Alok Kumar, Niranjan Bhowmick, Subrata Ghosh
Dr. B. R. Ambedkar, National Institute of Technology, Department of Textile Technology, Jalandhar-144011, Punjab, India

Characterisation of Fibre Lengths and Breakage Behaviour of Cotton Fly in Knitting Process

Opredelitev dolžine in oblike pretrgov bombažnih letečih vlaken pri pletenju

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Abstract
In this research work, the fibre fly from different zones in the knitting process, such as the cone unwinding, guide and the knitting zones, were collected and characterised. The results show that in the cone unwinding zone were formed 18% of shortest (i.e. ≤1 mm), 40% of shorter (i.e. 2–6 mm), 32% of short (i.e. 7–11 mm) and 10% of long (i.e. ≥12 mm) fibres, followed by shortest (14%), shorter (38%), short (30%) and long (18%) in the guide zone, and shortest (30%), shorter (36%), short (28%) and long (6%) in the knitting zone. The surface characteristics and breakage behaviour of fibre fly collected from three different zones were studied using a scanning electronic microscope. The majority of fibre fly are highly twisted, with kink bands with longitudinal and transverse cracks, and twist break in the form of ductile, granular and individual fibril break due to torsional fatigue under high tensile stress in the cone unwinding zone. The majority of fibre fly are found in twisted form with a flat surface, are bent with kink bands, surface peeling, a long axial crack and twist break, and either fibril failure or independent fibril failure due to the combination of flex and torsional fatigue under tensile stress in the guide zone. Surface peeling, bent along with the kink bands, and twist break, either with two and multiple splits or granular and ductile form, were observed in the fly of the knitting zone due to the combined effect of torsional, flex and abrasion fatigue under tensile stress.
Keywords: fibre fly, unwinding zone, guide zone, knitting zone, weft knitting, cotton

Izvleček
V tej raziskavi so bila v različnih območjih pletenja, tj. v območju odvijanja preje z navitka, v območju dovajanja preje in v območju zapletanja, zbrana in analizirana leteča bombažna vlakna. Rezultati so pokazali, da je v coni odvijanja preje z navitka nastalo 18 % najkrajših vlaken, dolgih ≤1 mm, 40 % krajših (2–6 mm), 32 % kratkih (7–11 mm) in 10 % dolgih (≥12 mm) vlaken. V coni dovajanja preje je nastalo 14 % najkrajših, 38 % krajših, 30 % kratkih in 18 % dolgih vlaken, v coni zapletanja pa je nastalo 30 % najkrajših vlaken, 36 % krajših, 28 % kratkih in 6 % dolgih vlaken. Lastnosti površine in pretrgov zbranih letečih vlaken so bile proučene s pomočjo rastrskega elektronskega mikroskopa. Pokazalo se je, da je bila večina letečih vlaken visoko vita, imela so lokalne prečne zdrse v strukturi, vzdolžne in prečne razpoke, pretrge v obliki duktilnih, zrnatih in fibrilnih poškodb, kar je bilo posledica torzijskih obremenitev in visokih nateznih napetosti pri odvijanju preje. Večina letečih vlaken je imela poškodbe, od zasukov, zravnih površin, ukrivljenosti, lokalnih zdrsov, površinskega pilinga, do dolgih aksialnih razpok in torzijskih pretrgov, kjer so zaradi kombinacije upogibnega in torzijskega utrujanja ter nateznih obremenitev v coni dovajanja preje nastali pretrgi fibrilov ali neodvisni pretrgi fibrilov. V območju zapletanja so nastala leteča vlakna s poškodbami v obliki pilinga površine, upogibov in zdrsov strukture, pretrgov zaradi vitja z dvema ali več razcepi, zrnatih in duktilnih pretrgov kot posledica kombiniranega učinka torzijske, upogibne in natezne napetosti vlaken.
Ključne besede: tvorba puhka, poškodbe vlaken, pretrg vlaken

Corresponding author/*Korespondenčni avtor:*
Alok Kumar, Assitant Professor
E-mail: akv.nit@gmail.com

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1 Introduction

Fibre fly liberation from cotton spun yarn is a common phenomenon in weft knitting. Cotton spun yarn has inherent characteristics of yarn hairiness that comprises fibre ends and loops protruding from the yarn surface. Many of these fibres are either fractured or pulled out from the surface of the yarn and deposited in and around the different zones of a knitting machine, i.e. the cone unwinding, guide and knitting zones, during the knitting process. These deposited fibres are either picked up by the incoming yarn, break yarn/needles or deteriorate the fabric appearance. The generation of fibre fly reduces machine efficiency by 5–15%, while fabric faults increase by 15–25% and fabric weight decreases by 0.5–1.0 % [1–3]. Apart from these specific problems, at high concentrations, suspended particulate matter of cotton dust and fibre fly pollute the indoor atmosphere, which poses health hazards to staff, particularly those susceptible to respiratory illness [4, 5]. In this respect, many researchers have studied the length distribution of fly in a particular zone of a knitting machine with the aim of predicting the possible mechanism of fly generation during the knitting process.

Researchers [2, 6–11] have studied in detail the length distribution of fibre fly collected in different sectors, i.e. the cone unwinding zone, guide zone and knitting zone of a circular weft knitting machine. They reported that most fibre fly of less than 10 mm in length is found in the cone unwinding zone and knitting zone, while fibre fly of more than 10 mm in length is found at the top stop-motion and the positive feed device.

However, one researcher [6, 7, 12] observed that edge fibres are highly abraded where the fineness of the fibre fly is much less than that of virgin fibres. They also reported that fibre fly may be released in different zones of a knitting machine due to the fracturing of previously damaged protruded fibre or the pulling out of protruded fibre from the yarn surface. The mechanism of pulling and fracturing the protruded fibre of yarn may be different for each zone of a knitting machine. To date, however, no one has studied in detail the breakage behaviour of fibre fly in specific zones of a knitting machine. This study thus aimed to classify the fibre length of the fly with percentages in the specific zones of a knitting machine and to characterise the nature of fibre break in the three different zones of a knitting machine.

2 Materials and methods

2.1 Materials

To observe the length distribution, surface characteristics and breakage behaviour of fibre fly, 100% J-34 cotton was used to prepare combed ring spun yarn (Table 1). The unwaxed yarn samples (cones) were processed in a laboratory knitting machine (Table 1). The different sectors of the knitting machine were separated by plastic sheets to segregate the fibre fly liberated in these zones. This fibre fly was collected separately via air suction, using a vacuum cleaner and by changing the filter media.

Table 1: Materials and process properties and parameters

Material/ process	Properties/parameters
Fibres	Raw material: J-34 cotton Mean length = 19 mm *CV* of length = 50.9% Micronaire = 3.4
Yarn	Linear density = 30 tex
Knitting machine	Harry Lucas single feeder circular knitting machine (5919 CK) Machine gauge = 14 x 2,54 cm Yarn feed rate = 112 m/min Yarn input tension = 5 cN Fabric take-up load = 308 g
Atmosphere	Humidity = 65±2% Temperature = 25± 2 °C

2.2 Testing methods

Length distribution of fibre fly

To determine the length distribution of cotton fibre fly, a sample of fibre fly was pasted on a slide with the help of seed oil. Ten slides were prepared from each individual zone in the same way. A random selection method was used to select collected fibre fly for spreading on a slide. The prepared slide was placed on millimetre graph paper. The length of fibre was then observed manually using a pick glass as shown in Figure 1.

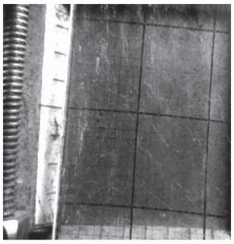


Figure 1: Measurement view of fibre fly on millimetre graph paper under a pick glass

The lengths of fibre fly were classified to four groups of lengths: shortest (≤1 mm), shorter (2–6 mm), short (7–11 mm) and long (12 mm and above) as shown in Table 2. The shortest lengths of fibres were used according to the reference [3, 4, 10] because the fibres may be inhaled by staff in the knitting process, while other fibres were classified as researchers reported in their work [10].

To measure the length distribution of fibre fly randomly, 100 fibres were selected from each of the three zones of the knitting machine.

Table 2: Classification of lengths of fibre fly in different zones

Classes of fibre fly	Length [mm]
Shortest	≤1
Shorter	2–6
Short	7–11
Long	≥12

Surface characteristics and nature of breaks of fibre fly

To study fibre fly morphology and the nature of breaks, a small amount of fibre fly was selected randomly from the collected fibre fly for all three zones. A JSM 6510 LV scanning electron microscope (SEM) was used to view the microscopic details of fibre fly. The test samples coated with gold were fixed on a flat sample holder with the help of an adhesive.

3 Results and discussions

Cone unwinding zone

The fibre fly length distribution of the cone unwinding zone is given in Figure 2. It shows the classes of

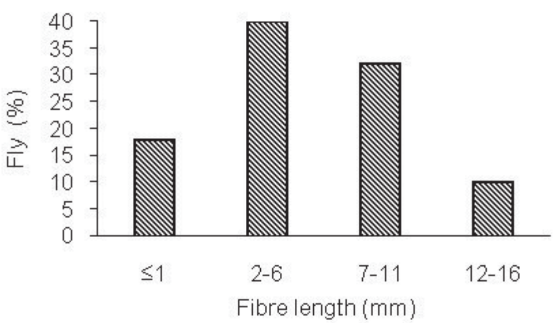


Figure 1: Length distribution of fibre fly in the cone unwinding zone

fibre length with respect to fibre fly percentages in the cone unwinding zone of the knitting machine.

It is evident from the figure that the shortest classes of fibre lengths are 18%, shorter (40%), short (32%) and long (10%) in the cone unwinding zone. It is clear from the figure that 90% of fly had a fibre length of less than 11 mm. Fibres of these lengths may be released as fly due to the fracturing of entangled fibre [7] because the length of the fly is much less than the average length of the fibre. A total of 10% of fly had a fibre length in the range of 12–16 mm. Long, protruded fibre may be pulled out from the yarn structure due to loose gripping in the yarn structure during cone unwinding. This is in line with reported work [7, 10] in which it was observed that 90% of fly with a length of less than 10 mm is generated due to the fracturing of the surface fibre of cotton yarn during the unwinding of the cone package. Long, but loosely held fibre in the yarn structure is pulled out during cone unwinding. Furthermore, the surface of the broken fibre and the breakage pattern of fly collected from the cone unwinding zone were observed using a scanning electron microscope (SEM), and are shown in Figures 3a–3e. The results show that the surface of fibres are highly twisted (Figure 3a), have kink bands with longitudinal and transverse cracks (Figure 3b), twist break in ductile form (Figure 3c), twist break with individual fibril breaks (Figure 3d) and twist break in granular form (Figure 3e).

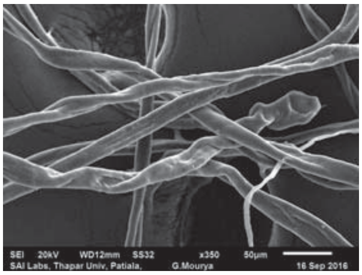
The majority of fly have a highly twisted form, with kink bands with longitudinal and transverse cracks, and twist break in ductile, granular and individual fibril break in the cone unwinding zone. These protruded fibres may be subjected to torsional fatigue under a certain level of tensile stress during cone unwinding. A similar fracture pattern was observed by researchers [3, 5, 11, 16] on cotton fibre and other fibres under torsional fatigue. They reported that microcracks appear on the surface of fibres under axial stretching and propagate either axially or transversely, ultimately resulting in fibre failure under tensile stress.

Guide zone

The fibre length distribution of fly released in the guide zone of the knitting machine is shown in Figure 4.

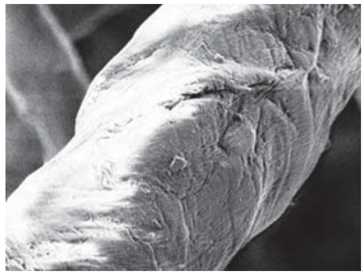
It is evident from the bar graph that the fly percentages of the shortest, shorter, short and longest length

a)



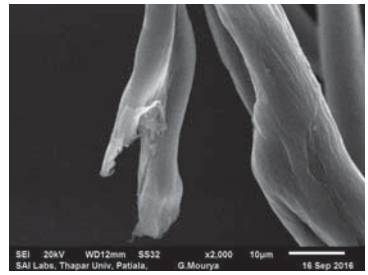
Highly twisted fibre (magnification 350-x; 50 μm)

b)



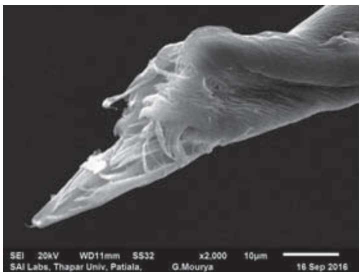
Kink bands with longitudinal and transverse cracks (magnification 10,000-x; 10 μm)

c)



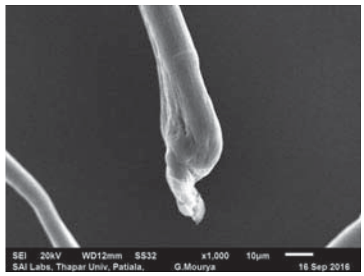
Twist beak in ductile form (magnification 2,000-x; 10 μm)

d)



Twist break with fibril breaks individually (magnification 350-x; 50 μm)

e)



Twist break in granular form (magnification 1,000-x; 10 μm)

Figure 3: Scanning electron microscopic views of fibre fly in the cone unwinding zone

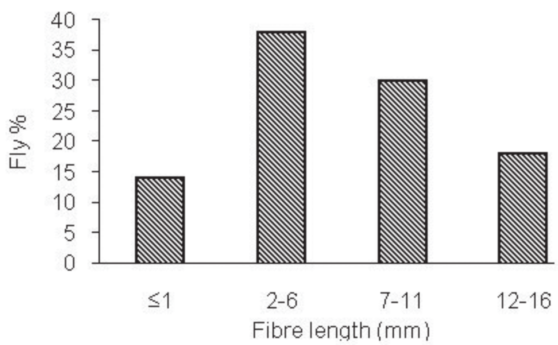
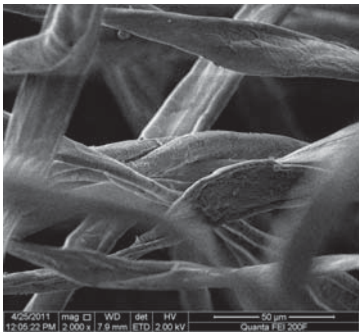


Figure 4: Length distribution of fibre fly in the guide zone

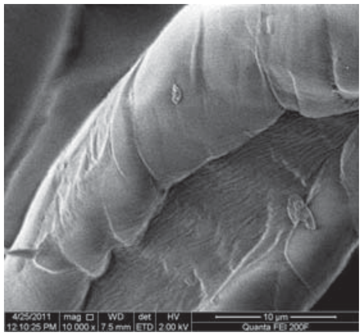
in the guide zone are 14%, 38%, 30% and 18% respectively. A total of 82 % fly have a fibre length of less than 11 mm. It can be said that these three classes of length may be released as fly due to the fracturing of protruded fibre from the yarn surface. The protruded fibre may be subject to strong frictional resistance by the yarn surface and guide surface against the rotational speed of the yarn. In this zone, fly with a length of 12–16 mm is generated due to the detachment of a few, loosely held long protruded fibres, either over the twisting of protruded fibre or the twist loss of yarn at the rotational speed of the yarn [10, 11]. The surface of the broken fibres and the breakage pattern of the fly were observed under a scanning electron microscope (SEM), as shown in Figure 5a–5j. The results show that the surface of the fibre is twisted with a flat surface (Figure 5a), twisted and bent with kink bands (Figure 5b), a running axial crack with kink bands and surface peeling (Figure 5c), twisted with a transverse cut and surface peeling near bent kink bands (Figure 5d), an independent fibril break at the neck of twisting (Figure 5e), an independent fibril failure at the neck of twisting (Figure 5f), a twist break (Figure 5g), a twist break at the neck of twisting (Figure 5h), a twist break with multiple splits and a twist break (Figure 5i); and a twist break with two splits (Figure 5j). The majority of fibres are in twisted form, with a flat surface bent with kink bands, surface peeling, a long axial crack and a twist break from either fibril failure or independent fibril failure. These fibre fly may be generated due to the combination of torsional and flex fatigue under tensile stress in the guide zone. Similar types of failure of cotton fibre and other fibres under flex and torsional fatigue with tensile stress were observed by researchers [13–16].

a)



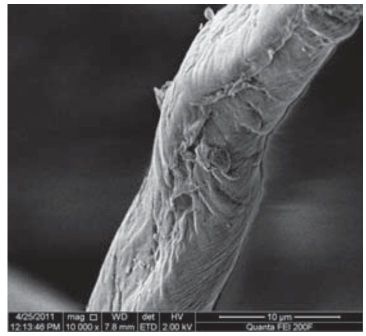
Twisted with flat surface (magnification 2,000-x; 50µ)

b)



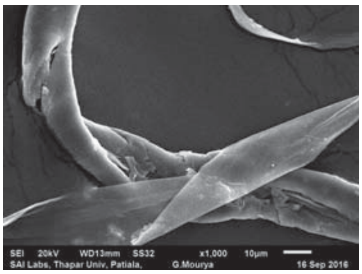
Twisted and bent with kink bands (magnification 5,000-x; 20µ)

c)



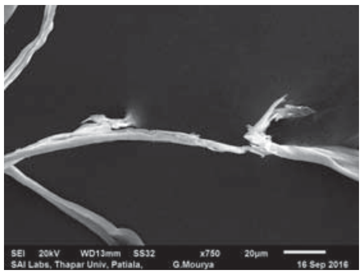
Running axial crack with kink bands and surface peeling (magnification 1,000-x; 10µ)

d)



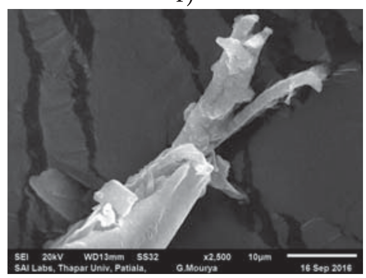
Twisting with transverse cut, surface peeling near kink bands and bent (magnification 1,000-x; 10µ)

e)



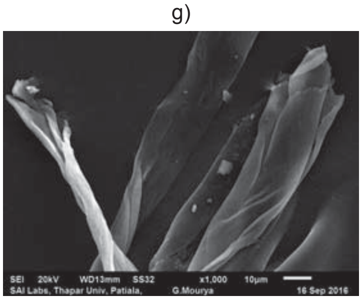
Independent fibril break at the neck of twisting (magnification 750-x; 20µ)

f)



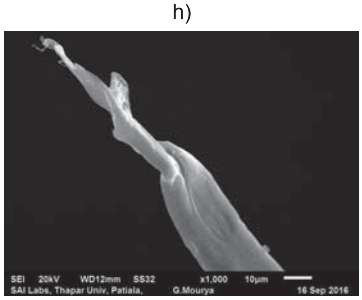
Independent fibril at the neck of twisting (magnification 2,500-x; 10µ)

g)



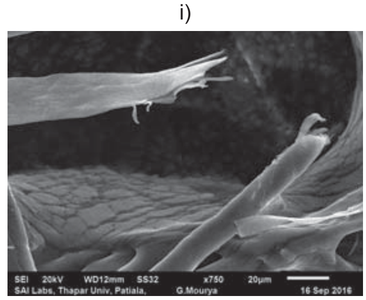
Twist break (magnification 1,000-x; 10µ

h)



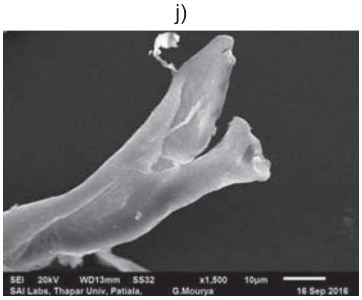
Twist break at the neck of twisting (magnification 1,000-x; 10µ)

i)



Twist break with multiple splits and twist break (magnification 750-x; 20µ)

j)



Twist break with two splits (magnification 1,500-x; 10µ)

Figure 5: Scanning electron microscopic views of fibre fly in the guide zone

Knitting zone

Figure 6 shows the distribution of fibre lengths released as fly in the knitting zone of the knitting machine. It was observed that the fly length of the shortest, shorter, short and long fly was 30%, 36%, 28% and 6% respectively in the knitting zone. A total of 94 % of fly have a fibre length of less than 11 mm. It was noted here, as well, that fibre lengths of less than 11 mm may be released as fly due to the fracture of protruded fibre from the yarn surface.

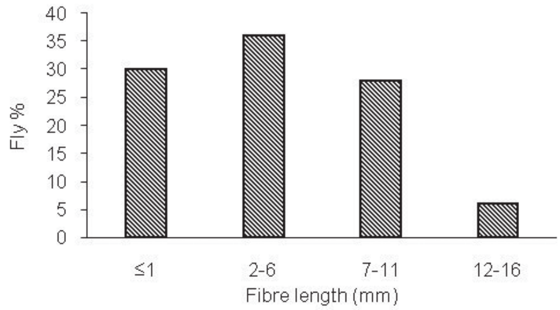
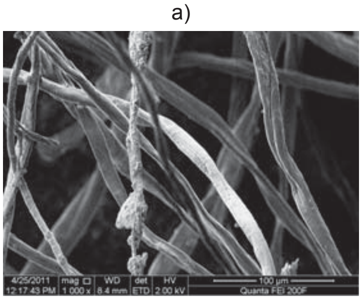


Figure 6: Length distribution of fibre fly in the knitting zone

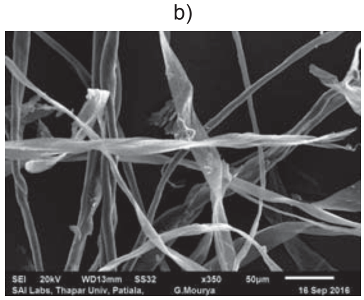
Protruded fibres may be subject to strong frictional resistance to the rotational speed of the yarn surface itself, the surface of needles, sinkers and the surface of old loop yarn during the formation of new loops [10]. It was also observed that only 6% of fly are more than 12 mm in length, which is the shortest length of all three zones. A length of fly may be released due to the momentary twist loss of yarn during the bending and unbending of yarn in the knitting zone [10, 11]. Fibre fly in the knitting zone was examined under a scanning electron microscope, as shown in Figures 7–8. Figure 7a shows a twisted form with surface peeling; Figure 7b shows a twist break with two splits; Figure 7c shows twisted and bent kink bands with an independent fibril break; Figure 7d shows a twist break with a fibril break, Figure 7e shows a twist break with multiple splits; Figure 7f shows a twist break with two splits; Figure 8a shows a twist break in granular form with surface peeling; Figure 8b shows a twist break with two splits and surface peeling; Figure 8c shows a twisted form with a fibril break, Figure 8d shows a twist break with independent fibril tearing; Figure 8e

a)



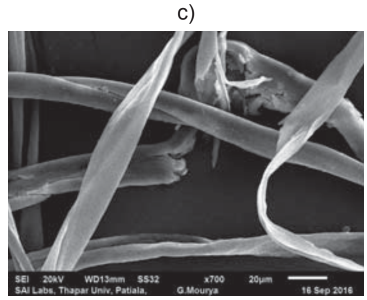
Twisted form with surface peeling (magnification 1,000-x; 100μm)

b)



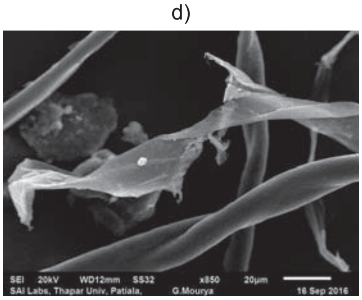
Twist break with two splits (magnification 350-x; 50μm)

c)



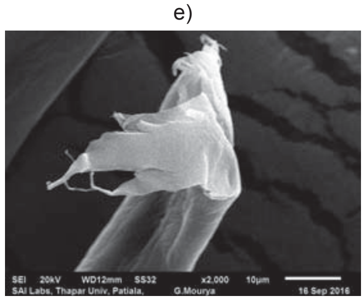
Twisted form and bent kink bends with an independent fibril break (magnification 700-x; 20μm)

d)



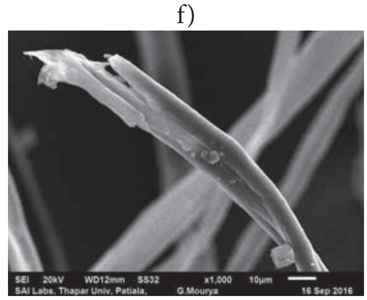
Twist break with fibril break (magnification 850-x; 20μm)

e)



Twist break with multiple splits (magnification 2,000-x; 10μm)

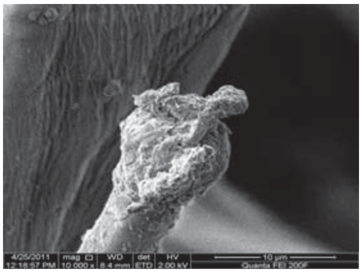
f)



Twist break with two splits (magnification 1,000-x; 10μm)

Figure 7: Scanning electron microscopic views of fibre fly in the knitting zone

a)

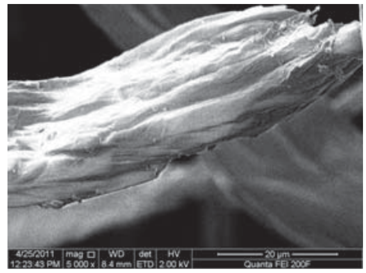


Twist break in granular form with surface peeling (magnification 8,000-x; 10μm)

b)

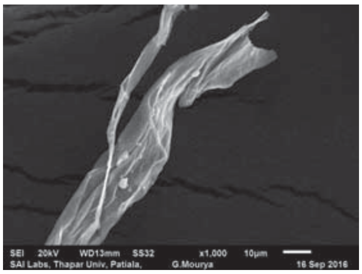
Twist break with two splits and surface peeling (magnification 5,000-x; 20μm)

c)



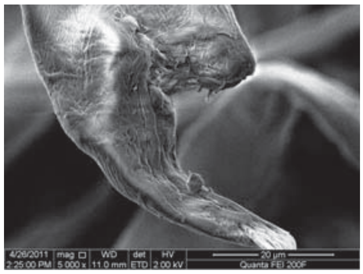
Twist break with fibril break (magnification 4,000-x; 30μm)

d)



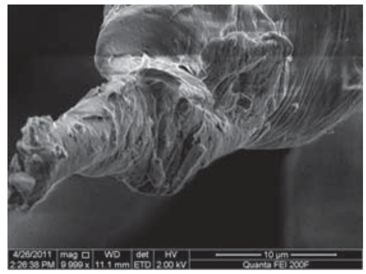
Twist break with independent fibril tearing (magnification 1,000-x; 10μm)

e)



Twist break in ductile form (magnification 5,000-x; 20μm)

f)



Twist break in granular form (magnification 4,000-x; 30μm)

Figure 8: Scanning electron microscopic views of fibre fly in the knitting zone

shows a twist break in ductile form; and Figure 8f shows a twist break at the neck of twisting. Surface peeling, bent along with kink bands, and a twist break with either two or multiple splits of granular and ductile form were observed. These types of deformations prior to the failure of the cotton fibre may be due to the combination of flex, torsional and abrasion fatigue under tensile stress in the knitting zone. Similar types of deformations were observed in the flex, torsional and abrasion fatigue of cotton fibre under certain conditions [13–16].

4 Conclusion

Between 82 and 94% of liberated fibre fly are less than 11 mm in length. This behaviour was observed for all the three zones where the fly was collected. The longest fibre length was observed in the guide zone (where 18% of fly was longer than 11 mm in length) due to the momentary twist loss of yarn. The surface of the broken fibre and the breakage pattern of fibre fly collected in the unwinding zone were highly twisted, with kink bands with longitudinal and transverse cracks, a twist break in the form of a ductile, granular or individual fibril break due to torsional fatigue under tensile stress in the cone unwinding zone. The fly in the guide zone was in twisted form, with a flat surface, bent with kink bands, surface peeling, a long axial crack and a twist break from either fibril failure or independent fibril failure due to the combination of flex and torsional fatigue under tensile stress. Surface peeling, bent along with kink bands, a twist break with either two and multiple splits of granular or ductile form were observed in the fly in the knitting zone due to the combined effect of torsional, flex and abrasion fatigue under tensile stress.

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