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Analysis of the Correlation Between Crimp Parameters and its Effect on Yarn Strength and Hairiness

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Abstract
The objective of this paper is to analyse the correlation between crimp parameters and the effect of crimps on yarn strength and hairiness. Crimp is an essential property for natural and man-made fibres. Crimps always form with different parameters as they are very much irregular in size and shape. So, if the crimps are regular in size and shape, the end products like yarn and fabric properties will improve. Jute is a natural fibre with no natural crimp. In this research work, the gear crimping method was used as a mechanical crimping system to impart a regular size and shape of crimps into jute sliver. As a result, crimp parameters like the crimp length and crimp angle become uniform, and it is then easy to measure them. Results also showed that the crimp length is directly proportional and the crimp angle is reversely proportional to the number of crimps per unit length, and they are highly correlated. It was also shown that crimp and crimp parameters also affect the yarn strength and hairiness. In conclusion, it is revealed that with an increase in the number of crimps, the yarn strength was increased and hairiness was decreased.

Keywords
mechanical gear crimp, correlation, crimp length, crimp angle, yarn strength, yarn hairiness.

1. Introduction

There is a great importance in this paper for the field of textile spinning as crimp parameters, strength and hairiness are discussed. Different scholars have conducted studies related to this at different times, revealing different results. Crimp is defined as the waviness of a fibre, i.e. the condition in which the axis of a fibre departs from a straight line and follows a simple, complex or a irregular wavy path in the same phase [1]. Although crimp is one of the most significant features of natural and man-made fibres, there is no consent about how to quantify crimp in terms of measurable parameters [2]. The characterisation of fibre crimp can generally be divided into static and dynamic parameters [3]. Static parameters describe the geometrical shape of crimp bows, and dynamic parameters describe the tensile fibre behaviour attributed to the crimped shape of the fibre [4].

Geometrical crimp describes simple physical parameters such as the number of crimp waves or their amplitude, as well as sophisticated functions of fibre helices and their statistical evaluation in terms of spatial volume [5]. Both idealised geometrical shapes describe two parameters, commonly the wavelength λ and amplitude A. Consequently, it is revealed that two parameters are necessary for the complete geometrical description of crimp. However, simple parameters such as the leg length and crimp angle are dependent on the loads applied during measurement [6]. The wavelength λ of fibre crimp is measured as twice the distance between two crossings of the fibre with the zero axis. It is not possible to measure this directly, due to the fibre crimp certainly being too irregular and the small measuring quantities, which cause difficulties. Hence, the crimp length L_c, as the average length of fibre in one crimp is sometimes used to describe crimp [7], where

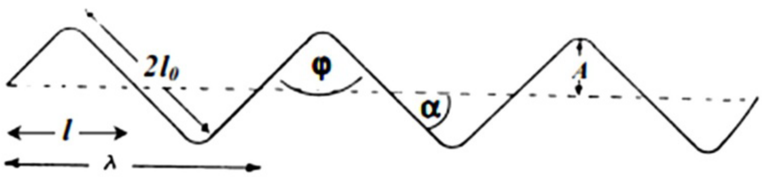

Fig. 1. Idealised Geometry of Stuffer Box Crimped Fibre [9]

$$L_c = 1/2\ \lambda \text{ [mm] or [inch]}$$

The crimp number or crimp count is defined as the number of crimps per unit length, which characterises the number of crimp bows or waves C_n per unit length of straightened fibre L_o. The unit length L_o is taken as 1 inch in the US, whereas in Europe 100 mm or 1 cm is used. The angle α between the leg of the crimp wave and the zero line is used to characterise crimp geometry. The crimp angle φ is the angle between the two legs of a crimp bow, as shown in Figure 1, indicating the sharpness of the crimp [8].

Yarn strength and hairiness are important properties for the end uses of yarns and fabrics. It was found by different researches that yarn strength and hairiness are related with crimps. The crimp behaviour of crimped fibres has a considerable variation in the break stress and strain of individual fibres, and this fibre property is important for any prospective yarn model [10]. It is also important that the imposition of crimp on a normally straight fibre changes the mechanical behaviour of the fibre,

n = number of crimp waves per unit length of fibre	L = n l = crimped length of fibre
φ = crimp angle	λ = 2l = wave length of crimped fibre
l_o = side length of one crimp bow	A = crimp amplitude
L_0 = 2n l_o = extended length of fibre	α = angle between crimp leg, fibre axis
l = width of one crimp bow	

Table 1. Description of Figure 1

Raw material	Yarn count (Tex)	Number of crimps per (2.54 cm)	Yarn twist per 2.54 cm
100 % jute fibre	218	3	4.5
	258	4	
	311	5	

Table 2. Materials used in this research

especially tensile strength properties [11]. A highly crimped fibre will behave spring-like under compression. Yarn hairiness is also another important property that is related to crimps, which becomes less with an increase in the number of crimps per unit length [12]. Correlation is a statistical technique that can show whether and how strongly pairs of variables are related. A positive correlation exists when as one variable increases, the other variable also increases and vice versa. In statistics, an impeccable positive correlation is represented by the value +1, while 0 indicates no correlation, and +1 a perfect positive correlation. A negative correlation is an inverse or opposing relationship between two variables such that they move in opposite directions. In statistical terminology, an inverse correlation is denoted by the correlation coefficient r having a value between -1 and 0, with r = -1 indicating a perfect inverse correlation. The Pearson r correlation is widely used in statistics to measure the degree of the relationship between linear related variables.

2. Materials and Method

2.1. Materials Used

Bangla white B grade jute fibres, a product of Bangladesh, were used as raw materials to produce yarn. The raw jute fibres were conditioned with 20% emulsion. The emulsion was prepared using 9% rice bran oil, 90% water, and 1% emulsifier. The conditioning of jute fibres with emulsion was done to make them soft and flexible. During carding, the fibres were passed through two pairs of worker-strippers, one cylinder and one doffer on a breaker card machine, and 4½ pairs of worker-strippers, one cylinder, and two doffers on finisher card machine. The fibres became separated, more parallel and straight when passed the carding machines, forming carded slivers. Three draw frame machines were used to process the jute fibre. Doubling of the first, second and third draw frames was done normally: 2:1, 3:1 and 2:1. Jute slivers were produced with different numbers of crimps: 3 crimps / 2.54 cm, 4 crimps/ 2.54 cm and 5 crimps / 2.54 cm. As the gear crimping system was used to impart crimp into the jute slivers, any fraction number of crimps was not possible here. Moreover, 6 numbers of crimps per unit length were not feasible, because of fibre damage. Hence, it is a limitation of the gear crimping method. Different yarns were produced using these jute slivers with different numbers of crimps. All the machine parameters were kept identical to control the yarn properties. Table 2 shows the materials used in this research.

2.2. Method Used

Yarn strength was measured in agreement with the test method provided by the ASTM D 2256-10 standard. Yarn hairiness was measured with the use of a Yarn Evenness Tester, Premier 7000. Crimp parameters, such as the crimp length and crimp angle, were measured by means of a Projectina microscope - DMM 2000.

3. Experimentation

3.1. Experimentation of crimp length and crimp angle

Crimp parameters like the crimp length and crimp angle were measured by a projectina microscope. A DMM 2000 projection microscope was used in this research to measure the crimp length and crimp angle of jute sliver. This instrument uses PIA-7000 software for image processing, comparison and measuring in combination with a digital camera. In this research, the image was enlarged 5 times only. Firstly, the width of one crimp bow (l) was measured, then the crimp length of the fibre was measured using the formula, L = nl, where, L is the crimp length of the fibre, n the number of crimps per unit length, and l is the length or width of one crimp bow. The crimp angle was also measured using the projectina microscope, which is the angle between the two legs of a crimp bow.

3.2. Experimentation of yarn strength

Yarn strength was measured using a Universal Tensile Strength Tester , James Heal. In accordance with ASTM D 2256-10, the single strand method was used to measure the yarn strength. The tests were carried out at a machine speed of 300 mm/min, break destination of 20%, jaw scheme 5 and 250 mm jaw separation.

3.3. Experimentation of yarn hairiness

Yarn hairiness was measured using a Yarn Evenness Tester, Premier 7000, India. The test speed was maintained at 25 m/min during the yarn test. Yarn hairiness was also checked by the projectina microscope. Table 3 shows

Number of crimps per 2.54 cm	Width of one crimp bow l (mm)	Crimp length of fibre L (mm)	Crimp angle (φ)
3	8.83	26.49	145.03°
4	6.87	27.48	136.67°
5	5.63	28.15	126.16°

Table 3. Parameters of a crimp for different numbers of crimps per unit length

S.N	Relation between	Correlation (r)	Regression (p)
1.	Number of crimps per unit length (2.54 cm) and crimp length of fibre (mm)	r = 0.9976	p = 0.0440
2.	Number of crimps per unit length (2.54 cm) and crimp angle (φ)	r = - 0.9978	p = 0.0418

Table 4. Correlation and regression between the number of crimps, crimp length and crimp angle

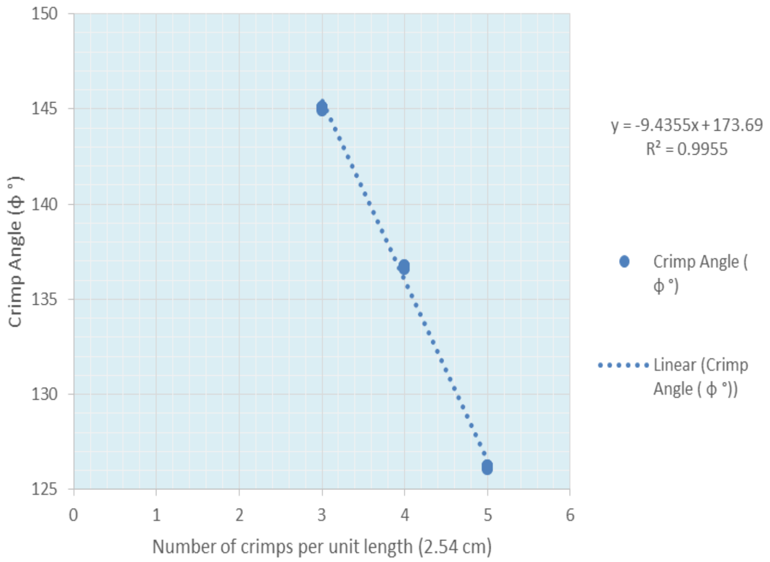

Fig. 2. Relation between number of crimps and crimp angle (φ)

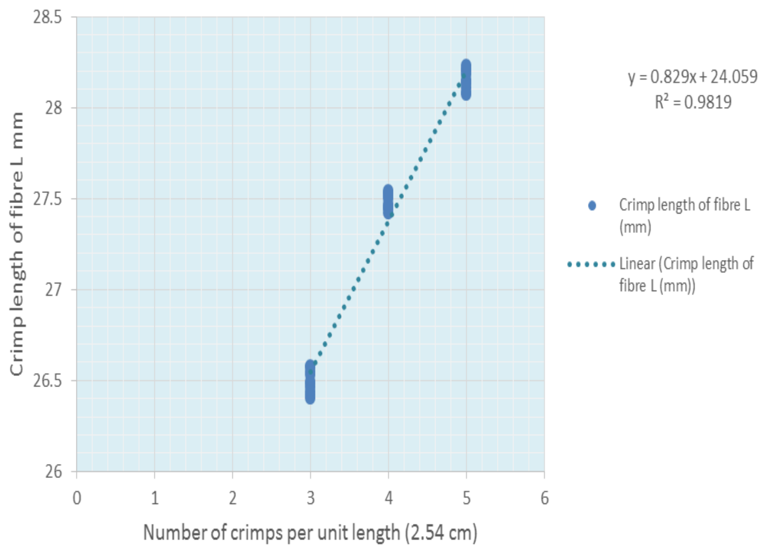

Fig. 3. Relation between number of crimps and crimp length of fibre

the parameters of a crimp for different numbers of crimps per unit length.

4. Result and Discussion

4.1. Crimp angle and crimp length

The crimp angle and crimp length are related to the number of crimps per unit length. It is found that when the number of crimps is increased, the crimp length increases, while the crimp angle decreases. When the number of crimps per unit length is increased, more of the length of the fibre is compressed in a fixed length, as a result of which the crimp length increases. The correlation between the number of crimps per unit length (2.54 cm) and the crimp length of fibre is strongly positive linear, It means there is a significant linear relationship between the number of crimps per unit length (2.54 cm) and the crimp length of the fibre because the correlation coefficient r is 0.9976 and the p value - 0.0440, which is significantly different from zero. The value of p is less than α i.e. $p< 0.05$ (alpha), which reveals there is a highly significant positive relationship between the number of crimps per unit length and crimp length of the fibre. It is also found that there is a significant linear relationship between the number of crimps per unit length (2.54 cm) and the crimp angle of the fibre, because the correlation coefficient r is -0.9978 and the p value - 0.0418. The value of p is less than α i.e. $p< 0.05$ (alpha), which shows there is a highly significant negative relationship between the number of crimps per unit length and crimp angle of the fibre. Table 4 shows the correlation and regression between the number of crimps, crimp length and crimp angle. Figure 2 shows the crimp length of the fibre (mm), Figure 3 the crimp angle (φ), and Figure 4 the yarn strength. However, it will be very helpful to select the optimum number of crimps per unit length for further research work. The number of crimps affects the strength of the yarn, and it is also related to the crimp length and crimp angle.

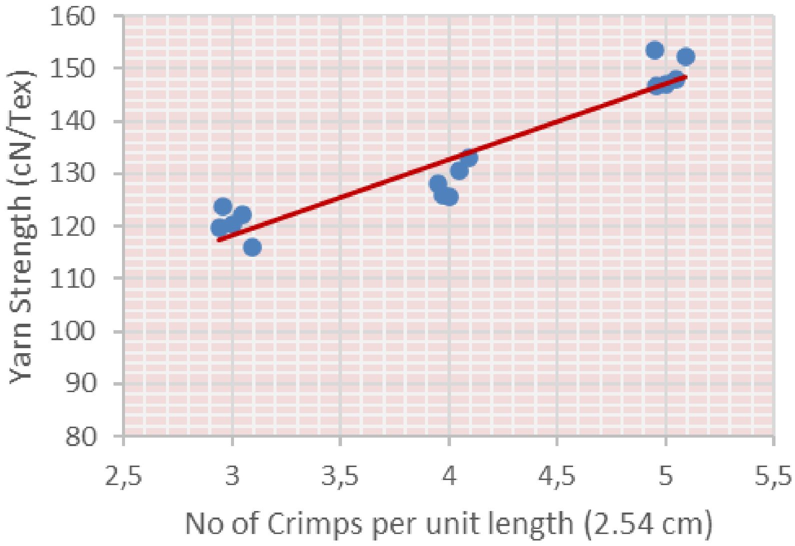

Fig. 4. Relation between number of crimps and yarn strength

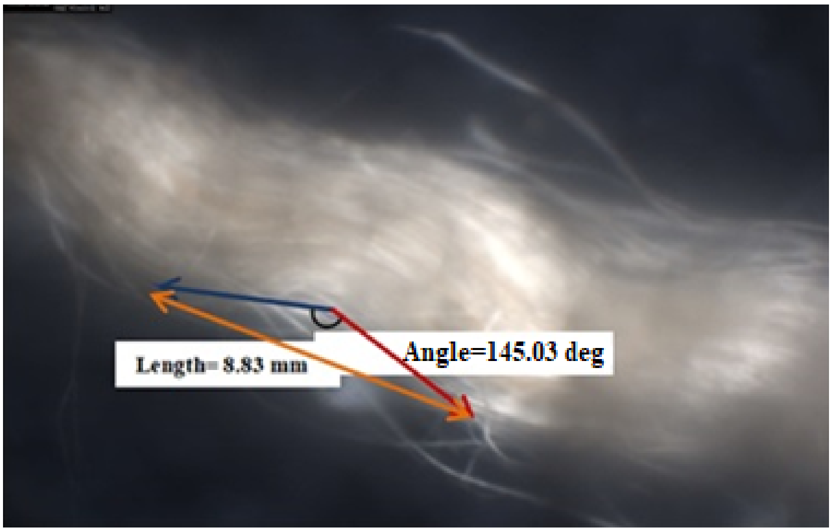

Fig. 5. Width of one crimp bow and crimp angle for 3 crimps per unit length (2.54 cm)

4.2. Yarn Strength

Yarn strength is highly related to the crimp. It is seen that the yarn strength increases with the number of crimps per unit length, which happens when the number of crimp increases per unit length, and more of the quantity or volume of fibre accumulates and compressed in the same length. As a result, the yarn becomes regular with less unevenness and bulky, and the strength increases. During the test, for 3, 4 and 5 crimps, the maximum breaking force was required 25.86 N, 32.71 N and 45.75 N, respectively. As the count of jute yarn was different for a different number of crimps, the single yarn strength or tenacity was converted into cN/Tex. The single yarn strength was found for 3, 4 and 5 crimps per unit length: 120.46 cN/Tex, 128.74 cN/Tex and 149.56 cN/Tex, respectively. At every step, the strength was increased gradually. The elongation % also increased with the increased number of crimps. Table 5 shows the breaking force, single yarn strength or tenacity and elongation percentage of yarns with different numbers of crimps per unit length.

4.3. Yarn hairiness

The hairiness of yarn is a property that indicates the number and length of loose fibre ends and loops protruding from the body of the yarn. The total number of

	Breaking force (N)			Yarn strength or tenacity (cN/Tex)			Elongation %		
	3 crimps/ 2.54 cm	4 crimps/ 2.54 cm	5 crimps/ 2.54 cm	3 crimps/ 2.54 cm	4 crimps/ 2.54 cm	5 crimps/ 2.54 cm	3 crimps/ 2.54 cm	4 crimps/ 2.54 cm	5 crimps/ 2.54 cm
1	25.67	32.56	46.96	119.60	128.06	153.50	1.39	1.51	1.97
2	26.26	33.24	45.32	122.35	130.74	148.11	1.19	1.58	1.72
3	25.89	31.96	45.01	120.49	125.70	147.13	1.49	1.71	1.87
4	24.91	33.87	46.59	116.06	133.22	152.29	1.48	1.36	2.27
5	26.58	32.04	44.91	123.46	126.02	146.80	1.68	1.41	2.47
Avg	25.86	32.71	45.75	120.46	128.74	149.56	1.44	1.51	2.06

Table 5. Breaking force, single yarn strength or tenacity and elongation percentage of yarns with different numbers of crimps per unit length

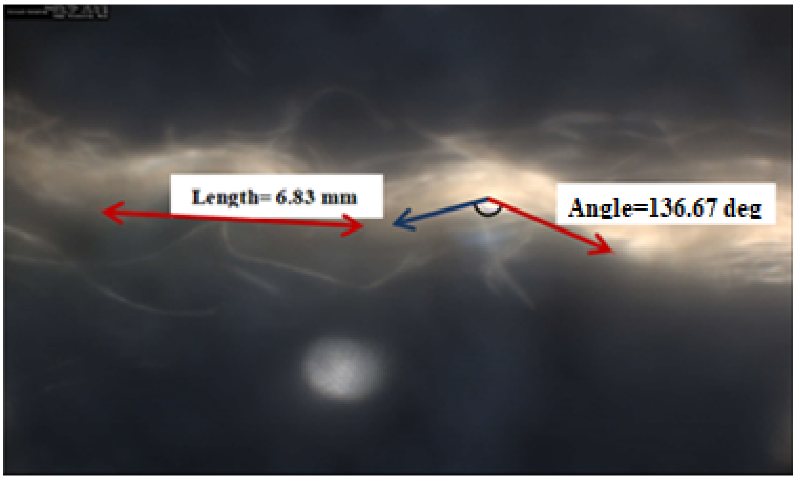

Fig. 6. Width of one crimp bow and crimp angle for 4 crimps per unit length (2.54 cm)

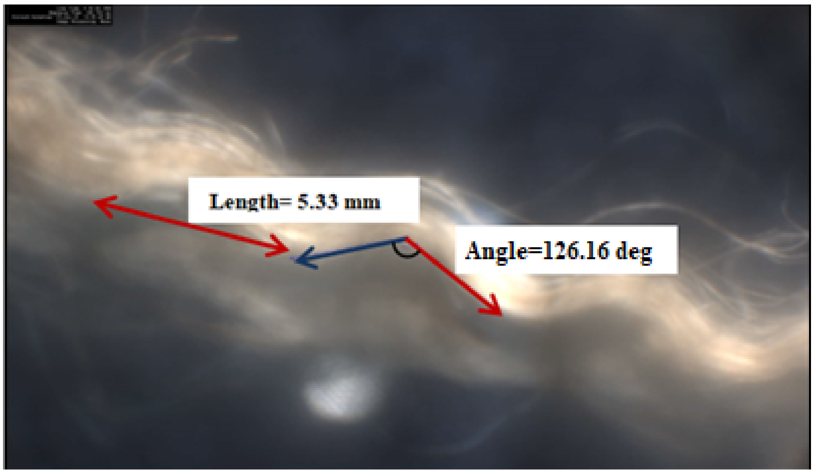

Fig. 7. Width of one crimp bow and crimp angle for 5 crimps per unit length (2.54 cm)

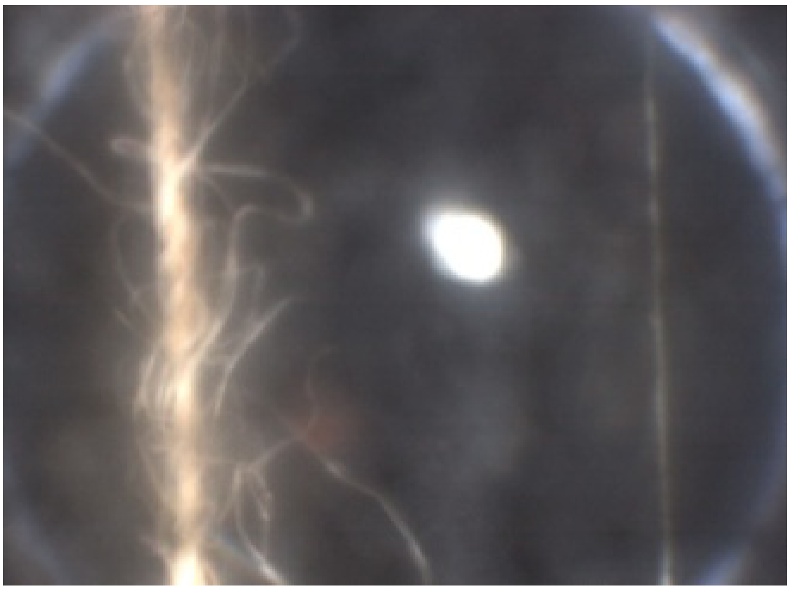

Fig. 8. Hairiness of yarns

protruding hairs in a fixed length of yarn is counted for a given time with the yarn running at a known speed. Here, the yarn was running at 25 m/min. Hairiness is a unique feature of staple fibre yarns that distinguishes it from filament yarns. The hairiness was 6.75, 5.87 and 4.72 for 3, 4 and 5 crimps per unit length, respectively. More hairiness was found for a lower number of crimps, and gradually the hairiness was reduced with an increase in the number of crimps per unit length.

4.4. Microscopic Observation

Microscopic views of the jute sliver were taken to access the crimp length and crimp angle. Three views were taken with this instrument. Figures 5, 6 and 7 show the width of one crimp bow and crimp angle for 3, 4 and 5 crimps per unit length (2.54 cm).

5. Conclusion

Crimp is a very significant property of fibres for subsequent processing like spinning and weaving. Hence, the number of crimps per unit length and crimp parameters affect the properties of products such as yarns and fabrics. It is shown in this research that crimp length and crimp angle are related to the number of crimps. The crimp length increases and the crimp angle decreases when the number of crimps increases per unit length. It can be said that the crimp length of fibre is directly proportional and the crimp angle is inversely proportional to the number of crimps per unit length. It is also found that the properties of yarn like the hairiness and strength of yarn are improved due to the progressive increase in the crimps per unit length. The yarn strength increases and the hairiness decreases with an increase of crimps. This research work will be helpful for researchers to select the optimum number of crimps for specific end uses.

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