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Effect of core thread tension on structure and quality of multi-thread bouclé yarn

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The effect of core thread tension on the structure and quality of multi-thread bouclé yarn has been studied experimentally. The core thread tension is controlled using the tension rollers and is set at five different values. The results show that the number of bouclé profiles increases to approximately 36 per metre, and relatively low variability of the size of bouclé profiles is secured. Hence, the fancy bulkiness of the bouclé yarns increases by approximately 92 mm^2/m. Moreover, the circularity ratio of fancy profile increases to reach approximately 64% which is important for bouclé yarns. Further, by setting the core thread tension to approximately zero, only 50% extra supply of one effect thread is sufficient to manufacture the final multi-thread bouclé yarns. Therefore, it is possible to reduce the usage of materials and to improve the fancy yarn structure and quality.

Keywords: Bouclé yarn, Fancy yarn, Hollow-spindle, Thread tension, Yarn quality, Yarn structure

1 Introduction

Bouclé yarn is a basic type of overfed fancy yarn. It is defined as "a compound yarn consisting of a twisted core with an effect yarn wrapped around it so as to produce wavy projections on its surface... bouclé yarn exhibits an irregular pattern of semi-circular loops and sigmoid spiral."[1]. Several researchers studied overfed fancy yarns. Some of their studies reported the relationships between the technical conditions of production and the geometrical structure of the ultimate fancy yarns[2-4]. The determined technological conditions were related to the manufacturing process and the machines used. For example, the technological conditions for the hollow-spindle machine were the delivery speed, the hollow-spindle rotational speed and the supply speed. Some of these manufacturing processes were conducted in one stage by using a hollow-spindle spinning machine; others were conducted through two stages or more. Many different types of fancy yarn ranging from spirals, to snarls, loops, arcs, knots, etc, were engineered depending on various technological conditions. It has been reported that bouclé yarns are made, traditionally, through three stages (a ring-frame and two twisters) or through two stages (a ring-frame and a two-for-one fancy yarn twister)[5]. However, a previous study showed that bouclé yarns can be produced from slivers in one stage on a hollow-spindle spinning machine. That study was concerned with the effect of production speed on the bouclé yarn characteristics. Both the subjective and objective methods of testing were used. A good agreement between the two methods for many characteristics of the yarns was found[6].

Recently, the manufacture of multi-thread bouclé yarns in one process by a combined twisting system, that is, a hollow-spindle and a ring-twister, in one machine was studied[7]. These bouclé yarns were used to make knitted fabrics, in particular, single jersey and rib 1×1. Single and plied yarns of standard and high-bulk acrylic were used for the effect threads, while single nylon yarns for the core and the binder components. Factors studied were the direction of twist of the core thread and the effect thread, the overfeed ratio of the effect thread and its thickness. The bouclé yarns manufactured were measured in terms of the number of the effect profiles, per unit length, and the maximum height of the bouclé profile[7]. More recently, in a similar research, rib 2×1 and 2×2 knitted fabrics made from bouclé yarns were studied[8].

Study of the manufacturing process of multi-thread fancy yarns on hollow-spindle spinning machines was first reported by Alshukur and Fotheringham[9]. They studied the effect of false-twist on the structure, aesthetics and mechanical properties of overfed fancy yarns and gimp fancy yarns. They reported that the false-twist hooks of hollow-spindle spinning machines made multi-thread fancy yarns have highly corrugated or wavy structure. Moreover, this study advised fancy yarn spinners to always consider the use of false-twist hooks in order to improve the quality of multi-thread fancy yarns.

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Tensioning the core thread component plays an important role during manufacturing some types of fancy yarn by using drafted slivers or rovings, i.e. button yarns, on hollow spindle spinning machines. Otherwise, it may prove difficult to form the button fancy profiles over the fancy yarn surface. However, such a practice has not been studied when the same technology is used to produce multi-thread fancy yarns, such as bouclé yarns. Therefore, in this investigation, the effect of tension of the core thread on structure and quality of multi-thread bouclé yarns has been studied. This study is based on the fact that a tensioned core thread may not bend as easily as the effect thread(s) during the formation of the intermediate product within the hollow spindle. Therefore, controlling the level of tension of the core thread may result in the movement of the core thread as a straight line, spiral or balloon, corresponding to different levels of tension.

2 Materials and Methods

The Gemmill & Dunsmore 3 hollow-spindle spinning machine (UK) was used in this study and it was a six-spindle machine as demonstrated by Alshukur and Fotheringham[9]. In the present study, the core thread was an undyed cotton ply yarn having a resultant linear density 144tex/2, while the effect thread was a 120tex/2 lambs wool ply yarn. The binder was a 29.5tex open-end rotor-spun cotton yarn. Tension of the core thread was controlled via the tensioning rollers. The machine settings used to make all the multi-thread fancy yarns and their structural parameters are given in Table 1. The structural parameters, i.e. the number of wraps and the overfeeding ratio, were kept the same. The only variable during manufacturing was the level of tension of the core component. The nominal overfeed ratio (η %) and the real overfeed ratio (Δ%), as given in Table 1, were calculated using the following formulae:

$$\eta = (SS/DS) \times 100 \quad \ldots (1)$$

$$\Delta = [(SS-DS)/DS] \times 100 \quad \ldots (2)$$

where DS is the speed of delivery rollers, which controls the resultant fancy yarn; and SS and the speed of the supply rollers, which controls only the effect thread.

All fancy yarns made were first sampled as recommended in previously published papers[10,11]. The samples were preconditioned and then conditioned in accordance with the British Standard (BS EN ISO 139:2005). A subjective and objective assessments[10,11] were used to measure the effect thread profiles. The measurements included the number of fancy profiles (per m), the size (or area) of fancy profile (in mm^2), the circularity ratio of fancy profile (CR %) and the shape factor of fancy yarn (ShF). The circularity ratio of fancy profile is a measure of the roundness of the contour of the fancy profile when it is observed under a microscope[10]. It is calculated in this study as a relationship between central moments of the observed contour using image analysis software. The ShF is defined as the product of the average number of fancy profiles and the average size of fancy profile[10]. The quality of bouclé yarn improves when it has a high number of fancy profiles, which are more consistent in size. Extremely large fancy profiles were considered as defects of the structure because they are easily deformable; thus they do not hold any specific shape. They usually cause several problems in further processing and usage when the yarns are converted into fancy fabrics. Furthermore, the higher the value of the circularity ratio of fancy profile, the better is the quality of bouclé yarn. Moreover, generally speaking, higher values of the ShF indicate greater fancy bulkiness of fancy yarns, assuming that the yarn has a high number of fancy profiles. This is an advantage for fancy yarns, including bouclé yarns[10, 11]. Sixteen specimens were sampled from each fancy

Table 1—Machine settings and yarn structure for this study

Fancy yarn	Core thread tension, g	Machine settings			Fancy yarn structural parameters		
		Delivery speed (DS) m/min	Supply speed (SS) m/min	Rotation speed (RS), rpm	Number of wraps (W), wpm	Nominal overfeed ratio (η %)(SS/DS) × 100	Real overfeed ratio (Δ %) (SS-DS)/DS× 100
1	0						
2	5						
3	8	30	45	4500	150	150	50
4	17						
5	21						

yarn in order to measure the size of the profiles and their circularity ratio. The sampling pitch, that is the distance between sampled specimens, was 60 cm. The measurements were performed using the image analysis software AnalySIS FIVE developed by OLYMPUS Corporation. Ten measurements were sufficient to estimate the number of fancy profiles per metre for each of the fancy yarns.

3 Results and Discussion

The results of the testing procedures are given in Table 2. The average value and the standard deviation (SD) are studied for each property of the fancy yarns. With regard to the size of fancy profile, it is evident from Table 2 that the levels of tension, lower than 5 g (for the fancy yarns 1 and 2) creates smaller fancy profiles. The slightly larger fancy profiles for yarn 1 may be resulted due to the totally free movement of the effect thread without any crucial impediment by the zero-tension core thread. By increasing the tension, the fancy yarns start to develop bigger fancy profiles. There is also an increase observed in the variability of the size of fancy profile for the highest value of tension. It is found that the increase in the fancy profile size is less than 3 mm^2 when the tension is increased from approximately zero (for yarn 1) to 17 g (for yarn 4). When the tension is increased from 17g to 21 g, the average area of the profiles gets doubled from ~ 22 mm^2 to ~ 44 mm^2. It is thought that a core thread tension of 17 g is critical for the manufacturing process when considering the materials and the machine settings used. The quality of the fancy yarns deteriorates dramatically beyond the threshold tension of 17 g. The CV% (Table 2) for the size of fancy profile may indicate the trend of variability of this property. It is also found that the number of fancy projections per unit length decreases with the increase in tension (Table 2). The number of fancy profiles is decreased by 40% from 36.7/m to 22.2/m, when the tension of the core is increased from approximately zero to 21 g. Furthermore, Table 2 shows that the tension of the core thread has an impact on the circularity ratio of fancy profile. The circularity ratio decreases from ~ 64% to 35% with the increase in tension. Therefore, depending on the recommendations and definitions given by Alshukur[10,11], the fancy profiles of yarn 1 are bouclé, while those of yarns 2, 3 and 4 may be regarded as semi-bouclé. However, those of yarn 5 are not bouclé. Additionally, Table 2 shows the impact of the core thread tension on the fancy bulkiness of the fancy yarns. It is firstly important to note that the high ShF value for yarn 5 does not reflect the visual fancy bulkiness of the yarn. Instead, it results from defective and extremely large fancy projections, as indicated in the subjective assessment and demonstrated in Fig. 1. Therefore, the value of ShF of yarn 5 is discarded. For the other yarns,

Table 2—Results of testing procedures

Fancy yarn	Core thread tension, g	Fancy yarn quality parameters								
		Size of fancy profile			Circularity ratio		Number of fancy projections			ShF, mm^2/m
		Mean, mm^2	SD, mm^2	CV%	Mean, %	SD, %	Mean, m^{-1}	SD, m^{-1}	CV %	
1	0	19.47	7.95	40.85	64	0.12	36.70	2.75	7.50	714.45
2	5	17.69	6.17	34.85	47	0.13	35.50	3.98	11.21	627.98
3	8	24.46	11.23	45.90	48	0.19	25.20	4.34	17.23	616.47
4	17	22.27	6.24	28.02	49	0.15	26.60	3.27	12.30	592.38
5	21	44.26	30.52	68.96	35	0.23	22.20	2.90	13.05	982.61

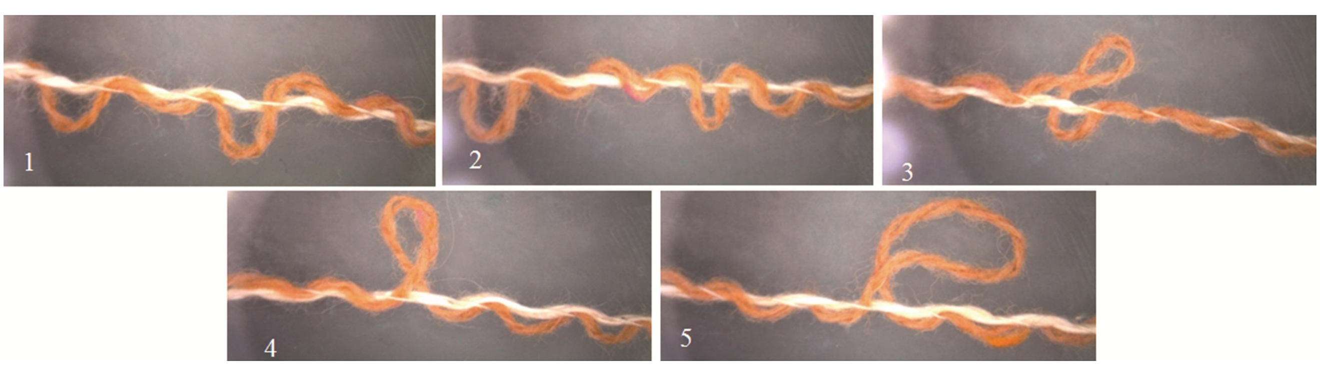

Fig. 1—Images of the fancy yarns 1-5

the ShF has a negative relationship with the core thread tension. When the tension is approximately zero, the ShF of the yarn is about 700 mm^2/dm. With the increase in tension up to 17 g, the ShF decreases.

Statistically, the differences among the fancy yarns related to the number of fancy profiles, the size of fancy profile and the circularity ratio of fancy profile, are all analysed using the ANOVA testing. The p-values of these tests are found to be 0.000, i.e. the probability of having these differences by chance is approximately zero. It is also found that the relationship between the number of fancy profiles and tension is linear and the regression formula is:

$$\text{Number of fancy profiles} = 35.9 - 0.648 \times \text{core tension} \quad \ldots (3)$$

where the fancy profiles are counted per metre and tension is measured in gram.

The statistical study of this regression model is given in Table 3. The values of the R^2 indicates that 74.9% of the variation in the number of fancy profiles (the dependent variable) is explained by the variation in the core tension (the independent variable). The SE (standard error) =3.74 projection per meter is small. The results of t-test (Table 3) indicate that the core tension is a significant factor at any significance level α>0.058, e.g. 0.06. Further, since the p-value of the ANOVA testing is significant at a significance level α=0.06, it is concluded that the core tension is also a key factor in explaining the variability of the number of fancy profiles.

3.1 Configuration of Core Thread within Spinning Zone

The configuration of the core thread within the first spinning zone is important for this study. The first spinning zone is located between the supply rollers and the in-let mouth of the spindle. This zone is studied using a Fujifilm Finepix HS20 EXR digital camera. With regard to fancy yarn 1, it is observed that all the fancy yarn components, including the core thread and the binder, has helical configuration. The helix is formed, because the core thread is fed to this zone in a slack motion which allows it to balloon and to form the helical configuration. Furthermore, the core thread is subjected to the pressure from the binder and, as a result, it bends easily. The core thread of fancy yarn 2 has also a spiral configuration which is similar to that of the binder and the effect thread (in its spiral sections). However, the core threads of yarns 3, 4 and 5 are moving in a straight path due to the high levels of tension.

3.2 Subjective Assessment

The subjective assessment is supported by the images of short sections of the five fancy yarns (Fig.1). This figure clearly illustrates that these fancy yarns are different from each other in appearance and morphology. The fancy yarn 1 is a multi-thread bouclé yarn. This fancy yarn appears to have regular structure compared to the rest. The fancy projections are relatively evenly distributed over this yarn surface and are separated with wide sigmoidal or spiral sections. The fancy projections are normal bouclé projections. A minority of the bouclé profiles is forced to locate spirally sideway over a turn or half a turn of the binder wraps. The fancy yarn 2 also demonstrates regular structure by having relatively evenly distributed fancy profiles. Some fancy projections are circular, arcs or waves. The sigmoid and spiral sections are fewer in comparison to the bouclé sections or corrugations of the same fancy yarn. Some of the fancy projections are closed; others are located sideways over the yarn surface, because they are forced to spiral by one or half a turn of the binder wraps. Table 2 demonstrates that the number of fancy projections on both fancy yarns 1 and 2 appears to be similar. It is believed that fancy yarn 2 is also a multi-thread bouclé yarn.

Regarding fancy yarn 3, the fancy projections are larger and the variation in the size is also higher, as compared to fancy yarns 1 and 2. Besides bouclé projections, there are other types of fancy profile which appear on fancy yarn 3. These range from corrugations; waves; diagonal bouclé projections (as a result of unequal length of the legs of the fancy projection); closed, elongated fancy projections; and some circular projections. The sections between the fancy profiles are narrow spirals. The regularity of the distribution of the fancy projections between the spiral sections is lower compared to the fancy yarns 1 and 2; it may be caused by the high variation in the size of profiles. The increased size of fancy projections for the fancy yarn 3 results in a dramatic

Table 3— Regression model of the number of bouclé profiles

Predictor	Coefficient	t-test	p-value of t-test	SE	R^2	ANOVA test	
						F	p-value
Constant of the model	35.854	12.93	0.001	3.74	74.9%		
Core tension	-0.6484	-2.99	0.058			8.96	0.058

reduction in the number of the fancy projections per unit length. Approximately 30% less projections are formed on fancy yarn 3 in comparison to that of yarn 2. It is also observed that the number of fancy projections is lower compared to fancy yarns 1 and 2. No specific commercial name of fancy yarn is capable of describing the fancy yarn 3. However, it is possible to define it as an overfed multi-thread fancy yarn.

Regarding yarn 4, the number of fancy projections appear to be similar to that of yarn 3 and lower than that of yarns 1 and 2. The fancy projections are a combination of bouclé, loops, diagonal bouclé, elongated closed projections, arcs, etc. All of them are separated by the spiral and sigmoidal sections. Some fancy projections are clustered in pairs at the same location along the axis of yarn 4. This yarn was designated as a multi-thread overfed fancy yarn.

Finally, yarn 5 has spiral sections separated by elongated fancy projections. The majority of these fancy profiles is much larger compared to other four yarns; however, the remaining fancy profiles of yarn 5 are small. As a result, the variability of the size of fancy profile is rather high. Some of the extremely large, closed fancy profiles are projecting crosswise; but the others are flexed, collapsed, laid over the yarn surface or rolled around the yarn surface. The distribution of the fancy projections along the yarn length is irregular. Due to the extremely large fancy profiles, the usage of the ShF to describe the fancy bulkiness of this fancy yarn is inappropriate. It is recommended not to manufacture such a yarn for commercial applications.

3.3 Impact of Core Tension as Observed

The impact of tension of the core thread is better understood by taking into account the configuration of the intermediate product, in particular its core component, within the first spinning zone. In general, the effect component assumes a helical path around the core thread, while manufacturing, due to the false-twist hook that is attached to the out-let mouth of the spindle. A sufficiently tensioned core thread becomes the straight axis of the helix. The centrifugal force, resulting from the rotational motion of the hollow spindle, among other factors, makes the helix of the effect thread relatively wide. As the effect thread helix becomes wider than needed, the resultant fancy projections may become extremely large. Additionally, a fewer fancy projections per unit length may appear. The sigmoidal sections may also become extremely narrow. In other words, the quality of the final yarn may become poor, which renders the fancy yarn losing its required fancy appearance. However, if the core thread is left to rotate free of tension, when it enters the first spinning zone, the situation may change; the quality of the resulting fancy yarn may improve. The rotating core thread is expected to form a balloon in the first spinning zone. In some special cases, two balloons are formed in this zone. When the core thread balloons in this zone, it becomes closer to the spiralling effect thread in each of its successive length-wise sections. When the binder fixes the core and the effect threads together the chance of forming extra fancy projections increases, along with the chance of forming arcs, waves, corrugations, or spiral sections. Furthermore, the height of the fancy projection becomes smaller. Consequently, the ultimate fancy yarn may have smaller fancy projections of similar sizes, more fancy projections and more waves and arcs, compared with the case of a tensioned, straight core thread. This means that the structure and quality of multi-thread fancy yarns can be improved without changing the number of wraps or the overfeed ratio. In some special cases it is possible to make a bouclé fancy yarn although using a relatively low overfeed ratio, e.g. fancy yarns 1 and 2. Controlling the level of tension of the core thread is possible via tensioning rollers used. Usually, the core thread is nipped by the rotating tensioning rollers which control its movement. A slightly extra rotational speed of those rollers than the delivery rollers suffices to pull the core thread forward to the first spinning zone free of tension. A minimum level of tension of the core thread may be considered to make the core thread balloons.

By discarding yarn 5 for the reasons stated above, it is confirmed that advantages of the fancy yarn 1 over the other yarns are as follows. Yarn 1 has the highest number of bouclé projections, which are larger than those of yarn 2. The size of bouclé profile of yarn 1 is 19.47 mm^2, which is suitable to the yarn thickness. Fancy yarn 1 has also the highest value of the ShF, i.e. 714.45 mm^2/m. This value makes yarn 1 as the fancy yarn, which has the highest fancy bulkiness. Additionally, yarn 1 has the highest value of the CR (64%). As a result, yarn 1 is regarded as the best-quality bouclé fancy yarn. The second bouclé yarn also has good quality, but with lower values of ShF (624.98 mm^2/m) and CR (47%) than the first bouclé yarn. The quality of the fancy yarns deteriorates severely when yarn 5 is made using the highest level of tension. Such detailed modifications in the structure and quality are assessed firstly statistically, and proved to be significant, then visually via a subjective method. The ability to make a bouclé yarn using only 50% extra overfeed of the effect thread means a considerable reduction in the costs, while increasing the profit margins. The impact upon the industry and nature is the ability to minimise the usage of resources. The experimental approach of this study is the first step to characterise the effect of tension of the core thread on multi-thread fancy yarns. Further studies may follow in the future to define these findings analytically.

4 Conclusion

The tension of the core thread of multi-thread bouclé fancy yarns, while manufacturing on hollow-spindle spinning machines and other hollow-spindle fancy twisters, plays an important role in shaping and controlling the structure and quality of the bouclé yarns. Low level of tension is beneficial for the structure and quality of bouclé yarns since it regulates the style of such fancy yarns. Low tension of the core thread (i) gives rise to the number of bouclé profiles along the length of the ultimate bouclé yarn; (ii) reduces the variability of the size of bouclé profiles, resulting in consistent and relatively smaller bouclé profiles; (iii) increases the circularity ratio of fancy profile and the shape factor of fancy yarn; and (iv) promotes regular spiral and sigmoidal sections and wavy corrugations between the fancy profiles. By reducing the tension of the core to its minimum level it is possible to manufacture bouclé yarns using only 50% extra supply of one effect thread (yarn 1) rather than two effect threads. This implies that the cost of production can be reduced, based on minimising the usage of the input material, in particular, the relatively expensive effect thread.

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