MPa, respectively (8).

The whole apparatus was placed into a water tank, and underwater shockwave was generated by means of explosion of detonating fuse, detonated by using an electronic detonator. Detonating fuse or explosives are usually placed at the distance from the workpice in suitable energy transferring medium such as water. The detonation wave propagates into the water and generates an underwater shock wave . Then the underwater shock wave propagates in the water towards the objective workpice or sample and impinges on sample surface. After application of underwater shock wave, samples were removed from the bags and was exposed to open air followed by characterization.

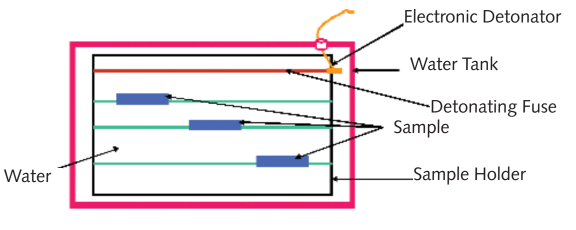

Fig. 1 Schematic of Experimental Setup.

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3.2. SEM Analysis

After the shockwave loading, jute fiber and cotton yarn were taken for SEM analysis. The Scanning Electron Microscope (Carry Scope JCM-5700, **JOEL Technology Ltd., Japan**) was used to observe the physical change of jute fiber and cotton yarn surface after shock loading. Prior to SEM investigation, the samples were dried in an oven for 60 min at 55°C and were gold coated for one min by using gold –coated sputter.

3.3. Breaking strength test

Shimadzu Autograph Automatic Load Strain Controller (DSS-10T by **SHIMADZU Corporation, Japan** was used for measuring the breaking strength of cotton yarn. Breaking strength of each specimen was measured according to ISO standard (9).

3.4. Moisture content test

The percentage of moisture content of jute fiber and cotton yarn was measured by using AND MF-50 Moisture Analyzer from **A&D Company Limited, Japan**.

In each experiment, the moisture content for 10 specimens was measured on the basis of different relative humidity and the average of 10 readings was used to calculate the percentage of moisture content of the specimens.

The moisture analyzer was operated at 105°C. Prior to the moisture content test, the samples were exposed to the open air in the uncontrolled lab atmosphere and had absorbed moisture from the environment.

3.5. Wicking test

A series of experiments on raw and shock treated cotton yarn were performed in distilled water. In these experiments, distilled water was used as wicking liquid. Radii of fibers in the yarn were assumed to be identical. Equal length and weight of raw and shocked yarn were used.

The schematic of experimental set up is shown in Fig. 2. In the figure, lab jack was used to hoist the liquid reservoir containing the wicking liquid, and the steel ruler to indicate the wicking height (10). The time and the corresponding position of the liquid were recorded.

3.6. Dye Permeability into Jute Fiber

Methylene Blue dye was dissolved, at first, by making paste with a small amount of water and then adding cold water. The dye bath was prepared by adding required percentage of dye based on the weight of fiber. The fiber liquor ratio was 1:50. Before immersing the jute fiber in the dye bath, it was soaked well and squeezed for even absorption of dye particles. The dyeing was started by immersing the materials and continued for 1 hour with occasional stirring by a glass rod, then allowed to continue for another 30 minutes as the bath cooled down. During dyeing, heated distilled water was added to the dye bath in order to maintain the fiber liquor ratio. After dyeing, the fibers were squeezed over the dye bath so that not a single drop of exhausted dye liquor was lost.

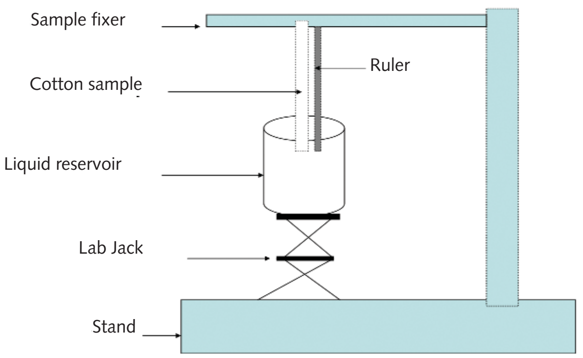


Fig.2: Experimental setup for wicking test.

The fibers were then rinsed thoroughly in cold distilled water and dried in air at room temperature(11). The rinsed water was added to the exhausted dye bath.

3.6.1 Dye permeability measurement

In order to measure and examine the dye permeability by the jute fiber as well as percentage of dye absorption by the jute fiber, the GENESYSTM 10VIS Spectrophotometer was used and the results as a percentage of dye absorption or dye permeability= (Do- De /Do) 100 is recorded. Where, Do and De are the original and exhausted dye bath concentration, respectively [9].

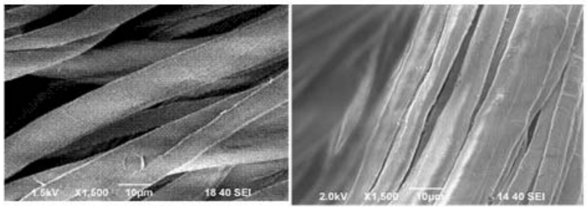
3.6.2 Calculation of the quantities of dye from stock solution

To calculate the quantities of dye, the following formula was used. Stock solution required (mL) = (W×P) ÷ C. Where, W is weight (g) of jute fiber sample to be dyed, P is percentage of dye to be used (expressed on the basis of the weight of fabric) and C is concentration of stock solution (g/mL).

4. Results and discussion

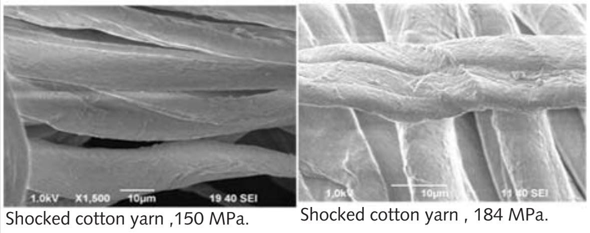
4.1. Fiber Morphology

The effect of underwater shock wave treatment on fiber morphology can be seen in figure 3 and 4. SEM images showed that some morphological changes on the shock loaded jute fiber and cotton yarn surface occurred including micro cracks, micro capillaries or micro roughness.



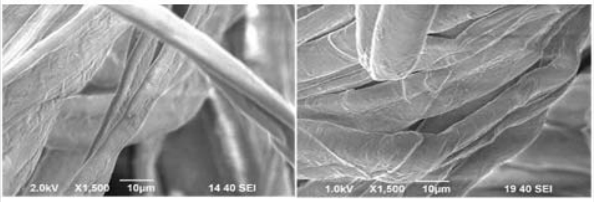
Raw cotton yarn.

Shocked cotton yarn ,100 MPa.



Shocked cotton yarn ,150 MPa.

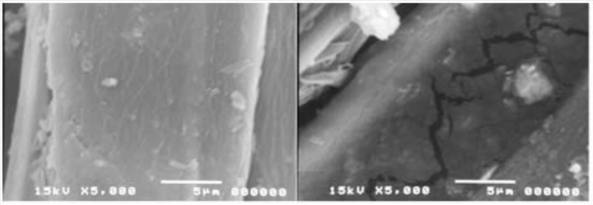
Shocked cotton yarn , 184 MPa.



Shocked cotton yarn , 200 MPa.

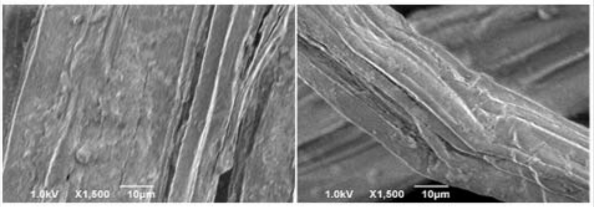
Shocked cotton yarn , 250 MPa.

Fig. 3: SEM images of raw and shock treated cotton yarn.



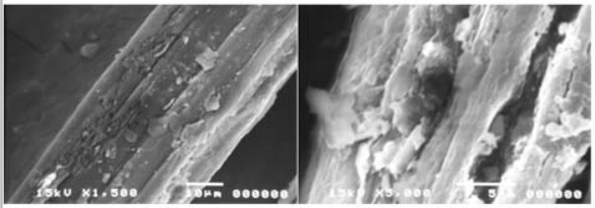
Raw jute fiber.

Shocked jute fiber, 100 MPa.



Shocked jute fiber,150 MPa.

Shocked jute fiber, 184 MPa



Shocked jute fiber, 250 MPa.

Shocked jute fiber, 300 MPa.

Fig.4: SEM images of raw and shocked jute fiber.

This indicates that micro cracks or micro roughness were induced when the high-pressure shock waves were impinged on the natural fiber surface. Apparently, propagation of shock waves in the water resulted in direct impact of the pressure front on the jute fiber and cotton yarn surface.

4.2. Breaking strength

Cotton fiber breaking strength can be seen graphically in figure 5. From the following figure, it has been found that the breaking strength of shock loaded cotton yarn is less than that of unshocked cotton yarn. Figure 5 shows this relationship. The loss in breaking strength of shock treated fiber might be caused by the production of micro cracks or roughness on its surface after shock loading.

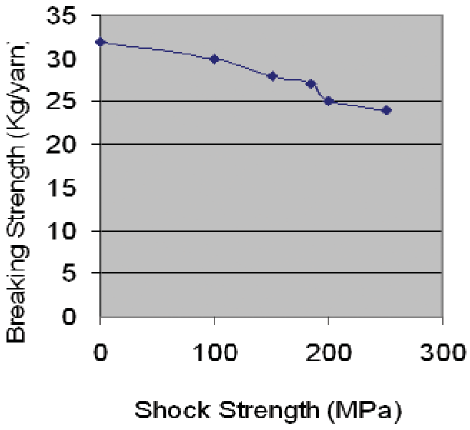


Fig. 5: Effect of shock strength on breaking strength of cotton yarn.

4.3. Moisture content

It can be observed from figure. 6 that all the treated samples attained higher moisture than virgin cotton yarns. The percentage of moisture content increases with the shock load increase. This means that by inducing micro cracks or roughness on the fiber surface of cotton yarn by an underwater shock wave, the cotton fibre becomes more effective for absorbing moisture from the environment. Micro cracks or roughness on the fiber surface increases with higher shock strengths and moisture penetrates easily into the fiber surface of cotton yarn after shock treatment. The higher level of polar sites or polar hydroxyl groups exposed to the fiber roughness during the shock wave treatment, yields more hydrophilic fiber surface.

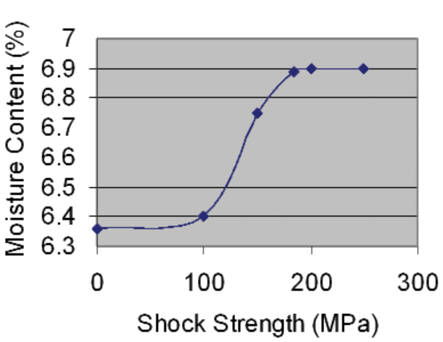


Fig. 6: Effect of shock strength on moisture content of cotton yarn.

4.4. Wicking

The effect of shock strength on wicking of cotton yarn can be seen in figure 7. Wicking rate of the shock treated cotton yarn increased with the increase of shock strength. Looking at the above figure it can be assumed that the higher rate of wicking by the treated cotton samples can be explained with the following possibilities:

(i) Shock wave treatment results in a yarn roughness as a result of surface cracking.Thus the size and shape distribution of the inter-fiber capillary spaces will be modified. This may lead to the unblocking of some capillaries promoting more rapid wicking.

(ii) During the shock treatment, micro capillaries or micro roughness were formed on the fiber surface, which may responsible to increase wicking rate. Wicking can occur when fibers assembled with capillary spaces between them are wetted by liquid. Capillary forces are responsible to drive the liquid in capillary spaces. The fiber surface properties and pore structure are the main determinants of wicking properties. The capillary principle dictates that smaller pores are filled first and are responsible for the front movement of liquid. As the smaller pores are completely filled, the liquid then moves to the larger pores(13).

(iii) Higher the level of exposure of polar sites or hydrophilic hydroxyl groups to the fiber roughness during the shock wave treatment, more will be the yield of wettable fiber surface.

(iv) The physical effect of the shock wave treatment through which surface erosion removes the layer of wax on the fiber surfaces, may render the yarn more wettable by water.

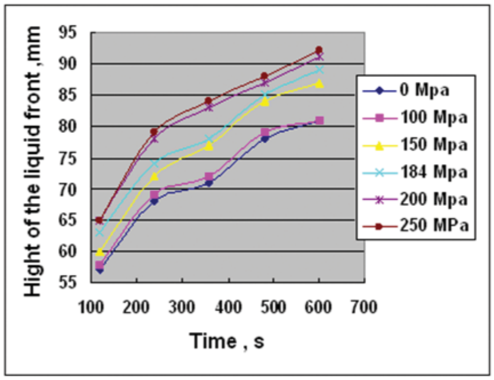


Fig.7. Effect of shock strength on wicking of cotton yarn.

According to the predicted results, microcapillary or micro roughness of yarn are responsible for the liquid absorption, diffusion and transporting during short time. Increase in yarn roughness due to action of high shock of its fibers increases the rate of water transport.

4.5. Permeability test of jute fiber

It has been observed from the figure 8 that permeability or absorption of dye increases, with an increase of shock strength. Micro cracks or cavities were formed on the fiber surface, as seen in SEM images, when the high strength underwater shock waves impinge on it. The higher dye permeability was obtained by the shock loaded jute fiber due to the generation of micro cracks or cavities on its surface. The Dye absorption of a fiber depends on the availability of total surface connected fiber pores and cavities in a fixed amount of fiber and the attraction force between the fiber and dye ions (14).

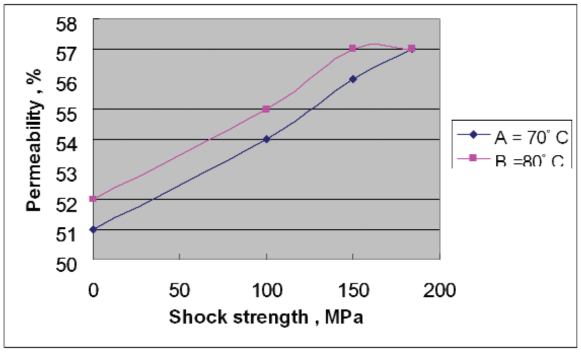


Fig.8. Effect of shock strength on dye permeability of jute fiber. (A = 70˚ C and B =, T 80˚ C , Dye concentration 1.0% , Time 60 min.)

5. Conclusions

The application of underwater shock wave for the treatment of natural fibers such as jute fiber and cotton yarn has been investigated in detail and conclusions are given as under. In order to process the fiber and obtain improved properties, natural fibers were subjected to the treatment of an underwater shock wave to create micro cracks on the fiber surface. The results of moisture content and liquid wicking rate of the shock treated cotton yarn measurements show that the treatment effect depends on the applied shock strength and on the distance between the yarn and detonating fuse.

Moisture content and wicking properties of cotton yarn increases with the increase of shock strength. At the shock wave strength of 150-250 MPa, the moisture content and wicking rate were improved but the fiber strength was decreased and above 184 MPa some yarn were found to be broken. The permeability of shock treated jute fiber is higher than that of unshocked. In case of strong underwater shock wave, the fibers would be broken; if the strength is too weak, the fiber surface would not be modified effectively.

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