Quality Aspects of Dref-III Spun Yarns by Optimisation of Parameters with Box and Behnken's 3x3 Model

Atin Chaudhuri[1] and P. K. Majumdar[2]

[1]Department of Jute and Fibre Technology, University of Calcutta, 35, Ballygunge Circular Road, Kolkata-700019, West Bengal, India.
[2]Government College of Engineering and Textile Technology, Serampore-712201, Hooghly, West Bengal, India.

Abstract

Studies have shown the effect of two different fibre parameters (fibre length and fibre fineness) as well as core-sheath ratio of yarn on the physical properties and structure of Dref-III yarns. Different response surface equations have been derived for prediction of different physical properties of Dref-III yarn with Box and Behnken's factorial design for 3-levels and 3-variables. Different contour curves have been constructed to study the interaction effect of various variables on different responses. Use of coarser fibre in normal range and increase in core content has a positive resultant effect on strength translation of fibre in yarn, specific work of rupture and evenness of yarn. Increase in fibre length and core content has increased the strength translation, breaking extension, initial modulus, evenness, specific work of rupture and packing coefficient of yarn. Increase in fibre fineness has raised the breaking extension of yarn largely. Interaction of fibre length with core content has a positive influence on strength translation of fibre, breaking extension and specific work of rupture yarn. Interaction of fibre length with fibre fineness has a negative influence on breaking extension and evenness of yarn. Interaction of core content with fibre fineness has a negative influence on evenness of yarn. No interaction effect can significantly influence on initial modulus and packing coefficient of yarn.

Key words: *Box and Behnken's model, Core-sheath ratio, Contour curves, Dref-III yarn, Response surface equations, Strength translation.*

1. INTRODUCTION

The core-sheath type bi-component structure of Dref-III yarn is quite complex[1]. Amount of compressive force generated by the sheath fibres is mainly governed by the characteristics of the sheath fibres and the sheath structure which in turn is being governed by the way the sheath fibres are laid on the core assembly. Manner of lying of sheath fibres on the core assembly during yarn formation is dependent upon the machine parameters[2], fibre parameters and yarn structural parameter like core-sheath proportion of the yarn. It is necessary to find the effect of the above parameters in controlling the yarn structure and ultimately different physical properties of the yarns. For investigating this, an appropriate factorial design has been used to optimise the effect of various parameters on yarn properties. Published works on the application of factorial design for optimising the parameters of Dref-III spinning process is scanty. In the present work, efforts have been made to investigate the effects of fibre parameters (fibre length and fibre fineness), and yarn structural parameter (core-sheath ratio) on the physical characteristics of Dref-III yarns using Box and Behnken[3] model for three variables and three levels.

2. MATERIALS AND METHODS

2.1 Materials

Polyester fibres with different staple length and fineness were used to study the effect of fibre and yarn parameters on yarn properties. The physical properties of these fibres are given in Table 1.

Table 1– Tensile properties of polyester fibres.

Staple length, mm	Linear density, Denier	Tenacity, cN/tex	Strength CV%	Breaking extension, %	Extension CV%	Work of rupture, mJ/tex.m
38	1.0	67.62	8.77	24.27	12	162.51
	1.5	71.49	7.23	23.71	14	171.32
	2.0	74.54	6.18	25.93	15	188.33
44	1.0	67.83	8.84	23.29	13	163.96
	1.5	72.39	9.57	23.91	14	178.71
	2.0	75.22	9.56	26.19	16	191.71
50	1.0	68.27	8.44	23.71	16	159.76
	1.5	72.16	9.5	23.26	14	173.97
	2.0	75.56	8.03	26.35	12	192.59

2.2 Methods

2.2.1 Sliver Preparation and Yarn Preparation

The requisite yarn samples were prepared in Dref-III spinning machine using 3.6 K tex sliver as feed materials (core as well as sheath) with the variation of fibre parameters and core-sheath content (Table 2) according to Box and Behnken's design of experiment[3] for 3-

levels and 3-variables as listed in Table 3 (actual values for corresponding code levels) with a constant delivery rate of 100m/min and desired drum speed 3600rpm. Different Dref-III yarns were prepared from different slivers and different core-sheath ratio. The physical properties of prepared Dref-III yarns are shown in Table 4.

Table 2– Actual levels of variables and coded levels

Variables		Levels		
		-1	0	+1
Core content, %	(F_1)	30	50	70
Fibre length, mm	(F_2)	38	44	50
Fibre fineness, denier	(F_3)	1.0	1.5	2.0

2.3 Testing and Evaluation

2.3.1 Evaluation of Tensile Properties of Fibres

Tensile properties of polyester fibres were carried out by Instron universal tensile strength tester (model 4411) with 10mm test length and 10mm/min strain rate. 20 tests were carried out for each sample to get average value of tensile properties. The stress-strain diagrams of the fibres are represented in Fig. A.

2.3.2 Evaluation of Tensile Properties of Yarn

Tensile properties of Dref-III yarns were measured after conditioning 48h[4] by Instron universal tensile tester (model 4411) with computer interface as per IS: 1671-1977 method[5] maintaining test length 50 cm and test speed 100mm/min. 25 tests were carried out for each sample to get average value of tensile properties.

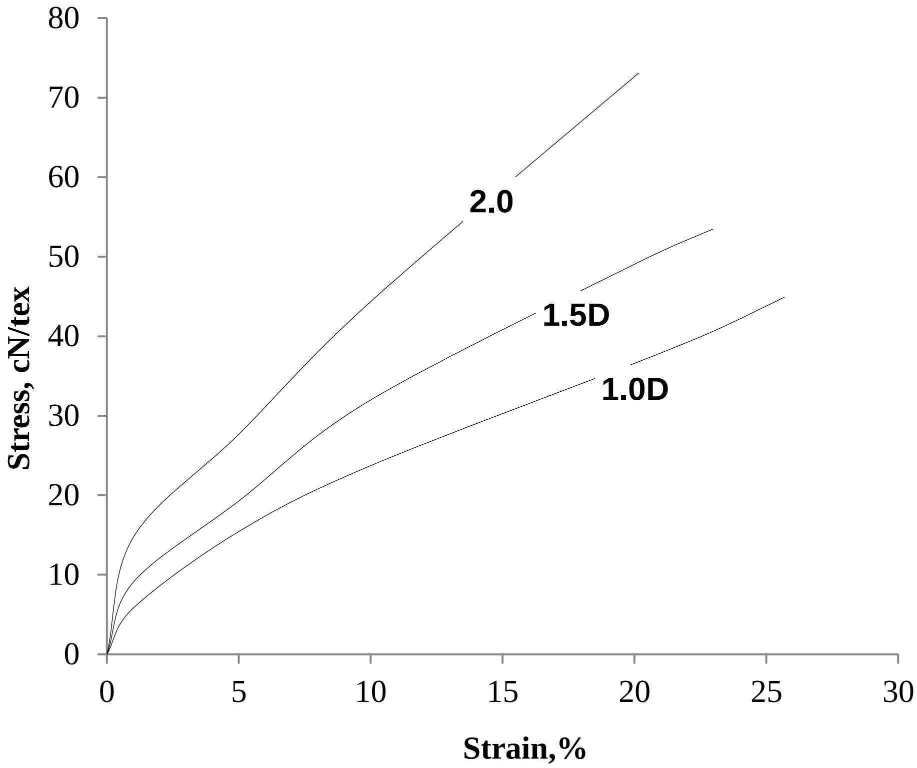


Fig. A− Stress-strain diagram of different polyester fibres

Strength translation of fibre in Dref-III yarn was calculated by using the following formula:

$$\text{Strength translation, \%} = \frac{\text{Yarn tenacity}}{\text{Fibre tenacity}} \times 100$$

The test results of various yarn properties as per design and their relationship are shown in Table 4. Table 5 represents the response surface equations for different response.

Results of all the response for various experimental combinations were processed for estimating the regression coefficients and their variance for preparation of **ANOVA** table. The regression coefficients were tested for significance at 95% confidence level using the above equations. Only significant terms were considered for construction of response surface equation. Calculated F-ratio values for different coefficient of the responses are listed in Table 6.

Table 3 – Box and Behnken's experimental plan for variation of three machine parameters and their three levels

Experiment number	Levels		
	F_1	F_2	F_3
FP-1	30	38	1.5
FP-2	30	50	1.5
FP-3	70	38	1.5
FP-4	70	50	1.5
FP-5	30	44	1.0
FP-6	30	44	2.0
FP-7	70	44	1.0
FP-8	70	44	2.0
FP-9	50	38	1.0
FP-10	50	38	2.0
FP-11	50	50	1.0
FP-12	50	50	2.0
FP-13	50	44	1.5
FP-14	50	44	1.5
FP-15	50	44	1.5

2.3.3 Measurement of Yarn Diameter and Packing Coefficient

The longitudinal yarn diameter was measured using Leitz optical microscope (model WILD M3Z) with video display monitor with a magnification of 40 X under a constant tension of 0.5 g/tex. The result obtained from 50 measurements was taken for each yarn sample to work out average diameter of the yarn.

The packing coefficient of Dref-III yarns was computed from the ratio of the bulk density of the yarn and fibre density using the following relations[6]:

$$\text{Packing coefficient } (\phi) \; \frac{\text{Bulk density } (V_d)}{\text{Fibre density}}$$

Where, $V_d = \dfrac{1.24 \times T \times 10^{-5}}{d_y^{2}}$ d_y is the grand average diameter of the yarn in cm, T is the linear density of the yarn in tex and ρ is the density of fibre (density for polyester fibre is taken as 1.38 gm/cm^3).

2.3.4 Evenness and Mass Irregularity of Yarn

Mass irregularity of the yarn expressed as percent mean deviation of mass/unit length (8 mm) expressed as U_m%[7] was evaluated using Uster Evenness Tester (model no.UT-3) after conditioning of yarn samples for 48h. The average of 5 measurements of 100m test length of yarn was taken for evaluation of mass irregularity.

3 RESULTS AND DISCUSSION

3.1 Effect of Core Content and its Interaction Effect with Fibre-length and Fibre- fineness on Yarn Properties.

3.1.1 Effect on Strength Translation

It is observed from Table 4 that strength translation (expressed as percentage) of fibres in Dref-III yarn is noticeably influenced by the core content in yarn. Response surface equation of strength translation for variation of fibre parameters, as shown in Table 5, also confirms the strong positive influence of core content on strength translation. Strength translation has been found to be influenced by the interaction of core content with fibre length. Number of load bearing fibres has increased with increase in core content in Dref-III yarn. Moreover, packing coefficient is also increased with higher proportion of parallel fibres as may be seen from response surface equation of packing coefficient (Table 5). Higher number of load bearing fibres with higher packing coefficient increases the strength translation in Dref-III yarns. Therefore, increase in core content in yarn has resulted increase in strength translation ratio of fibres in yarn.

Table 4 – Some physical properties of Dref-III yarns spun with variation of some machine parameters

Sample No.	Strength translation %	Breaking extension %	Initial modulus cN/tex	Specific work of rupture mJ/tex-m
1	21.46	17. 80	114.3	16.20
2	21.80	17. 10	96. 6	16.53
3	30.01	15.78	92. 9	12.44
4	34.27	17. 86	154.7	26.45
5	25.87	18.10	111.8	19.30
6	22.79	19.38	112.2	21.90
7	35.37	17.36	173.3	24.44
8	34.74	17.36	192.6	30.40
9	24.42	16.52	106.6	14.57
10	17.90	20.78	86.3	19.78
11	37.06	18.87	151.6	26.32
12	28.12	17.19	171.2	26.77
13	26.69	16.22	134.8	19.98
14	25.82	17. 67	140.7	19.50
15	25.95	17 .08	132.3	09.89

Table 5 – Response surface equation of different response of Dref-III yarn by variation of fibre and yarn parameters.

Response	Response surface equations for variation of fibre and yarn parameters	Correlation Coefficient
Strength translation,%	$26.15 + 3.826\ F_1 + 5.04\ F_2 - 2.37\ F_3 + 3.32\ F_3^2 + 3.95\ F_1 F_2$	0.962
Breaking extension,%	$16.99 - 0.502\ F_1 + 0.4834\ F_3 + 1.133\ F_3^2 + 0.695\ F_1 F_2 - 1.485\ F_2 F_3$	0.945
Initial modulus, cN/tex	$135.93 + 22.325\ F_1 + 21.75\ F_2$	0.914
Specific work of rupture, mJ/tex.m	$19.79 + 2.476\ F_1 + 4.135\ F_2 + 1.78\ F_3 + 0.134\ F_1^2 - 2.02\ F_2^2 + 4.09\ F_3^2 + 3.42\ F_1 F_2$	0.985
Unevenness, U_m%	$10.46 - 1.012\ F_2 + 1.385\ F_2^2 - 1.37\ F_1 F_2 + 1.04\ F_1 F_3 + 1.24\ F_2 F_3$	0.933
Packing coefficient	$0.428 + 0.079\ F_1 + 0.054\ F_2 + 0.23\ F_1^2$	0.891

Fig.1A shows the effect of interaction of core content with fibre length on strength translation through contour curves for 1.5 denier fibre fineness. They are obtained by adjusting the core content and variation of fibre length in yarn for different fibre fineness. Fibre length greater than 44mm requires less core content but fibre length less than 41mm requires higher core content to achieve same strength translation as shown in above contour curves.

Fig.1B shows the effect of interaction of core content with fibre fineness on strength translation through contour curves for 44mm fibre length respectively. Interaction effect of core content with fibre fineness has no significant effect in controlling strength translation of fibres in Dref-III yarn as obtained by comparing the value of regression coefficient of interactive terms with their corresponding F-ratio as shown in Table 6.

Table 6 – Value of F-ratio for regression coefficients of different response obtained by variation of fibre and yarn parameters

Response	Standard Deviation (σ)	Value of F-ratio			
		b_0	b_i	b_{ii}	b_{ij}
Strength translation, %	2.8355	30274	2.005	3.274	2.8355
Breaking extension, %	0.6948	0.8023	0.4913	0.8023	0.6948
Initial modulus, cN/tex	21.876	25.2603	15.4687	25.2603	21.876
Specific Work of rupture, mJ/tex.m	0.8796	1.6818	1.02989	1.6818	0.8796
Uneveness, Um%	.5967	1.2483	0.764	1.2483	0.5967
Packing Coefficient	0.219	0.0820	0.05023	0.0820	0.2190

3.1.2 Effect on Breaking Extension

With increase in core content, a drop in breaking extension of the yarn has been observed, as may be seen from response surface equation of breaking extension (Table 5), although no remarkable change in breaking extension values has been observed from . Increase in core content of yarn causes reduction in sheath fibre content of yarn. Lesser the number of sheath fibres, lesser is the radial force generation on core, resulting in lower breaking extension as the fibres start slipping early.

Fig.2A shows the effect of interaction of core content with fibre length on breaking extension through contour curves for 1.5 denier fibre fineness. Fig.2B shows the effect of interaction of core content with fibre fineness on breaking extension through contour curves for 44 mm fibre length respectively.

3.1.3 Effect on Initial Modulus

Increase in initial modulus of yarn has been observed with increase in core content (Table 4). Similar observation has also been found from the response surface equation of initial modulus of yarn (Table 5). Higher the core content, higher is the number of load bearing fibres, arranged in a more compact manner, resulting in increase in initial modulus.

Fig.3A shows the effect of interaction of core content with fibre length on yarn modulus through contour curves for 1.5 denier fibre fineness. Fig.3B shows the effect of interaction of core content with fibre fineness on yarn modulus through contour curves for 44 mm fibre length. Comparing the regression coefficient of interactive terms with their corresponding F-ratio (Table 6), it may be observed that interaction of core content with fibre length and fibre fineness have no significant influence in controlling initial modulus of yarn.

3.1.4 Effect on Specific Work of Rupture

Specific work of rupture values have been found to increase with increase in core content (Table 4) in yarn. It is also observed from response surface equation of specific work of rupture (Table 5) that specific work of rupture has increased with increase in core content and the rate of increase is higher at higher core content in yarn. A part of interaction effect of core content with fibre length has the inclusive effect in determination of specific work of rupture of Dref-III yarn. Increase in specific work of rupture may be due to higher resistance to slippage due to higher number of fibres and higher initial packing with increase in core content.

Fig.4A shows the effect of interaction of core content with fibre length on specific work of rupture of yarn through contour curves for 1.5 denier fibre fineness. Fig.4B shows the effect of interaction of core content with fibre fineness on specific work of rupture of yarn of yarn through contour curves for 44 mm fibre length respectively. Comparing the regression coefficient of interactive terms with their corresponding F-ratio (Table 6) respectively, show that core content and fibre fineness interaction has no significant influence in controlling the specific work of rupture of Dref-III yarn.

3.1.5 Effect on Yarn Unevenness

The unevenness of yarn has not followed any specific trend of change with the change in core content in the yarn (Table 4). Comparing regression coefficient of linear and quadratic terms with their corresponding F-ratio value (Table 6) respectively and observed from response surface equation of unevenness (Table 5), it may conclude that core content has no impact on yarn unevenness. However, interactive action of higher core content with high fibre length gives more even yarn, whereas, the interactive action of higher core content with comparatively coarser fibre gives more uneven yarn.

Fig.5A shows the effect of interaction of core content with fibre length on unevenness of yarn through contour curves for 1.5 denier fibre fineness. Fig.5B shows the effect of interaction of core content with fibre fineness on unevenness of yarn through contour curves for 44 mm fibre length.

3.1.6 Effect on Packing Coefficient

Initial increase in core content from 30% to 50% resulted very small increase in packing coefficient of yarn but increase in core content beyond 50% increased packing coefficient with a great extent (Table 4).

Similar results are also observed from response surface equation of packing coefficient (Table 5). Higher number of core fibres can produce more packed yarn.

Fig.6A shows the effect of interaction of core content with fibre length on packing coefficient of yarn through contour curves for 1.5 denier fibre fineness respectively. Fig.6B shows the effect of interaction of core content with fibre fineness on packing coefficient of yarn through contour curves for 44mm fibre length. Comparing the regression coefficient of interacting terms of variables with their corresponding F-ratio (Table 6), it is observed that no interaction effect is significantly responsible in controlling packing coefficient of Dref-III yarn.

3.2 Effect of Fibre Length and its Interaction Effect with Core Content and Fibre Fineness on Yarn Properties.

3.2.1 Effect on Strength Translation

Increase in fibre length resulted in increase in strength translation (Table 4) of fibres in Dref-III yarn. Similar observation has also been found from response surface equation of strength translation (Table 5) for variation of fibre parameters. Higher length of fibres in core increases the resistance to slippage due to higher overlapping length and higher length of fibres in sheath increases the number of wrappings. Interaction effect of fibre length with core content is expected to cause a positive change in strength translation of fibres.

Fig.1A shows the effect of interaction of fibre length with core content on strength translation through contour curves for 1.5 denier fibre fineness. Fig.1C shows the effect of interaction of fibre length with fibre fineness on strength translation of fibres through contour curves for 50% core content in yarn. This interaction has no significant role in determining strength translation of fibre as observed by comparing regression coefficient of interactive terms and their corresponding F-ratio (Table 6) respectively.

3.2.2 Effect on Breaking Extension

The effect of change in fibre length has not been shown any specific trend of change in breaking extension of yarn (Table 4). It has also observed from response surface equation (Table 5) for breaking extension, that fibre length has no significant influence on breaking extension of yarn. By comparing regression coefficient of linear terms and their corresponding F-ratio (Table 6) respectively, it is observed that interaction effect of fibre length with core content has positive significant effect and that of fibre length with fibre fineness has negative effect on breaking extension of yarn.

Fig.2A show the effect of interaction of fibre length with core content on breaking extension of yarn through contour curves for 1.5 denier fibre fineness. Proper interaction may give the improvement of breaking extension CV% of yarn. Fig.2C shows the effect of interaction of fibre length with fibre fineness on breaking extension of yarn through contour curves for 50% core content. Presence of longer coarser fibre in yarn showed reduction in breaking extension of yarn which may be due to less fibre content in core.

3.2.3 Effect on Initial Modulus

Presence of longer fibres in yarn resulted in increased initial modulus of yarn as shown in Table 4. Response surface equation (Table 5) for initial modulus also shows that initial modulus has been found to have major change with change in fibre length. The combined effect of higher overlapping length and higher wrapping due to presence of long fibres in core and sheath respectively may be the reason for higher initial modulus. On the other hand, interaction effect between any two parameters has no significant influence on initial modulus of yarn as observed from regression coefficient of interactive term and the F-ratio value, (Table 6) respectively.

Fig.3A shows the effect of interaction of fibre length with core content on yarn modulus through contour curves for 1.5 denier fibre fineness. Fig.3C shows the effect of interaction of fibre length with fibre fineness on initial modulus through contour curves for 50% core content.

3.2.4 Effect on Specific Work of Rupture

Specific work of rupture values have been found to increase with increase in fibre length as shown in Table 4. However, there is a threshold length above which the effect is negative as may be observed from response surface equation in Table 5.This may be due to buckling of the sheath fibres which ultimately resulted in reduction in the development of radial force

Fig.4A shows the effect of interaction of fibre length with core content on specific work of rupture of yarn through contour curves for 1.5 denier fibre fineness. Longer fibre with higher core content requires more energy to break. Fig.4C shows the effect of interaction of fibre length with fibre fineness on specific work of rupture of yarn through contour curves for 50% core content. This interaction has no significant influence in controlling the specific work of rupture of yarn as may be observed by comparing regression coefficient of interactive terms with their corresponding F-ratio value (Table 6) respectively.

3.2.5 Effect on Yarn Unevenness

Initial increase in fibre length may be improved unevenness of yarn (Table 4). But, use of very long fibres has increased the unevenness of yarn as may be seen from response surface equation of unevenness (Table 5).

Fig.5A shows the effect of interaction of fibre length with core content on unevenness of yarn through contour curves for 1.5 denier fibre fineness. Fig.5C shows the effect of interaction of fibre length with fibre fineness on unevenness of yarn through contour curves for 50% core content.

3.2.6 Effect on Packing Coefficient

Increase in fibre length improved packing coefficient of yarn (Table 4). Response surface equation of packing coefficient (Table 5) also supports the fact. Long fibres have utilised their long length for effective coiling around the core, thus imparting effective radial pressure to increase packing of fibres.

Fig.6A shows the effect of interaction of fibre length with core content on packing coefficient of yarn through contour curves for 1.5 denier fibre fineness. Fig.6C shows the effect of interaction of fibre length with fibre fineness on packing coefficient of yarn through contour curves for three different values of core content respectively. Comparing regression coefficient of interactive terms with their corresponding F-ratio value (Table 6) respectively, it can be concluded that no interaction effect of fibre length with other two parameters can significantly influence packing coefficient of yarn.

3.3 Effect of Fibre Fineness and its Interaction Effect with Core Content and Fibre Length on Yarn Properties.

3.3.1 Effect on Strength Translation

Some improvement in strength translation has been observed with the use of finer fibres in normal range as shown in Table 4. On the other hand, very finer fibre (micro denier level) produces less strength translation as observed from the response surface equation (Table 5) also support this. But, below certain denier value in the micro range, any further reduction in denier value of fibre would result in reduction in strength translation.

Fig.1B shows the effect of interaction of fibre fineness with core content on strength translation of fibres in Dref-III yarn through contour curves for 44mm fibre length. Fig.1C shows the effect of interaction of fibre fineness with fibre length on strength translation of fibres in Dref-III yarn through contour curves for 50% core content respectively. Comparison of regression coefficient of interactive terms of strength translation with their corresponding F-ratio value (Table 6) respectively, show that interaction of fibre fineness with other two parameters have no significant influence on strength translation of fibres in yarn.

3.3.2 Effect on Breaking Extension

Breaking extension of yarn does not show any improvement while using the fibres from 1.0 denier to 1.5 denier but some improvements are observed while using 2.0 denier fibres (Table 4). Response surface equation for breaking extension, (Table 5), also shows strong dependence of yarn breaking extension on fibre fineness. Higher the denier, higher would be the yarn breaking extension. The reason for this may be that the fibres used in the present study showed higher breaking extension with higher denier value. So the higher fibre breaking extension might have resulted in higher yarn breaking extension.

Fig.2B shows the effect of interaction of fibre fineness with core content on breaking extension of Dref-III yarn through contour curves for 44mm fibre length. Comparison of regression coefficient of interactive terms of breaking extension with their corresponding F-ratio value (Table 6) respectively clearly shows that this interaction has no significant influence in controlling breaking extension of yarn. Fig.2C shows the effect of interaction of fibre fineness with fibre length on breaking extension of Dref-III yarn through contour curves for 50% core content respectively.

3.3.3 Effect on Initial Modulus

Variation of fibre fineness has no influence on initial modulus of yarn (Table 4). Response surface equation for initial modulus of yarn (Table 5) also supports the above fact.

Fig.3B shows the effect of interaction of fibre fineness with core content on initial modulus of Dref-III yarn through contour curves for 44mm fibre length. Fig.3C shows the effect of interaction of fibre fineness with fibre length on initial modulus of Dref-III yarn through contour curves for 50% core content. Comparison of regression coefficient of interactive terms of initial modulus with their corresponding F-ratio value (Table 6) respectively, shows that interaction of fibre fineness with fibre length and core content has no significant influence in controlling initial modulus of yarn.

3.3.4 Effect on Specific Work of Rupture

Some improvement in specific work of rupture is observed by the use of coarser fibre in some cases as may be obtained from Table 4. Response surface equation (Table 5), also shows that the specific work of rupture of yarns is highly influenced by the fibre fineness. Coarser fibres have been found to give higher specific work of rupture. Coarser fibres used in this study showed higher strength and elongation. This may be reason for higher specific work of rupture with coarser fibres.

Fig.4B shows the effect of interaction of fibre fineness with core content on specific work of rupture of Dref-III yarn through contour curves for 44mm fibre length. Fig.4C shows the effect of interaction of fibre fineness with fibre length on specific work of rupture of Dref-III yarn through contour curves for 50% core content in yarn. Comparison of regression coefficient of interactive terms of initial modulus with their corresponding F-ratio value (Table 6) respectively, shows that interaction of fibre fineness with fibre length and core content has no significant influence in controlling specific work of rupture of yarn.

3.3.5 Effect on Yarn Unevenness

Table 4 does not show any specific trend of change in unevenness of yarn with variation of fibre fineness. Response surface equation for unevenness, as shown in Table 5, and by comparing regression coefficient of linear terms and their corresponding F-ratio (Table 6) respectively, it is evident that fibre fineness has no significant influence on yarn evenness. Only interaction effect of fibre fineness with fibre length and core content are responsible in controlling unevenness of yarn.

Fig.5B shows the effect of interaction of fibre fineness with core content on unevenness of Dref-III yarn through contour curves for 44mm fibre length respectively. Fig.5C shows the effect of interaction of fibre fineness with fibre length on unevenness of Dref-III yarn through contour curves for 50% core content.

3.3.6 Effect on Packing Coefficient

It has shown from response surface equation (Table 5) that fibre fineness has hardly significant influence on packing coefficient of yarn. Fig.6B shows the effect of interaction of fibre fineness with core content on packing coefficient of Dref-III yarn through contour curves for 44mm fibre length. Fig.6C shows the effect of interaction of fibre fineness with fibre length on packing fraction of Dref-III yarn through contour curves for 50% core content in yarn. Comparison of regression coefficient of linear, quadratic and interactive terms for packing coefficient with their corresponding F-ratio (Table 6) value respectively, it is evident that interaction effect of fibre fineness with core content and fibre length has no significant effect on packing coefficient of yarn.

4. CONCLUSION

4.1 The strength translation of fibres in Dref-III yarn has been found to increase largely by increase in core content. Use of coarser fibre in normal range has a positive resultant effect on strength translation. Only the interaction of fibre length with core content has a positive influence on strength translation of fibre in yarn.

4.2 Interaction of fibre length with core content has a positive effect whereas fibre length with fibre fineness showed negative effect on breaking extension of yarn.

4.3 Increase in core content and fibre length has increased initial modulus to great extent. No interaction effect between any fibre parameters and core-sheath ratio of yarn has showed any influence on initial modulus of yarn.

4.4 Increase in core content, use of coarser fibre and short fibre length have also increased specific work of rupture of yarn whereas use of very long fibre has reduced specific work of rupture of yarn drastically. Interaction effect of core-sheath content with fibre length has positive effect on specific work of rupture of Dref-III yarn.

4.5 Interaction effect of fibre length with core content has reduced the magnitude of yarn unevenness property whereas that of fibre fineness with core content and fibre length has added the magnitude of yarn unevenness.

4.6 Increase in core content and fibre length has largely increased packing coefficient of yarn. No interaction effect can significantly influence on packing coefficient of yarn.

REFERENCES

1. N. Balasubramanian, “Friction spinning – a critical review”, *Indian J. Fibre Text. Res.*, 17, (1992) 246.
2. A. Chaudhuri and P.K. Majumdar, “Studies on the physical properties of Dref-III spun yarns by variation of machine parameters with Box and Behnken’s 3x3 model”, *Indian J. Fibre Text. Res.*, 39, (2014) 43.
3. G. E. P. Box, and D. W. Behnken, “Some new three level designs for the study of quantitative variables”, *Technometrics*, 2(4), Nov.(1960) 455.
4. J. E. Booth, “Principles of Textile Testing”, 3rd edn (Newnes-Butterworths, UK), 1968,170.
5. Determination of yarn strength parameters of yarns spun on cotton system, Indian
    a. Standard Specifications IS: 1671-1977, (SP: 15-1981) (Bureau of Indian Standards, New Delhi) 1982, 54.
6. J E. Booth, “Textile Mathematics”, Vol. 2 (The Textile Institute, Manchester,UK), 975,330.
7. Application Handbook–Uster Evenness Testing (Zellweger Uster, Switzerland), 38,1986,92.

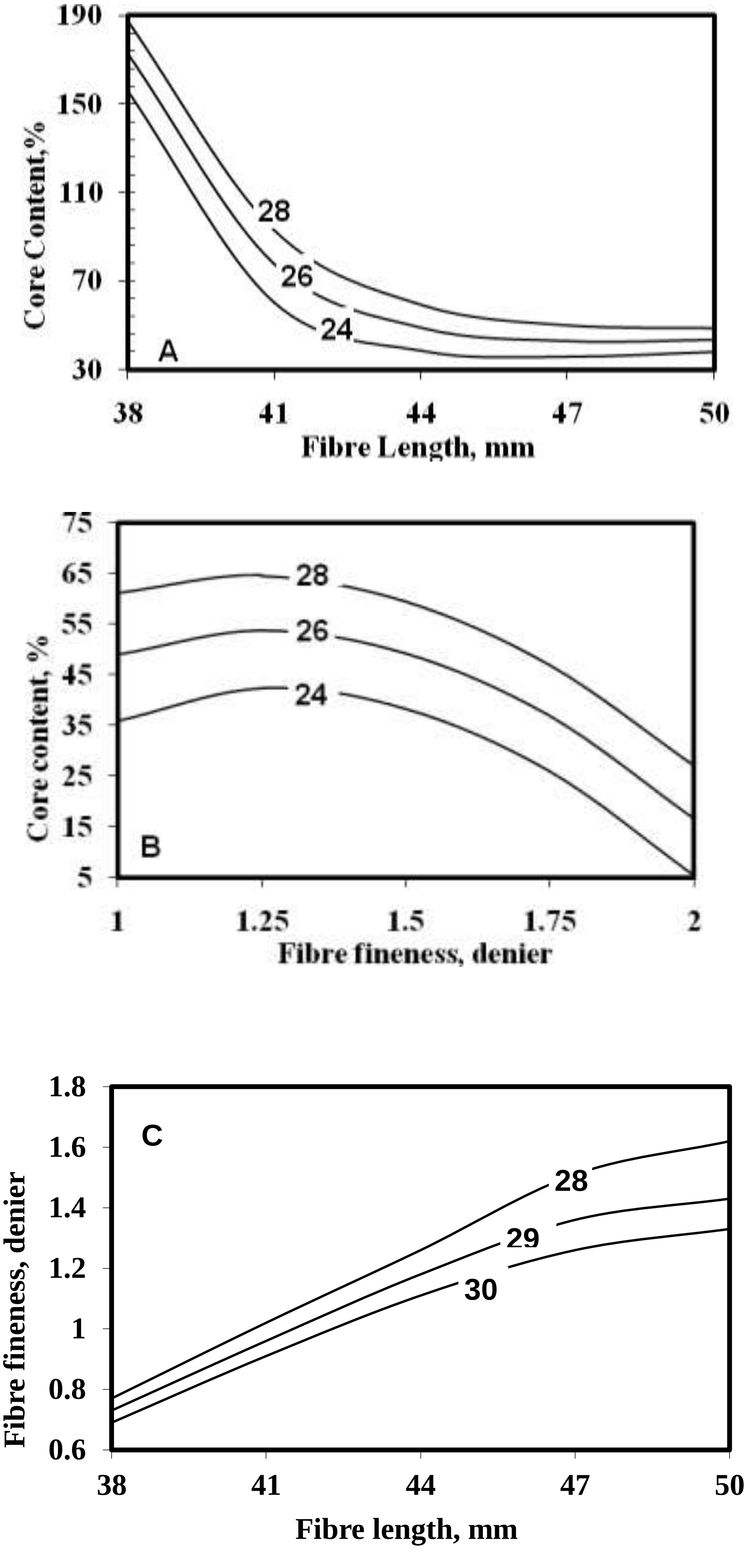
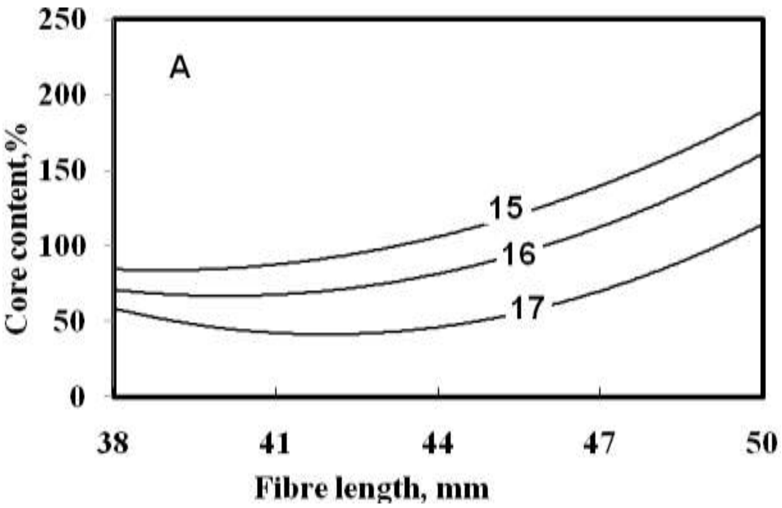
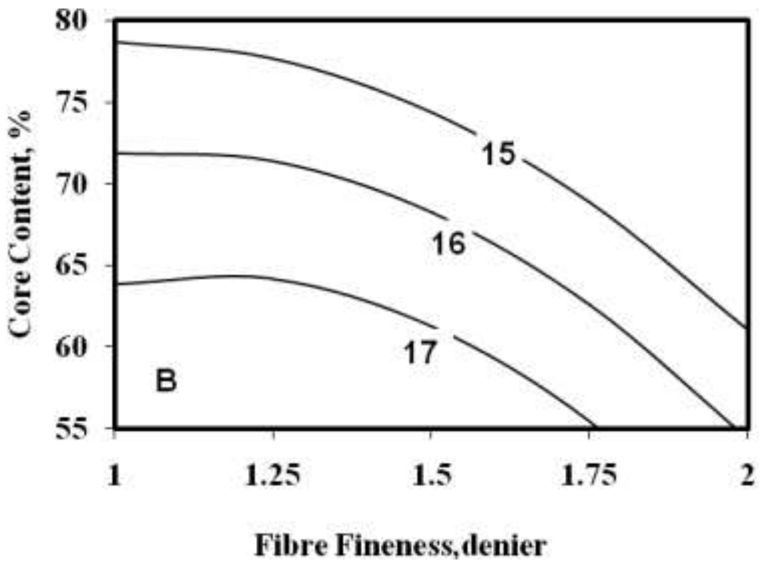

190
150
110
70
30
Core Content,%
28
26
24
A
38
41
44
47
50
Fibre Length, mm
75
65
55
45
35
25
15
5
Core content, %
28
26
24
B
1
1.25
1.5
1.75
2
Fibre fineness, denier
1.8
1.6
1.4
1.2
1
0.8
0.6
Fibre fineness, denier
C
28
29
30
38
41
44
47
50
Fibre length, mm

Fig.1− Contour for Strength Translation; A: 1.5 denier fibre fineness, B: 44mm fibre length and C: 50% core content.





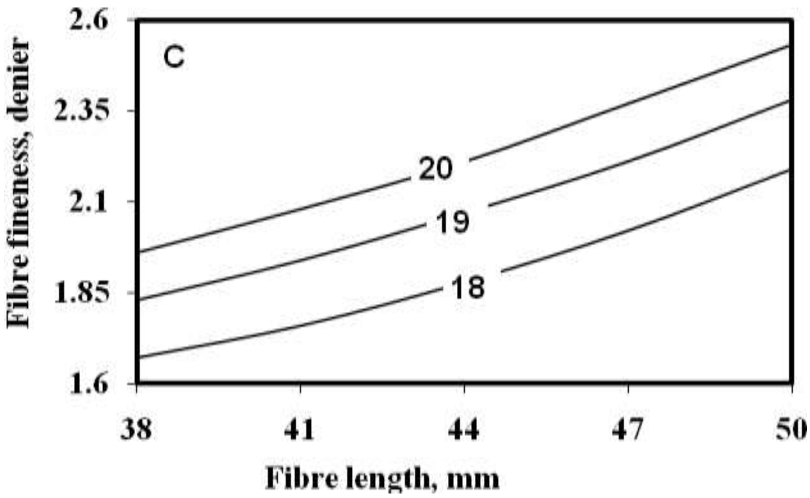
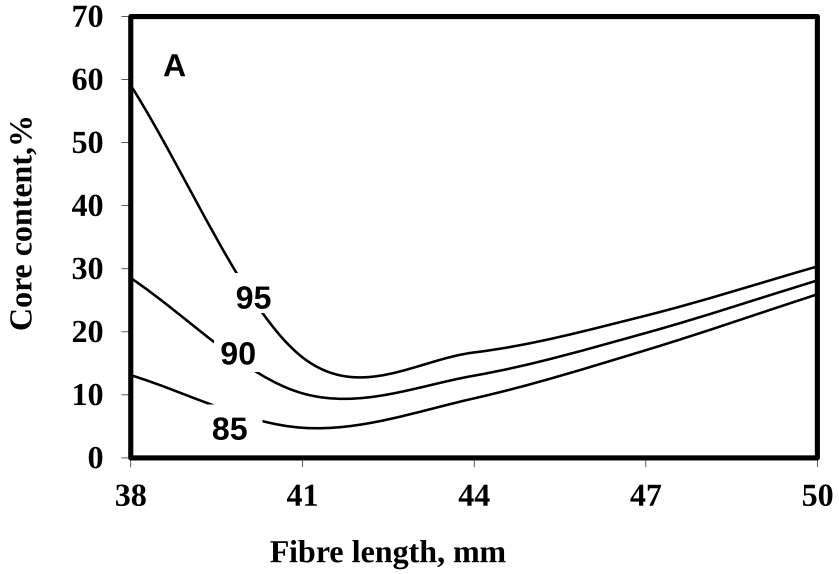
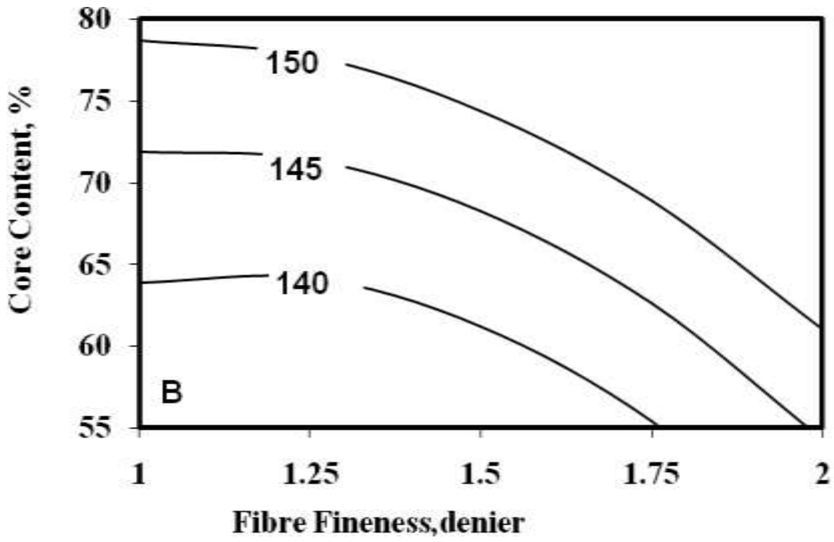


Fig.2− Contour for Breaking Extension; A: 1.5 denier fibre fineness, B: 44mm fibre length and C: 50% core content.





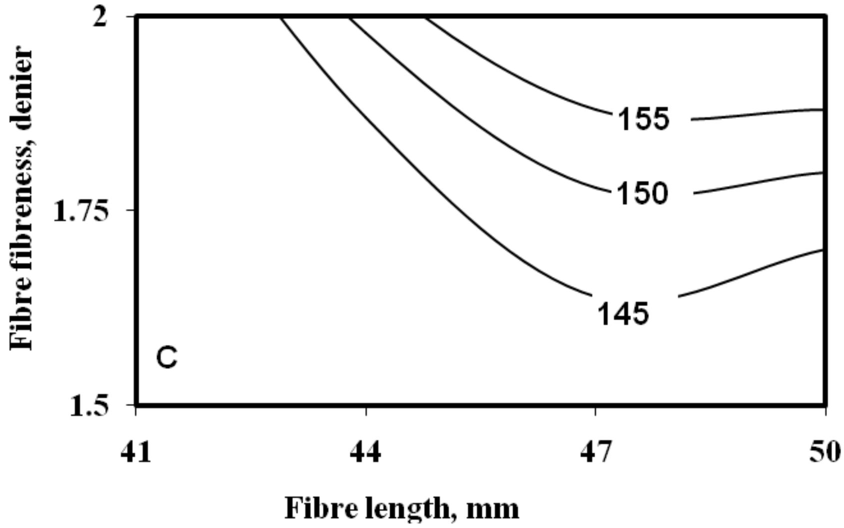
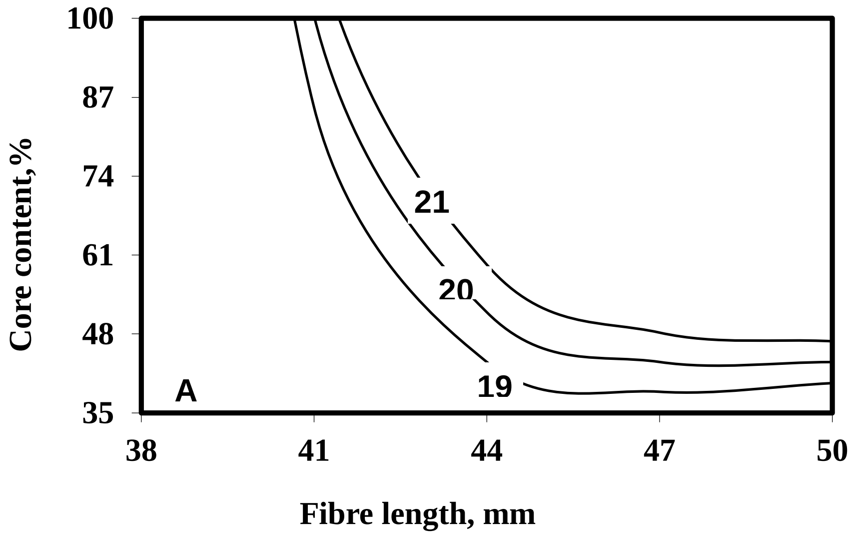


Fig.3− Contour for Initial Modulus; A: 1.5 denier fibre fineness, B: 44mm fibre length and C: 50% core content.



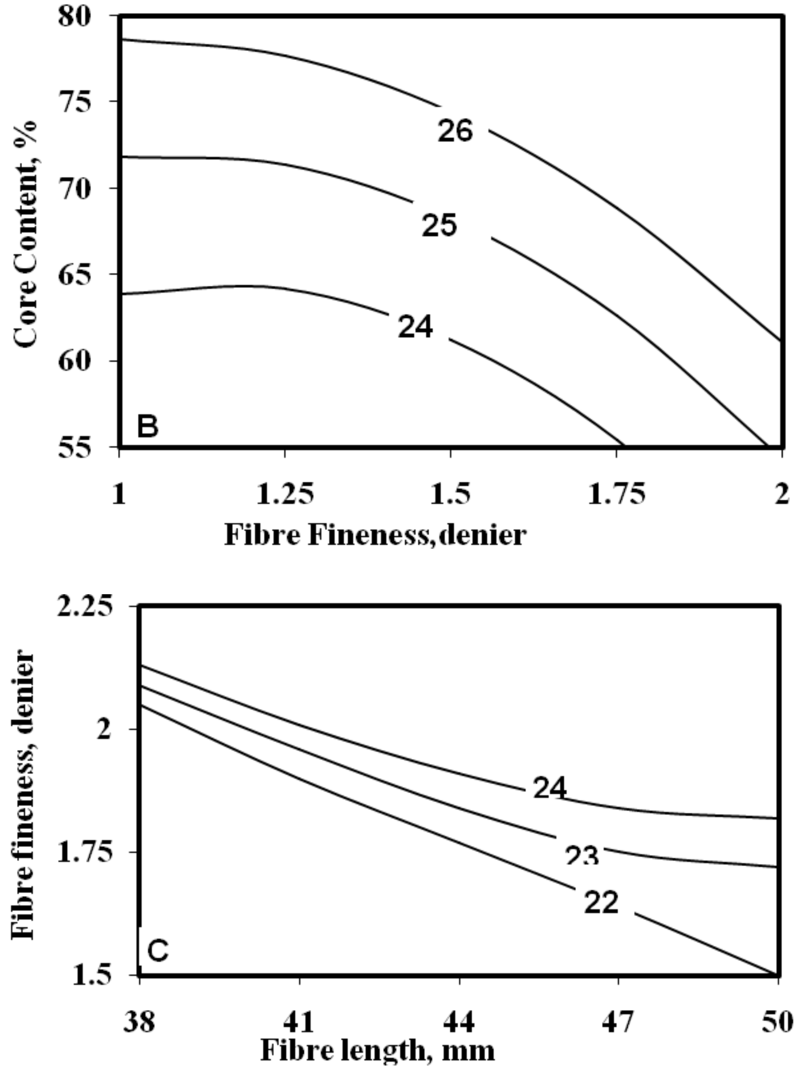


Fig.4− Contour for Specific Work of Rupture; A: 1.5 denier fibre fineness, B: 44mm fibre length and C: 50% core content.

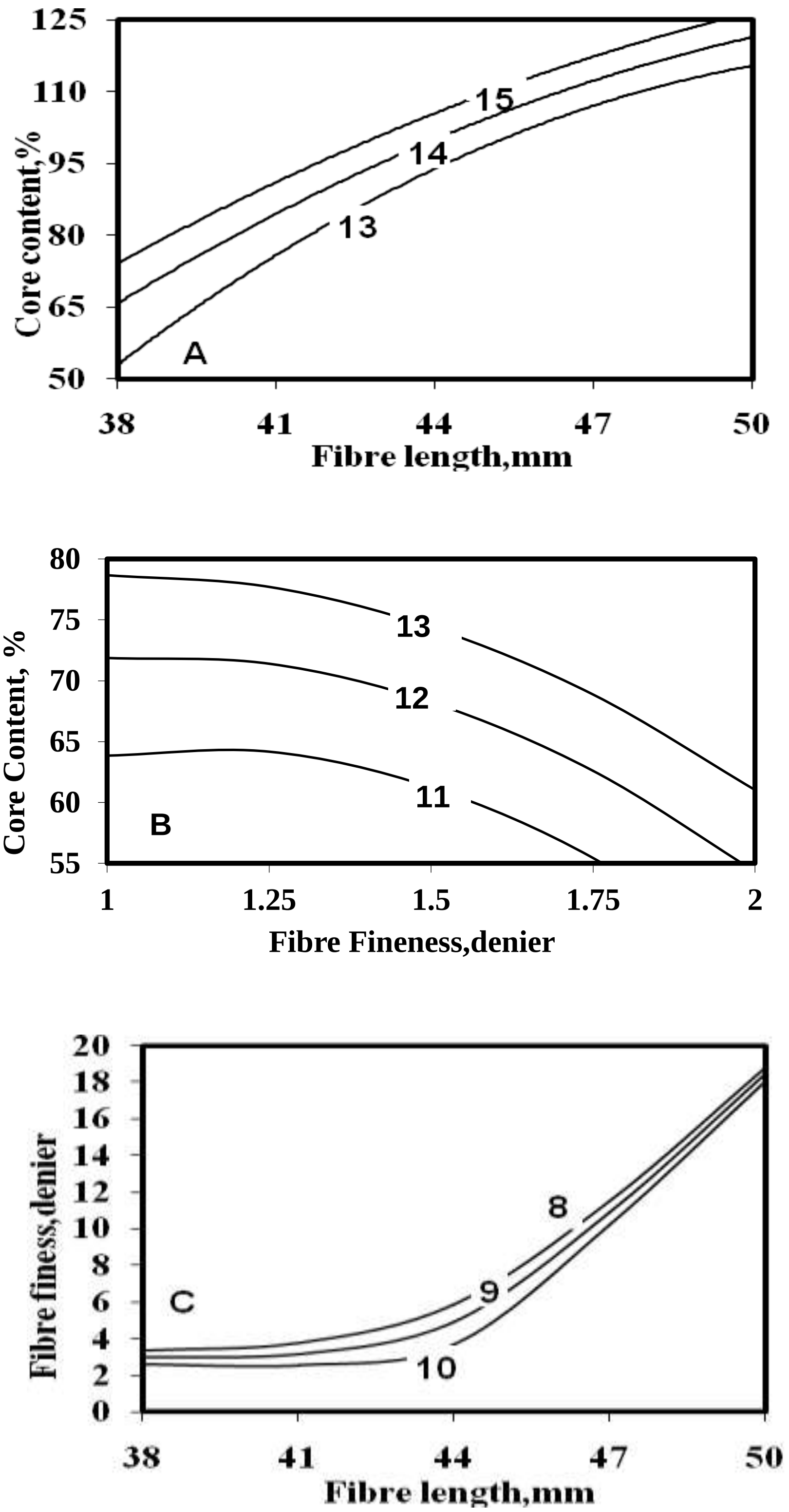


Fig.5− Contour for unevenness; A: 1.5 denier fibre fineness, B: 44mm fibre length and C: 50% core content.

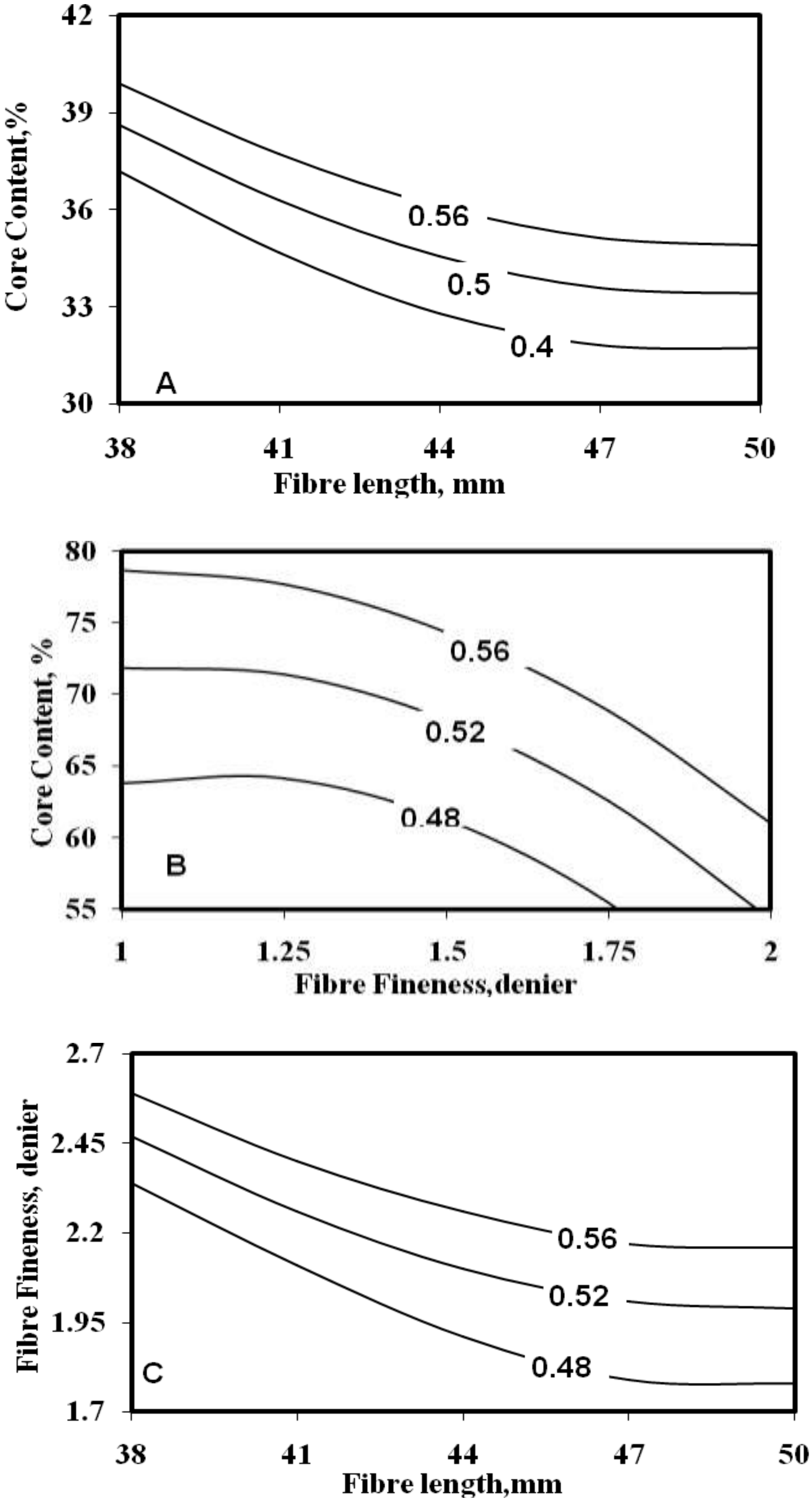


Fig.6− Contour for packing fraction; A: 1.5 denier fibre fineness, B: 44mm fibre length and C: 50% core content.