Predicting the nep number in cotton yarn - determination of the critical nep size

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ABSTRACT

One of the most important cotton yarn quality problem is its neppiness. The yarn nep source are neps and trash contained in raw material taken for production. Nevertheless, not all of them are transferred into the yarn and are the reason of yarn faults. During the technological process in the spinning mill there takes a place the cleaning of raw material. Moreover, among these neps and trash, which stayed in the fiber stream feeding directly the spinning frame, not all of them create a source of yarn neps. Neps and trash of a small size, below a critical value are not identified and registered by Uster Tester as yarn faults. Determination of the critical nep size is very important for predicting the nep number per 1000 m of cotton yarn. In the frame of this work the theoretical models on critical nep size in the function of the yarn linear density were derived. They allow calculating the critical nep size for cotton ring and OE yarns. The obtained experimentally results confirmed the theoretical models. Moreover, basing on the performed investigations it was found that the average density of neps of size bigger than the critical one is a variable and decreases with the increase of the yarn linear density.

Introduction

One of the most important problems of cotton yarn quality is neppiness. A nep is defined as a "point cluster of fibers introduced into the yarn causing the increase of its diameter" [Polish Standard PN-76/P-06742(1976)]. Neps create yarn faults, as seen by the human eye, and too many of these, negatively influence the aesthetic value of textiles, i.e. their smoothness and surface evenness.

The problem of yarn neppiness has been investigated by many researchers (El Mogahzy, 1997; Färber, 1996; Frydrych *et al.*, 2001; Frydrych, 1996; Furter and Frey, 1990; Hebert *et al.*, 1985; Lord, 1948; Peters, 1993. They were looking for reasons for nep creation during cotton processing, starting with cultivation and harvesting conditions, through spinning technologies, and finally finishing of the dyed fabrics and knitted goods. They found that yarn nep sources are neps and seed coat fragments contained in ginned lint taken for production. Nevertheless, not all of these neps are transferred into the yarn and are the cause of yarn faults.

Cleaning of raw material takes place during technological processes in the spinning mill. As a result, neps and trash in cotton diminish (sometimes even up to 90%). Moreover, among the neps and trash that remain after intensive cleaning of the fiber stream, directly feeding the spinning frame, not all of these create neps in the yarn. Small neps and trash, below a given critical value, are not identified and registered as yarn neps, because they are covered by fibers forming the yarn or lie below the sensitivity limit of the measurement device.

The aim of this work is to determine the critical nep size, i.e. above which the faults on the surface of a yarn of a given linear density occur. The knowledge of critical nep size is important from the point of view of predicting the nep number in a yarn on the basis of nep content in raw material (ginned lint) and intermediate (sliver, roving) products measured on the AFIS system. We conducted this research in the framework of a project funded by the Polish State Committee for Scientific Research.

Theoretical

Critical nep size in a function of the yarn linear density

It is assumed that the neps in the yarn have a spherical shape (Figure 1).

For classic yarns, a nep is a short thick place with a mass exceeding 200% of the average yarn. Therefore:

$$\boxed{m_n > 2 \cdot m_y} \qquad (1)$$

where:
m_n – nep mass,
m_y – mass of the yarn segment of the length d_y.

The mass of the analyzed yarn segment of length d_y equal to the yarn diameter is:

$$\boxed{m_y = Tt_y \cdot d_y} \qquad (2)$$

where:
Tt_y – yarn linear density.

The nep mass is calculated as follows:

$$\boxed{m_n = V_n \cdot \rho_n} \qquad (3)$$

where:
V_n – nep volume,
r_n – average nep density.

Due to the assumption that a nep has a spherical shape, we can write:

$$\boxed{m_{ncrit} = \frac{4}{3}\pi\left(\frac{D_{ncrit}}{2}\right)^3 g_n = 2 \cdot Tt_y \cdot D_{ncrit}} \qquad (4)$$

where:
D_{ncrit} – critical nep size.

We then introduced the symbol:

$$A = \frac{\rho_n}{\rho_f} \quad (5)$$

where:
r_f – average cotton fiber density.

After transformation eq. (4) takes the following form:

$$\frac{1}{6}\pi \cdot D_{ncrit}^2 \cdot A \cdot \rho_f = 2 \cdot Tt_y \quad (6)$$

Assuming that the average density of a cotton fiber is 1540 kg/m^3 (Zurek, 1975), after the transformation the relationship of the critical nep size can be presented as:

$$D_{ncrit}[mm] = 0.0498\sqrt{\frac{1}{A}} \cdot \sqrt{Tt_y} \quad (7)$$

Introducing the next symbol

$$B = 0.0498\sqrt{\frac{1}{A}} \quad (8)$$

We obtain the equation for the critical size of a nep in the classic yarn, expressed by the following formula:

$$D_{ncrit}[mm] = B \cdot \sqrt{Tt_y} \quad (9)$$

In the case of OE yarn, for which neps are measured with ± 280% limit, it follows that:

$$m_n > 2.8m_{yOE} \quad (10)$$

where:
m_{yOE} – mass of OE yarn segment of length d_y.

Following the derivation for the classic yarn, we obtain the following equation on the critical nep size for OE yarn:

$$D_{ncritOE}[mm] = 0.0589\sqrt{\frac{1}{A_{OE}}} \cdot \sqrt{Tt_{yOE}} \quad (11)$$

where:
Tt_{yOE} – linear density of OE yarn

After introducting:

$$B_{OE} = 0.0589\sqrt{\frac{1}{A_{OE}}} \quad (12)$$

where:
A_{OE} is a parameter describing the ratio of the average density of neps of a size above the critical one for OE yarn of a given linear density and cotton fiber density,

$$D_{ncritOE}[mm] = B_{OE} \cdot \sqrt{Tt_{yOE}} \quad (13)$$

Parameters A, B, A_{OE}, and B_{OE} can be found empirically.

Determining parameters of the model of critical nep size

In the previous section, the derived parameter A is a ratio of the average nep density and cotton fiber density, but the average nep density has not yet been determined. It varies due to very different nep structures in cotton. Neps of mechanical origin consisting only of tangled fibers are characterized by different densities than seed coat neps. Moreover, the tightness of fiber knots in neps is not the same. The average nep density depends on the degree of cotton processing. The size and structure of neps in cotton limit differ from the size and structure of neps in the particular intermediate products. In ginned cotton, seed coat neps represent about 12% of the total nep number. They are large, and their average size in raw material exceeds about 300-500 μm the average size of all neps in cotton.

During the spinning process, there is a decrease in the average size of all neps because large neps are removed more efficiently than small neps (Kluka *et al.*, 1998). The relation between the mean size of all neps and seed coat neps also changes. When predicting the number of neps in yarn, the average nep density in the fiber stream, from which the yarn is spun, is significant. Therefore, in the case of ring spun yarns, the number of neps in the roving which feeds the spinning frame was analyzed; whereas in the case of OE yarns in the fiber web taken from rotor was analyzed.

Ringspun yarns In order to determine the values of parameters A and B, the following were measured; randomly taken roving samples feeding the spindle of spinning frames, on which yarns of linear densities 20, 25, 30 and 50 tex were spun (10 specimens for each yarn lot), and ringspun yarn (carded) samples (of the linear densities mentioned above) produced from the tested roving on 10 different spindles of the same spinning frame. The roving was analysed (determination of neps and trash) on the AFIS system; whereas the yarns were analysed on the Uster® evenness tester. The cumulative curves for the number of neps and on total number of neps and trash in 1 gram of the roving were prepared on the basis of histograms obtained from the AFIS system. This was done by summing the neps and trash in descending order, ie., from the largest to the smallest. Figure 2 shows the graph with cumulative curves of neps as well as neps and trash together for roving feeding one spindle of the spinning frame. Identical graphs were prepared for the rest of the roving samples. In these figures, horizontal lines corresponding to the nep number per 1 gram of yarn produced from the given roving were drawn. We then calculated the nep number per yarn gram N_p according to the formula:

$$N_g = \frac{N_{1000}}{Tt_y} \qquad (14)$$

where:

N_{1000} –number of neps per 1000 m of yarn according to the Uster tester

Tt_y – linear density of yarn.

The value on the abscissa where the horizontal straight line interacts with the cumulative curves corresponds to the critical nep size. Following the described procedure, two values were determined for each sample:

D – corresponding to the critical nep size at the point of intersection of the cumulative curves of the sum of neps and trash

D_1 – corresponding to the critical nep size at the point with the intersection of the nep cumulative curve.

The values for 10 samples determined are presented in Table 1.

D best reflects the critical sizes of neps and trash in the roving, which are registered by the Uster tester as yarn neps. D_1 takes into account only the nep content; nevertheless, it may be more useful for predicting the number of neps in the yarn. Investigations have shown that nep size distributions are similar for the different rovings produced by the same system (carded and combed), which enables the theoretical function to be adapted to the empirical nep size distribution, and at the same time its derivative and survival function. Knowing the critical nep size for a given yarn linear density, it is possible to calculate the theoretical number of neps in the roving, the sizes of which are not above the critical value, and at the same time, to predict the number of neps per 1000 m of yarn. In this case, it is proposed to use D' as the critical nep size. Using the D value, which better reflects the real critical nep and trash sizes registered as yarn neps, for predicting the number of neps per 1000 yarnmetres, is difficult, because the theoretical distribution of trash particles in the roving is unknown. Investigations have shown that trash particle distribution in intermediate products (sliver, roving) is random and unpredictable. The difference between the determined values D and D_1 in the most cases is limited by the device's sensitivity limits, because the AFIS system classifies neps and trash according to size with a precision of up to 50 µm. Based on the empirically determined critical nep size for the particular yarn linear densities, the A and B values have been calculated using equations (8) and (9). It has been stated that A eq.(5) decreases with an increase in yarn linear density (Table 2). Because the average cotton fiber density is constant, it appears that with increasing yarn linear density, the average nep size changes. These are neps, of which the size is above the critical value for a given yarn linear density. Thus, in the further considerations, it has been assumed that A is dependent upon yarn linear density, and expresses the ratio of the average nep density of a size above the critical value for the given yarn linear density and cotton fiber density. On the basis of our experimental results, the following function has been selected:

$$A = 0.217 Tt_y^{-0.3266} \qquad (15)$$

which ascribes a value A to the appropriate yarn linear densities Tt_y. This is exhibited in Figure 3.

In a similar way a function characterizing the relationship between A_1 and yarn linear density was selected as follows:

$$A_1 = 0.2181 \cdot Tt_y^{-0.3021} \qquad (16)$$

Based on these functions, we calculated A and A_1 values, were calculated and found B and B_1 for cotton yarns with linear densities 15 to 20 tex (Table 3; Figure 4).

OE yarns Determining the OE yarn critical nep size is more complicated. and the distribution of the nep size (histograms) obtained from the AFIS system for slivers feeding the OE spinning frame cannot be used for this purpose. The sliver feeding OE spinning frame, prior to it entering the rotor, in which the yarn is formed, is individualized by the OE spinning frame or individualizer. As a result of this individualizer activity, there are changes in the basic fiber properties, the first of which is that nep and trash removal takes place (Frydrych and Matusiak, 2000). Efficient cleaning on the OE spinning frame removes almost 65-75% (by mass) of the trash in the sliver, whereas the efficiency of nep removal is around ten percent (Frydrych and Matusiak, 2000). Therefore, the number and structure of the neps and trash in the sliver differs significantly from the one in the fiber stream, from which the OE yarn is formed. In order to determine the critical nep size for an OE yarn, fiber samples taken directly from the rotor during the yarn production on the spinning frame BD 200 RCE were measured on the AFIS system. These fibers, before they were introduced into the rotor, passed through the individualizer zone. For these samples, the parameters characterizing neps and trash ie, the average number, size as well as size distribution were determined. Furthermore, the yarns were treated the same as the ringspun yarns, The OE yarns produced from the fiber stream also being measured on the Uster tester. Next, on the cumulative curves of neps and trash contained in the fiber stream taken from the rotor, lines corresponding to the number of neps per 1 gram of yarn were drawn. The experiments involved OE yarns of linear densities in the range of 15 to 50 tex. The experimental average critical values of nep sizes D and D_1 for OE yarns are presented in Table 4. Based on these results, the parameters A_{OE} and B_{OE} were calculated according to eqs, (12) and (13). In the case of OE yarns, the values of parameters A_{OE} and B_{OE} also changed according to the yarn linear density. The equation involving A_{OE}, expressing the ratio of the density of the average nep size above the critical one for a given

OE yarn linear density and the average cotton fiber density as a function of yarn linear density (Figure 5), can be written as follows:

$$A_{OE} = 0.1835 \cdot Tt_{yOE}^{-0.3253} \quad (17)$$

While the equation for $A_{1OE,}$ as a function of yarn linear density can be written as:

$$A_{1OE} = 0.1957 \cdot Tt_{yOE}^{-0.3357} \quad (18)$$

Based on Equations (17) and (18), the values of parameters A_{OE}, A_{1OE}, B_{OE}, and B_{1OE} for OE yarns of linear densities 15 to 50 tex (Table 5) have been calculated and are demonstrated in Figure 6.

Final form of the equation for critical nep size as a function of yarn linear density

Introducing equation (7) into the derived equation for the critical nep size for ring-spun yarn the relationship describing the variable A as a function of yarn linear density can be obtained (equation 15) and after some transformation can be written as follows:

$$D_{ncrit}\,[mm] = 0.107 \cdot Tt_{y}^{0.663} \quad (19)$$

Following this procedure, other equations describing critical nep size as a function of yarn linear density can be obtained as follows:

$$D_{1ncrit}[mm] = 0.107 \cdot Tt_{y}^{0.651} \quad (20)$$

$$D_{ncritOE}[mm] = 138 \cdot Tt_{yOE}^{0.663} \quad (21)$$

$$D_{1ncritOE}[mm] = 0.133 \cdot Tt_{yOE}^{0.668} \quad (22)$$

where:

D_{ncrit} – critical nep size for the ring–spun yarn.

$D_{ncritOE}$ – critical nep size for the OE yarn.,

D_{1ncrit} – approximate critical nep size for the ring-spun yarn.

$D_{1ncritOE}$ – approximate critical nep size for the OE yarns.

As mentioned earlier, D_{1ncrit} and $D_{1ncritOE}$, treated as approximate values of critical nep taking into consideration the nep present in the roving only, will be applied in further research aimed at predicting the number of neps in cotton yarns. Based on the derived eq. (19 ÷ 22), we calculated the critical nep size for all the ring spun and OE yarns with linear densities typical for Polish spinning mills, and presented in Table 6 and Figures 7 and 8.

Experimental verification of the theoretical model on the critical nep size

Ring-spun cotton yarns

In order to verify the theoretical model for the critical nep size in the ring-spun yarns, five additional yarn samples of 15, 20, 25, 30 and 50 tex were produced. The model was verified by comparing the theoretical critical values of nep size calculated using the equation here described with the experimental values determined as described previously. Agreement was based on the results of all the ring-spun yarns. Ten specimens each of yarn were taken with linear densities 20, 25, 30 and 50 tex produced to determine model parameters A and B and five specimens of yarns with linear densities 15, 20, 25, 30, 40 and 50 tex. The agreement of empirical and calculated results were assessed by means of a t-Student test:

$$t = \frac{|A - \bar{a}|}{SD}\sqrt{n-1} \quad (23)$$

where: t (t-Student variable), A (value calculated according to the model (assumed value)), ā (average of measurements), SD (standard deviation), n (the number of measurements). The calculated and critical values of t-Student variables are given in Table 7. The calculated t values were compared with the value for the t- Student distribution at:

k = 14 degrees of freedom and probability 0.95 for yarns with linear densities of 20, 25, 30 and 50 tex ($t_{14;0.95}$=2.14),

k = 4 degrees of freedom and probability 0.95 for yarns with linear densities of 15 and 40 tex ($t_{4;0.95}$=2.78).

There is an agreement between the experimental and calculated critical nep sizes D and D_1 on the basis of the formula (an exception is the value D_1 for the yarn with a linear density of 20 tex).

OE cotton yarns

In order to verify the theoretical model, OE yarns with linear densities 20, 25, 30, 40 and 50 tex were produced. According to the procedure described earlier, the critical nep size for the particular yarn samples was determined experimentally and then compared these with the theoretical values calculated by means of equations 20 and 21.

The agreement between the experimental and assumed values was assessed by calculating t-Student value and comparing it with the critical value $t_{n-1;0.95}$ according to the t-Student distribution for all OE yarns, i.e., for model parameters of A_{OE} and B_{OE} for samples produced for verification purposes. The results are presented in Table 8.

For all OE yarn variants, with the exception of yarn with a linear density 30 tex, the experimental critical nep sizes agree with the assumed values. OE yarns are characterized by a much lower number of neps per 1000 m than ring-spun yarns.

Recalculating the number of neps in a yarn per unit mass (1 g), small values often found, especially for coarser yarns (linear density of 40 or 50 tex), sometimes close to 0. For this reason, some of the yarn samples having few neps couldn't be used for model verification.

Conclusions

The theoretical model allows one to calculate the critical nep size for cotton ring-spun and OE yarns. The experimental results confirm the theoretical model. The general agreement between the theoretical and experimental critical nep sizes has been reported. Moreover, based on these investigations it has found that the average density of neps larger than the critical level one is a variable and decreases with increasing yarn linear density.

Determining the critical nep size for the ring-spun yarns is very important from a practical point of view, because it allows one to predict the number of neps in cotton yarn based on the characteristics of the neps in the roving neppiness as measured on the AFIS system. The work is now being extended to allow the number of neps in ring-spun yarn to be predicted from the number of neps in the cotton lint. It will also enable one to determine whether the number of neps changes during processing on machinery of known working efficiency. Determining the critical number of neps for OE yarn has less practical significance, because the nep removing efficiency of the opening system in the OE spinning frame makes this much more difficult, or in the case of modern machinery, even impossible.

Also, OE yarns produced on the new generation of OE spinning frames are characterized by very high quality and neps in these yarns do not present an important technological problem, hence extending the work to the prediction of neps in OE yarns has less significance from a practical point of view.

Determining the critical nep size for OE yarns within the scope of this work has a "knowhow" value, enabling comparisons of the properties of cotton yarns produced by the two spinning technologies, i.e. ring-spun and open-end.

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Table 1. *Critical nep sizes for ring-spun yarns.*

Number of spindle	20 tex		25 tex		30 tex		50 tex	
	D [μm]	D_1 [μm]	D[μm]	D_1[μm]	D[μm]	D_1[μm]	D[μm]	D_1[μm]
1	751	725	866	817	1106	1085	1330	1261
2	744	712	875	844	1025	955	1348	1335
3	766	737	975	948	1016	979	1485	1261
4	704	695	939	875	1065	1033	1516	1516
5	712	669	906	885	1053	988	1353	1318
6	850	769	1008	993	1098	988	1225	1144
7	725	696	975	954	875	850	1462	1462
8	736	720	859	841	1002	960	1408	1340
9	750	725	896	860	1202	1164	1463	1352
10	769	739	1058	1025	984	945	1475	1375
Average	751	719	936	904	1043	995	1407	1336
SD*	40.87	27.79	66.81	70.93	86.47	84.86	90.80	104.62

* SD – standard deviation

Table 2. *A and B values determined experimentally.*

Yarn linear density (tex)	B	B_1	A	A_1
20	0.168	0.161	0.088	0.096
25	0.187	0.181	0.071	0.076
30	0.190	0.182	0.068	0.075
50	0.199	0.189	0.063	0,069

Table 3. *A, A_1, B, B_1 values for the ring-spun yarns.*

Yarn linear density [tex]	A	A_1	B	B_1
15	0.08961	0.09624	0.16636	0.16053
20	0.08157	0.08823	0.17436	0.16766
25	0.07584	0.08248	0.18084	0.17340
30	0.07145	0.07806	0.18630	0.17825
40	0.06505	0.07156	0.19526	0.18616
50	0.06048	0.06690	0.20251	0.19254

Table 4. *Critical nep size values for OE yarns: A_{OE} and B_{OE} parameters determined experimentally.*

No	Linear density of OE yarn [tex]	D[μm]	D_1[μm]	B	B_1	A	A_1
1.	15	832	814	0.215	0.210	0.075	0.079
2.	20	921	913	0.206	0.204	0.085	0.083
3.	25	1234	1199	0.247	0.240	0.057	0.060
4.	28	1272	1263	0.240	0.239	0.060	0.061
5.	30	1375	1354	0.251	0.247	0.055	0.057
6.	35	1388	1388	0.235	0.235	0.063	0.063
7.	40	1666	1677	0.263	0.265	0.050	0.049
8.	50	1772	1735	0.251	0.245	0.055	0.058

Table 5. *Calculated values A, A_{1OE}, B_{OE} and B_{1OE} for OE yarns.*

Tt_y	A_{OE}	A_{1OE}	B_{OE}	B_{1OE}
15	0.0760	0.0788	0.214	0.210
20	0.0692	0.0716	0.224	0.220
25	0.0644	0.0664	0.232	0.229
30	0.0607	0.0625	0.239	0.236
40	0.0553	0.0567	0.251	0.247
50	0.0514	0.0526	0.260	0.257

Table 6. *Calculated values of critical nep size.*

Tt_y	D [mm]	D_1 [mm]	D_{OE} [mm]	$D_{1\,OE}$ [mm]
15	0.644	0.622	0.827	0.812
20	0.780	0.750	1.001	0.984
25	0.904	0.867	1.160	1.143
30	1.020	0.976	1.310	1.291
40	1.235	1.177	1.585	1.564
50	1.432	1.361	1.837	1.815

Table 7. *t-Student variables: Calculated and critical values.*

Linear density of yarn (tex)	Repetitions	*Calculated value of t-Student variable*		Critical value of t-Student variable $t_{n-1;\,0.95}$
		D	D_1	
15	5	0.339	0.571	2.78
20	15	1.555	2.243	2.14
25	15	1.984	2.147	2.14
30	15	0.418	0.467	2.14
40	5	0.983	1.010	2.78
50	15	1.792	1.619	2.14

Table 8. *t–Student variables: Calculated and critical values for OE yarns.*

No	Linear density of yarn [tex]	Repetitions	Calculated value of t-Student variable		Critical value of t-Student variable $t_{n-1;0.95}$
			D	D1	
1.	15	3	0.53	0.20	4.30
2.	20	7	0.34	0.50	2.45
3.	25	12	0.46	1.96	2.20
4.	28	4	0.87	1.03	3.18
5.	30	26	2.72	2.20	2.06
6.	35	2	0.71	0.49	12.71
7.	40	10	0.03	0.02	2.26
8.	50	9	1.88	2.00	2.31

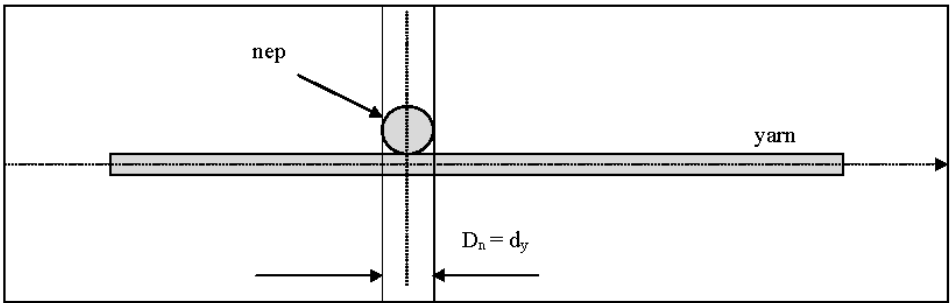

Figure1. *Schematic figure of a yarn segment with nep.*

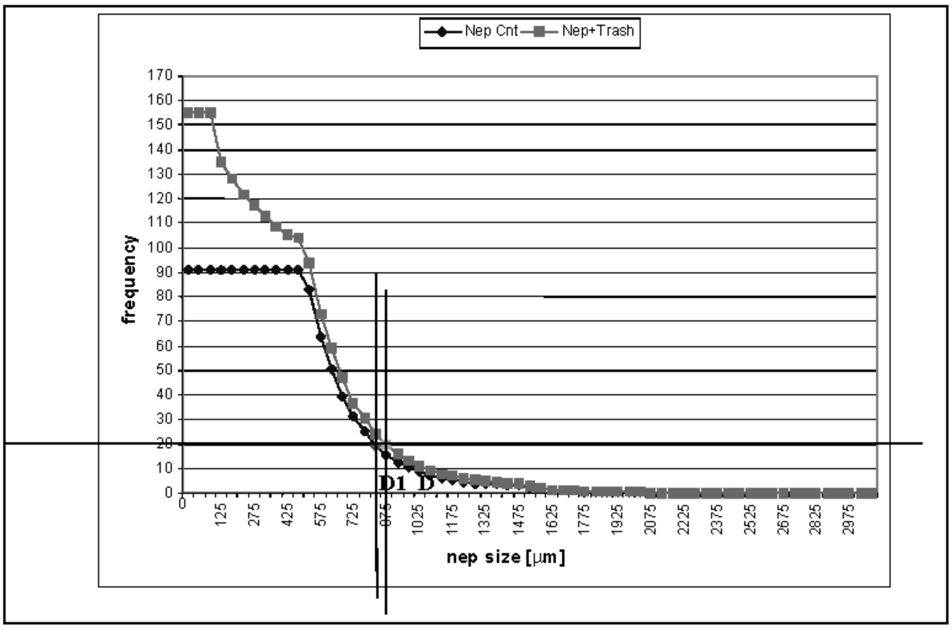

Figure 2. *Cumulative curves of neps and trash in roving.*

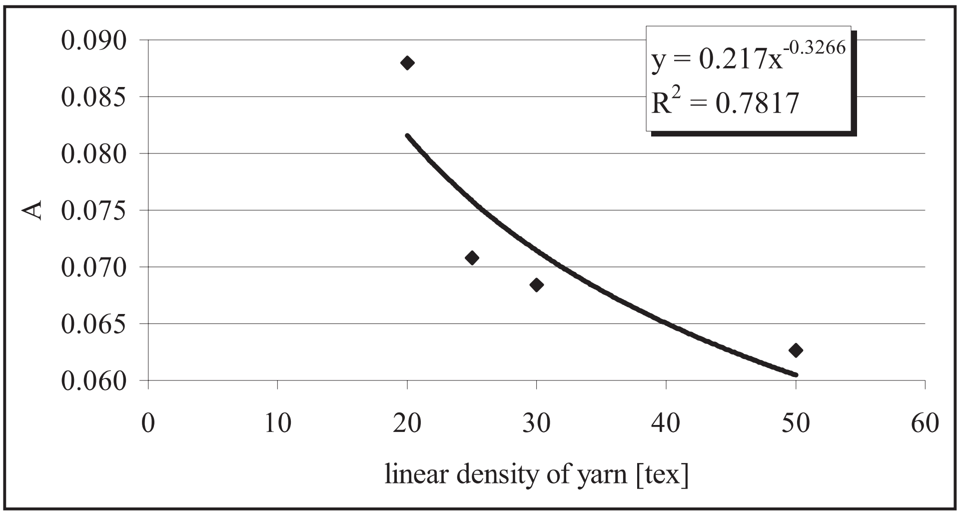

Figure 3. *A as a function of ring-spun yarn linear density.*

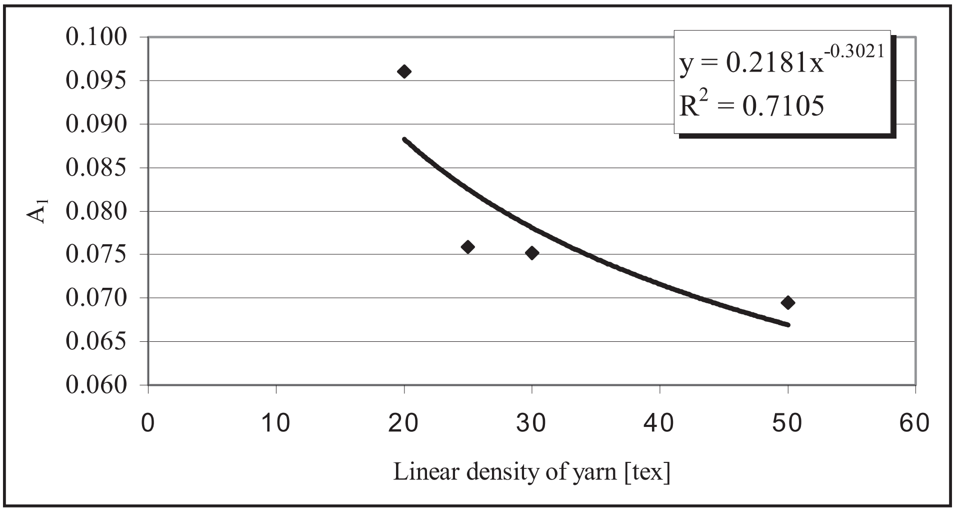

Figure 4. *A_1 as a function of ring-spun yarn linear density.*

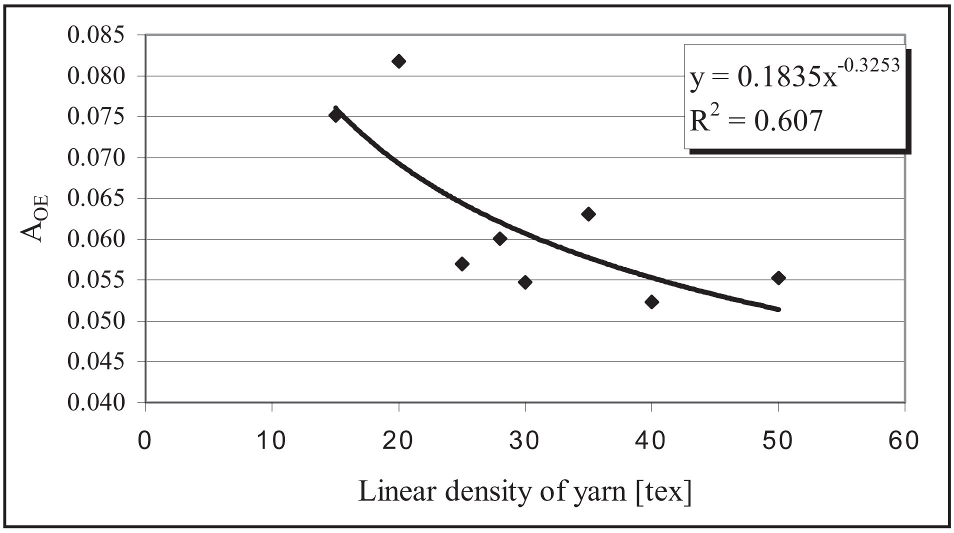

Figure 5. *Variable A_{OE} as a function of OE yarn linear density.*

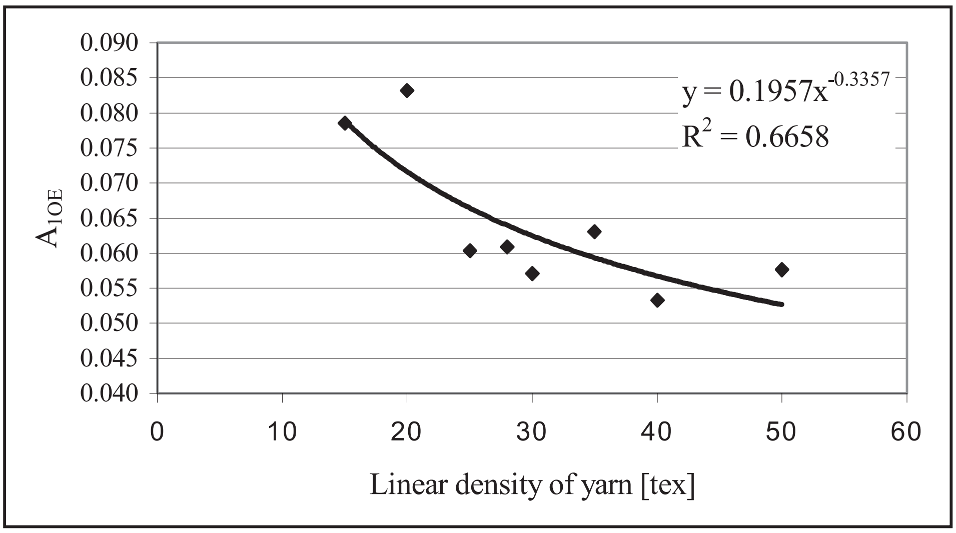

Figure 6. *Variable A_{1OE} as a function of OE yarn linear density.*

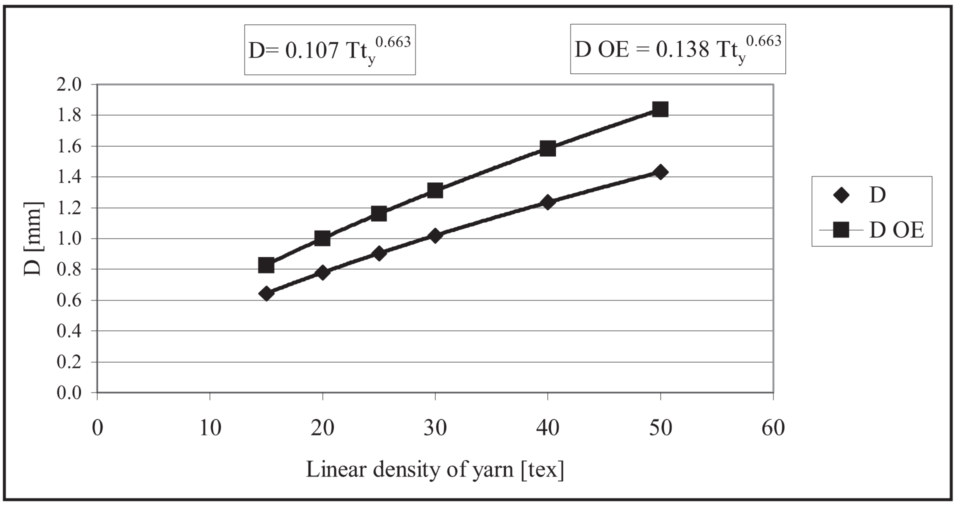

Figure 7. *Critical nep size as a function of ring-spun and OE cotton yarn linear density.*

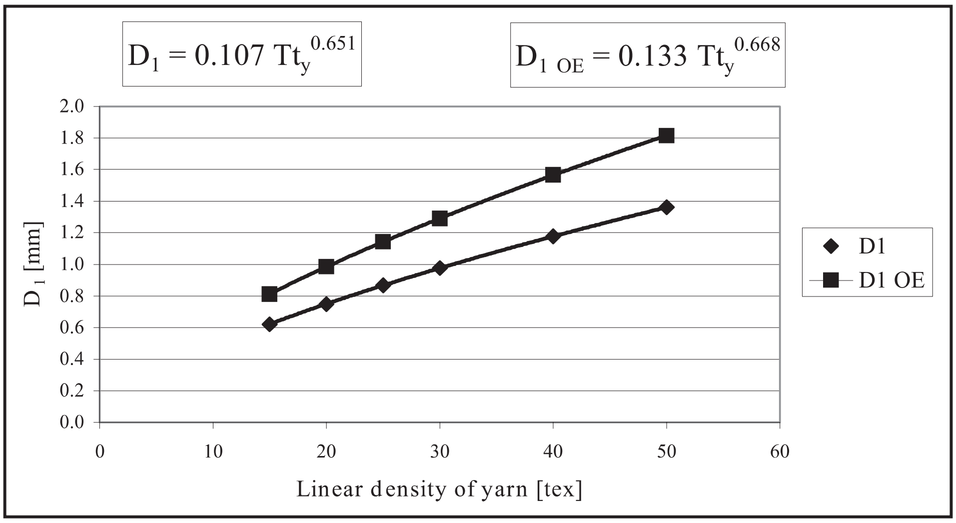

Figure 8. *Approximate critical nep size as a function of ring-spun and OE cotton yarn linear density.*