Study on the Chemical Modification, Process Optimization and Spinning Properties of Jute Fibre

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Abstract

A series of wet chemical processing sequences are needed to improve the spinnability of jute fibre. The experiment was conducted in Textile Physics Division of Bangladesh Jute Research Institute during 2014 and 2015. For the improvement of spinning properties of jute fibre some chemical treatments were done. Modifying factors such as softening agent concentration, NaoH concentration, time, and Material Liquor Ratio (MLR) were optimized as NaoH: 15 g/l, Softening agent: 2.5 g/l, time:20 minutes and MLR-1:10, after alkali and softening treatment. From the study, it was found that the breaking twist means spinnability has increased than that of raw jute fibre. Furthermore, the modified jute fibre had better soft feeling than raw jute fibre. The modified jute fibre should be could be blended with cotton for the production of jute-cotton blended yarn using traditional spinning technology.

1. INTRODUCTION

Jute fibre, a natural composite of cellulose, hemicelluloses and lignin, is abundantly grown in Bangladesh, India, China and Thailand. It is widely used for the manufacture of flexible packing fabrics, decorative fabrics and in some other fields. Some major plus points about jute are its agro-based, annually renewable and biodegradable nature and availability at a low cost (1, 2). It has high tensile strength with good dimensional stability, moisture absorption and sound insulation properties. However, it has some inherent drawbacks (1,2) reflected in its stiffness and harshness, meshy structure with variable fibre length, fineness, branching nature and low extensibility. On the other hand due to the ecofriendly nature of jute, the meaningful R & D efforts on further improving its field production in respect of quality, yield and cost and textile related properties and processibility including spinability by chemical treatments have gained importance. Since every fibre has a specific limitation with regard to practical use, there is a tendency in the recent years with the advancement of fibre science and technology to modify properties of a textile fibre by chemical treatments for extending its use. An improvement in flexibility or pliability of jute can be effected by the removal of either lignin or hemicelluloses, while an appreciable increase in extensibility occurs after a treatment with a strong swelling agent. Although this treatment tends to reduce the strength, the spinning performance of the fibre is likely to improve on account of better pliability and an increased realization of the percentage substance strength. There are some reports in the literature on chemical treatment of jute with special reference to those aimed at improving its spin ability (3-7). Recently due to the improvement of people's living standards and need for environmental protection, the demand of natural biodegradable and ecofriendly fibres is rising day by day. Ramie, flax, hemp and some other vegetable fibres have been used as textile materials, but jute fibre is basically used for traditional purposes. If jute could be used to replace cotton, ramie and flax partially as textile material, not only the cost could be reduced but also a new market would be provided for jute products (8-12). In contrast, Statistical Design of Experiment advocates the changing of many factors at the same time in a systematic way, ensuring the reliable and independent study of the factors' main and interaction effects. Once the factor effects have been adequately characterized, steps can then be taken towards their appropriate control during production, so that variability (the cause of poor quality) in the products performance is minimized (13). Full factorials are utilized when experimentation is easy or when the number of factors is smaller than 3 or 4. Professor Genichi Taguchi, Director of the Japanese Academy of Quality, took up this idea. He devised a quality improvement technique that uses experimental design methods for efficient characterization of a product or process, combined with a statistical analysis of its variability. DOE (Design of Experiment) is used to investigate the causes of variation. DOE is performed off-line and identifies the sources of a problem in a process that must be controlled. It identifies which factors in a process may not be as critical as other factors, determines interaction within a process, and may be used to improve the quality of a process (14). DOE can be applied to identify the critical factors of chemical treatments of jute and select the best combination of the treatment parameters. At present, jute is the third foreign currency earner agricultural product in Bangladesh and it is next to the garment sector. But now it is facing stiff competition from the synthetic counter parts to the world textile market. To overcome the competition, diversified usages of jute have become essential. Blending of jute with other fibres may be considered as alternative and possible diversified usages of jute yarns and fabrics. Because of great abundance of jute in Bangladesh and shortage of cotton, jute can be blended with cotton to manufacture jute-cotton blended yarns to take the advantage of the lower price of jute fibre. Usually for perfect blending of jute with cotton, chemical modification of jute is done and it has been reported in different literature. However, there has been no study on the optimization of jute fibre modification by chemical and physical means reported so far. Full factorial experimental design is a statistical tool for process optimization and is being used in process control. This has been applied in this research work.

2. MATERIALS AND METHODS

Materials

Jute: Jute fibre of 80 days aged with breaking strength 36.20g/tex, breaking twist33 tpi and fineness 3.5 tex.

Chemicals: Sodium hydroxide, Softening Agent (Beso Soft), Wetting Agent (Lisapol) acetic acid , Hydrogen per oxide, Sodium Silicate and Sodium carbonate. All chemicals are supplied by MERCK, Mumbai, India

Methods

a) **Chemical Modification (caustic treatment)**

Recipe:

Sodium Hydroxide (NaOH) (g/l) = 15 g/l and 20 g/l
Wetting agent (Lisapol) = 1g/l fixed
Temperature = Room temp.
Time (min) = 10 min and 20 min
Material Liquor Ratio = 1:10 and 1:15
Hot Washing/ Neutralization with acetic acid =10 g/l

b) **Bleaching (whitening) and Softening**

Recipe:
Hydrogen peroxide = 8 g/l)
Sodium Silicate = (6 g/l)
Sodium Carbonate = (2g/l)
Temperature = $(80 \pm 5)^{0}$C
Time = 1 hr,
M:L ratio = 1:10, Beso soft (softening agent) = 2.5 g/l and 5.0 g/l

Table 1: Design of experiment formulation

Notation	Factors	Unit	**Levels**	
			Low Level (-)	**High Level (+)**
A	NaOH Concentration	gm/l	15	**20**
B	Softening Agent Concentration	gm/l	2.5	**5.0**
C	Time	min	10	**20**
D	**Material Liquor Ratio (MLR)**		**1:10**	**1:15**

c) **Experimental Design Formulation**

Factors and Levels

Factors are design parameters that influence the performance

Example: Sodium Hydroxide Concentration (g/l), Softening Agent Concentration (g/l), Time, Material Liquor Ratio (M:L)

Levels are: Value that a factor assumes when used in the experiment

Example: Sodium Hydroxide Concentration (g/l): 15, 20

Table 2: Four Factors and two levels matrix for the experimental design

A+		**A-**			
B+	B-	B+	B-		
1 ++++	2 +-++	3 -+++	4 --++	C+	**D+**
5 ++-+	6 +--+	7 -+-+	8 ---+	C-	
9 +++-	10 +-+-	11 -++-	12 --+-	C+	**D-**
13 ++--	**14** +---	**15** -+--	**16** ----	**C-**	

Standard Design of Experiment (DOE) nomenclature typically uses the minus sign (-) for low level and plus sign (+) for high level. Since, we have considered 4 factors and 2 levels, therefore, 2^4 = 16 combinations area required.

d) Procedure (for a 2^4 factorial):

For the afore-said DOE the following steps were taken into consideration:

1. Four factors have been selected named, Sodium Hydroxide Concentration (g/l), Softening Agent Concentration (g/l), Time and Material Liquor Ratio (MLR) based on their importance of function. Designate then A.B.C. and D respectively.
2. Two levels have been determined for each factor. The first level, labeled (-), is usually, the lower level for that factor. The second level, labeled (+), is assumed for high level.
3. Drawing up a matrix showing the sixteen combinations by which each factor is tested with each level of every other factor.
4. Running an experiment with each combination and record the output each cell.

Chemical Treatment Procedure:

- Samples of 100gm jute were treated in a beaker with **20g/l sodium hydroxide and** 1 g/l(fixed) wetting agent **for 20 min with a M: L ratio of 1:15** at room temperature;
- Samples were washed with water several times, neutralized with acetic acid, bleached with hydrogen peroxide, sodium silicate and Sodium carbonate maintaining temperature $(80 \pm 5)^{0}$ C, for 1 hour at pH10-10.5;
- **Finally softened with 5g/l softening agent (baso soft).**

By the above procedure, Experiment-1 is completed. Rest fifteen (15) experiments were completed by the same way according to experimental design.

Jute fibres were caustic treated, bleached and softened according to the mentioned experimental design. Spinning properties were determined after completion of each chemical treatment combination. Bundle Strength (ASTM D 1445-05), breaking twist (ASTM D 1423-02), and fineness (ASTM D 1577-07), (linear density) were measured with Stelometer, Trumac (twist tester) and weighing balance respectively at standard atmospheric condition.

3. RESULTS AND DISCUSSIONS

For spinning, fine fibre with adequate strength, breaking twist and linear density is required. From the table-3 it was observed that optimum results are found in experiment no-11. From table 4 and 5 it is found that higher level sodium hydroxide concentration (20g/l) is worse than lower level concentration (15g/l) for 4.72% strength loss of fibre. From table 6 and 7 it is found that higher level sodium hydroxide concentration , lower level softening agent concentration and higher level ML ratio are responsible for breaking twist loss of 11.15% , 2.81% and 8.94% respectively. From table 9 it was found that lower level softening agent concentration is responsible for linear density (tex).

The modification process is necessary for improving the textile properties of jute fibre. The treated jute fibre was modified by varying sodium hydroxide concentration, Softening agent concentration, treatment time and ML ratio. From the study, it was found from table 5, 7 & 9 that A (+) is worse than **A (-) by** 4.72% strength loss of fibre means ***caustic treatment by 15g/l is better than 20g/l***. Similarly B(+) is worse than **B (-)** by 7 tpi (2.81%) breaking twist loss means that ***softening treatment by 2.5g/l is better than 5g/l.*** C (-) is worse than **C(+)** means ***caustic treatment time 20 minutes is better than 10 minutes***. D (+) is worse than D **(-)** by 4.38% strength loss of fibre means MLR 1:10 is better than 1:20. Now, it is concluded that Sodium hydroxide concentration, Softening agent concentration, treatment time and ML ratio were the most important parameters for modifying process. From Table 3 it was found that the results of full factorial design experiment the strength 32.08 (g/tex), breaking twist 38 (tpi) and fineness (linear density)- 1.85 (tex) were obtained with the optimum treating conditions such as sodium hydroxide of 15 g/l, softening agent 2.5.0 g/l, time 20 min and M:L ratio 0f 1:10.

Table 4: Four factors and two levels matrix with cell number, combination and output value for fibre strength

A+		A-					
B+	B-	B+	B-				
1 **++++** **(25.85)**	2 +-++ (29.00)	3 -+++ (30.12)	4 --++ (29.43)	C+	D+	114.40	**227.38**
5 **++-+** **(27.85)**	6 +--+ (26.54)	7 -+-+ (29.65)	8 ---+ (28.94)	C-		112.98	
9 **+++-** **(27.89)**	10 +-+- (29.66)	11 -++- (32.08)	12 --+- (28.56)	C+	D-	118.19	**237.82**
13 **++--** **(30.42)**	14 +--- (29.76)	15 -+-- (28.45)	16 ---- (31.00)	C-		119.63	
112.01	114.96	120.30	117.93				
226.97		**238.23**					

Table 3: Spinning properties under different experimental conditions

	Inputs					**Outputs**		
Experimental Design	Sample No	NaOH conc.(g/l)	Softening agent conc. (g/l)	Time (min)	Material Liqour Ratio (MLR)	Fibre strength (g/tex)	Breaking twist (tpi)	Linear density (tex)
	1	20	5.0	20	1:15	25.85	24	1.98
	2	20	2.5	20	1:15	29.00	30	2.45
	3	15	5.0	20	1:15	30.12	32	2.84
	4	15	2.5	20	1:15	29.43	28	3.45
	5	20	5.0	10	1:15	27.85	26	2.34
	6	20	2.5	10	1:15	26.54	25	2.56
	7	15	5.0	10	1:15	29.65	34	3.12
	8	15	2.5	10	1:15	28.94	35	2.85
	9	20	5.0	20	1:10	27.89	27	2.77
	10	20	2.5	20	1:10	29.66	32	3.06
	11	**15**	**5.0**	**20**	**1:10**	**32..08**	**38**	**1.85**
	12	15	2.5	20	1:10	28.56	36	3.12
	13	20	5.0	10	1:10	30.42	33	2.88
	14	20	2.5	10	1:10	29.76	34	2.94
	15	15	5.0	10	1:10	28.45	28	3.45
	16	15	2.5	10	1:10	31.00	29	2.66

Table 5: Factorial effect on strength

A-	**120.30+117.93 = 238.23**	**A(+) is worse than** A(-) by **4.72% strength loss of fibre**
A+	**112.01+114.96 = 226.97**	
B-	**114.96+117.93 =233.89**	**B(+) is worse than B(-)**
B+	**112.01+120.30 =232.31**	
C-	**119.63+112.98 =232.61**	**No significance difference**
C+	**114.40 +118.19 =232.59**	
D-	**118.19+119.63 =237.82**	**D(+) is worse than** D(-) by **4.38% strength loss of fibre**
D+	**114.40+112.98 = 227.38**	

Table 6: Four factors and two levels matrix with cell number, combination and output value for breaking twist

A+		A-					
B+	B-	B+	B-				
1 ++++ (24)	2 +-++ (30)	3 -+++ (32)	4 --++ (28)	C+	D+	114	**234**
5 ++-+ (26)	6 +--+ (25)	7 -+-+ (34)	8 ---+ (35)	C-		120	
9 +++- (27)	10 +-+- (32)	11 -++- (38)	12 --+- (36)	C+	D-	133	**257**
13 ++-- (33)	14 +--- (34)	15 -+-- (28)	16 ---- (29)	C-		124	
110	121	132	128				
231		**260**					

Table 7: Factorial effect for breaking twist

A- 132+128 = 260 **A(+) is worse than** A(-) **by 29 tpi (11.15%) breaking twist loss** **A+ 110+121 = 231**
B- 121+128 =249 **B(+) is worse than** B(-) **by 7 tpi (2.81%) breaking twist loss** **B+ 110+132 =242**
C- 120+124 =244 **C(-) is worse than** C(+) **by 3 tpi** **C+ 133 +114 =247**
D- 133+124 =257 **D(+) is worse than** D(-) **by 23 tpi (8.94%) breaking twist loss** **D+ 114+120 =234**

Table 9: Factorial effect for fineness in tex

A- 11.26+12.08 = 23.34 **A(-) is worse than A(+) by 2.36 tex** **A+ 9.97+11.01 = 20.98**
B- 11.01+12.08 =23.09 **B(-) is worse than** B(+) **by 1.86 tex** **B+ 9.97+11.26 =21.23**
C- 10.87+11.93 =22.80 **C(-) is worse than** C(+) **by 1.26 tex** **C+ 10.72 +10.80 =21.54**
D- 10.80+11.93 =22.73 **D(-) is worse than D(+) by 1.14 tex** **D+ 10.72+10.87 =21.59**

Table 8: Four factors and two levels matrix with cell number, combination and output value for fineness in tex

A+		A-					
B+	B-	B+	B-				
1 ++++ (1.98)	2 +-++ (2.45)	3 -+++ (2.84)	4 --++ (3.45)	C+	D+	10.72	**21.59**
5 ++-+ (2.34)	6 +--+ (2.56)	7 -+-+ (3.12)	8 ---+ (2.85)	C-		10.87	
9 +++- (2.77)	10 +-+- (3.06)	11 -++- (1.85)	12 --+- (3.12)	C+	D-	10.80	**22.73**
13 ++-- (2.88)	14 +--- (2.94)	15 -+-- (3.45)	16 ---- (2.66)	C-		11.93	
9.97	11.01	11.26	12.08				
20.98		**23.34**					

4. CONCLUSION

The effects of sodium hydroxide, softening agent, time and material liquor ratio were the process conditions examined. With respect to strength, breaking twist and linear density sodium hydroxide concentration, Softening agent concentration, treatment time and ML ratio were the most important parameters. A full factorial experiment was designed to optimize the conditions for modification.

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