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Effect of linear density of feed yarn filaments and air-jet texturing process variables on compressional properties of woven fabrics

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The influence of yarn feed and process parameters used in the production of air-jet textured yarn on compression and recovery behavior of air-jet textured yarn fabric has been studied. Yarn linear density per filament and air-jet texturing process parameters, such as overfeed, air pressure and texturing speed are the key factors which influence yarn structure and hence fabric properties. The individual effect of feed yarn properties and air-jet process variables in the production of air-jet textured yarn has been studied in term of potential contribution and normalized regression coefficient on fabric low load compression behavior. Fabric low load compression-recovery behavior has been analyzed by defining compression parameter, recovery parameter and resiliency. Analysis shows that most dominating factor to explain the air-jet textured yarn fabric low-load compression properties is overfeed percentage, while linear density per filament is most dominating factor affecting fabric resiliency.

Keywords: Air-jet textured yarns, Compression properties, Compression parameter, Linear density, Recovery parameter, Resiliency, Woven fabrics

1 Introduction

Texturing is the method by which compact structure of continuous filament yarn is modified to impart texture to filament bundle, which will provide bulk like spun yarn for better comfort characteristics to the fabrics made from them. In air-jet texturing, filament yarn with certain overfeed is fed in cold supersonic airstream toproduce entangled filament bulked yarn of low extension ability. It is known that air-jet textured yarn has certainly good resemblance of spun yarn due to unique structure. The low-load compression behavior of woven fabrics is very significant in term of handle and comfort. Compressibility is one of the important properties of the fabric which affects the softness and fullness of the fabric. Fabric compression is strongly correlated to its geometry, and the structural properties of yarnand fibre, from which it is constructed. It is also useful for fabric handling during garment manufacturing. In addition, it is found that the analysis of the pressure thickness relationship may shed light on the structure of the fabrics.

The analysis of compression behavior of textile ensemble was first studied by Schiefer[1], who developed the compression meter and defined the association between the thickness of fabric and the compression force. Later Van Wyk[2] introduced a model based on the analysis of compression behavior of woolen fabric. This model was considerably extended by many researchers[3-5] to elaborate the compression properties of nonwoven, woven and knitted fabrics. Kothari and Das[6] studied the compression properties of nonwoven geotextile by evaluating two parameters α and β to represent the compression and recovery curves respectively by an empirical model. Matasudaira and Qin[7] analyzed the compression curve by dividing it in five zones and defined the regression constant for each. Gurumurthy[8] used fabric geometrical parameter as a input to an artificial neural network model to predict fabric compression properties of different cotton woven fabrics and compared the modeled results with corresponding Kawabata data. Rengasamy *et al.*[9] reported the effect of feed yarn fineness and process parameter of core and effect of air-jet textured yarn on fabric compression properties.

The present study is aimed at explaining the pressure-thickness relationship of woven air-jet textured yarn fabrics in low-load regions by suitable mathematical coefficients using empirical modeling. The individual effect of feed yarn parameters like

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linear density per filament and process parameters like overfeed, air pressure and texturing speed on the air-jet textured yarn fabric compression-recovery behavior has been studied. The contribution of each yarn feed and process parameters on the measured fabric properties is also evaluated in term of potential contribution and normalized regression coefficient.

2 Material and Methods

2.1 Raw Materials

Three polyester fully drawn yarns having linear density of 111.1/100, 111.1/50 and 111.1/33 dtex with circular cross-section and semi dull luster were used for the study. Tenacity values of these yarn were 3.38, 3.35 and 3.11 cN/dtex respectively

2.2 Methods

2.2.1 Preparations of Samples

Three different levels of each parameter at equal intervals were taken as low, medium and high (coded as -1, 0, +1) values and theses values were used in different combinations according to the 4 variable 3 level Box-Behnken design.

Total 28 samples were prepared at different levels of linear density per filament, overfeed, airpressure and texturing speed after the randomization of the experimental runs of Box-Behnken design as per run order given in Table 1. The following machineparameters were kept constant during the production of all samples:

Machine used	:	Eltex AT/HS
Nozzle used	:	Hemajet S325
No. of yarn fed together	:	2
Wetting	:	1l/jet/h
Stabilization heater temperature	:	180 □C
Mechanical stretch	:	4.3%
Winding underfeed	:	0.6%

Plain woven fabric samples were prepared with twisted 166.66/144 dtex polyester multifilament yarn as warp on Lakshmi shuttle loom at 120 picks/min and a reed space of 56 inches (1422 mm). Twenty eight air-jet textured yarns (Table 1) were used as weft to prepare fabric samples. The ends/cm and pick/cm on loom were kept 28.4 and 25.2 respectively. The grey fabrics was then relaxed in jet dying machine at boil with 1% non-ionic detergentfor 45 min. The fabrics were then heat-set on stenter at 18 m/min speed with 3.5% overfeed allowing 5% widthwise shrinkage at 180°C. The heat-set fabrics had ends per cm and picks per cm were kept 29.9 and 28.4 respectively.

A digital thickness tester was used to measure compression and recovery property. Fabric was placed between anvil and pressure foot of 110 mm diameter to apply pressure of 1gf/cm^2 on the fabric for 30 s, and thickness was measured as initial thickness (T_o). The compressive loads were increased in the thirteen steps and thickness was recorded after waiting for 30 s in each step. After getting a pressure of 20 gf/cm^2, the pressure was gradually reduced in same steps and resultant thickness values were recorded in the same way during recovery cycles.

2.2.2 Experimental Data and Analysis

Figure 1 shows a typical set of data thickness-pressure loading and unloading cycle. In order to fit the appropriate curve to both for loading and unloading data of various fabrics, following two sets each having five equations were tried:

	Ist Set (Loading)	IInd Set (Unloading)
(i)	$T / T_f = e^{-\alpha (P / P_f - 1)}$	$T / T_f = e^{-\beta (P / P_f - 1)}$
(ii)	$T = T_f - \alpha (P / P_f - 1)$	$T = T_f - \beta (P / P_f - 1)$
(iii)	$T / T_f = (P / P_f)^{-\alpha}$	$T / T_f = (P / P_f)^{-\beta}$
(iv)	$T / T_f = 1 - \alpha \times (\log_e P / P_f)$	$T / T_f = 1 - \beta \times (\log_e P / P_f)$
(v)	$T = \alpha / \log_e P$	$T = \beta / \log_e P$

where α and β are the compression and recovery parameters respectively; and T_f and P_f, the final thickness and pressure respectively. We have performed curve fitting with the help of Matlab curve fitting tool for all the above equations using loading and unloading data of the fabrics. We obtained five different curves for each set of data and corresponding least square errors. The curve number 4 of the first set was found for loading and curve number 3 of the second set for unloading fit in case of the fabrics studied with minimum least square error. Therefore, the following equation represents the loading and unloading behavior of woven fabrics used for this study:

$T / T_f = 1 - \alpha \times (\log_e P / P_f)$

$T / T_f = (P / P_f)^{-\beta}$

Figure 1 shows typical best fitted compression and recovery curves of a fabrics. The work done during compression can be given by the following equation:

$$W_c = \int_{T_0}^{T_f} P\,A\,dT = P_f A \int_{T_0}^{T_f} e^{-1/\alpha\left(1-\frac{T}{T_f}\right)} dT$$

Table 1 — Box-Behnken design for the variables used for study and their corresponding air jet textured yarn properties

Sample No.	Run order	Process parameters				Experimental values			
		Linear density /filament dtex	Overfeed %	Air-pressure bar	Texturing speed m/min	Physical bulk %	Instability %	Tenacity cN/tex	Loss in tenacity %
1	3	1.11	18	8.5	400	214.3	0.22	2.64	22.0
2	24	3.33	18	8.5	400	170.6	0.65	2.57	17.5
3	26	1.11	36	8.5	400	320.0	3.60	1.87	44.7
4	12	3.33	36	8.5	400	248.8	6.26	1.98	36.2
5	11	2.22	27	7.0	300	210.3	3.15	2.39	28.6
6	18	2.22	27	10.0	300	250.1	1.65	2.13	36.3
7	16	2.22	27	7.0	500	206.5	5.01	2.51	25.0
8	4	2.22	27	10.0	500	239.8	4.35	2.24	33.2
9	22	1.11	27	8.5	300	278.2	0.95	2.25	33.3
10	14	3.33	27	8.5	300	203.4	2.95	2.22	28.7
11	23	1.11	27	8.5	500	264.0	2.15	2.34	30.9
12	28	3.33	27	8.5	500	195.4	4.65	2.31	25.8
13	7	2.22	18	7.0	400	182.2	0.39	2.71	19.1
14	13	2.22	36	7.0	400	245.6	4.69	2.33	30.5
15	15	2.22	18	10.0	400	198.5	0.80	2.61	22.2
16	19	2.22	36	10.0	400	286.4	4.30	2.03	39.5
17	17	1.11	27	7.0	400	250.2	2.85	2.21	34.5
18	20	3.33	27	7.0	400	190.3	5.26	2.30	26.2
19	27	1.11	27	10.0	400	288.4	2.34	2.04	39.6
20	1	3.33	27	10.0	400	214.3	4.95	2.08	33.2
21	8	2.22	18	8.5	300	192.1	0.38	2.66	20.6
22	9	2.22	36	8.5	300	268.2	3.25	2.09	37.5
23	5	2.22	18	8.5	500	190.2	0.54	2.73	18.4
24	10	2.22	36	8.5	500	256.2	5.64	2.20	34.4
25	2	2.22	27	8.5	400	222.6	2.68	2.15	35.8
26	17	2.22	27	8.5	400	224.3	2.86	2.17	35.2
27	21	2.22	27	8.5	400	224.2	2.74	2.20	34.2
28	15	2.22	27	8.5	400	223.2	2.65	2.18	34.8

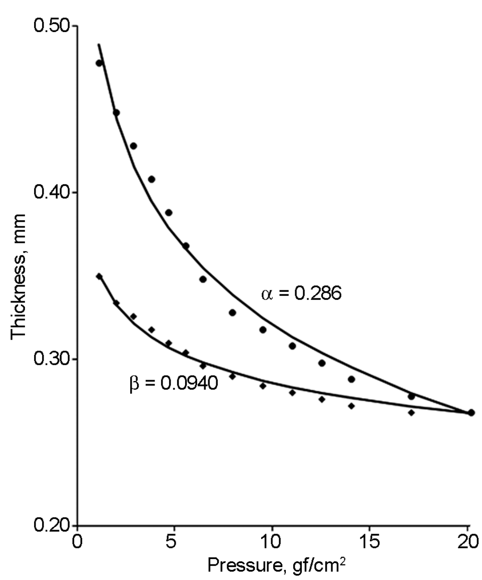

Fig. 1 — Best fitted curve for pressure-thickness data with actual valuesfor air-jet textured yarn fabrics

where T_o and T_f are the initial and final thickness respectively; and P_f, the final pressure at 20gf/cm^2. The work done during recovery can be given by the following equation:

$$W_r = \int_{T_f}^{T_r} P\, A\, dT = A P_f \int_{T_f}^{T_r} \left(\frac{T}{T_f}\right)^{-1/\beta} dT$$

where T_r is the recovered thickness at pressure 1gf/cm^2. Fabric resiliency was calculated with the help of following formula:

$$\text{Resiliency (\%)} = (W_r / W_c) \times 100$$

where Wc is the compression energy under fitted compression curve and W_r, the recovered energy under fitted recovery curve.

2.2.3 Methodology of Analysis

The textured yarn samples were tested and results are shown in Table 1 for physical bulk, instability, and loss in tenacity. The corresponding textured yarn fabric samples were also tested for loading and unloading characteristics and data are shown in Table 2. To observe the effect of individual parameters, the regression equations were formed with the help of Design Expert 8.0 software package. The general form of the equation adopted is given below:

$$P=C_0+C_1X_1+C_2X_2+C_3X_3+C_4X_4+C_5X_1X_2+C_6X_1X_3+C_7X_1X_4+C_8X_2X_3+C_9X_2X_4+C_{10}X_3X_4+C_{11}X_1^2+C_{12}X_2^2+C_{13}X_3^2+C_{14}X_4^2$$

where P is the property being studied; X_1, the linear density per filament; X_2, the overfeed; X_3, the air pressure; X_4, the texturing speed; and C_0-C_{14}, the regression coefficients.

The regression coefficients from the model equations as established for the all fabric properties are given in Table 3. From the established regression model, normalized regression coefficients and per cent contribution were computed for each linear, interactive, and quadratic term. To calculate normalized regression coefficient general form of regression equation is converted in following form and then fitting of the multiple regression equation was done:

$$(P-\overline{P})/\sigma_P=Z_0+Z_1\,(X_1-\overline{X_1})/\sigma_{X_1}+Z_2\,(X_2-\overline{X_2})/\sigma_{X_2}+Z_3\,(X_3-\overline{X_3})/\sigma_{X_3}+\ldots..$$

where σ is the standard deviation of term associate, $\overline{X_n}$, the mean of the term associate; and Z_n, the normalized regression coefficient of term n.

The standardized regression coefficients represent the change in terms of standard deviations in the dependent variable that result from a change of one standard deviation in an independent variable. Normalized regression coefficients are more

Table 2 — Compression and recovery parameters of air-jet textured yarn fabric

Sample No.	Initial thickness (T_o) mm	Compressed thickness (T_f), mm	Recovered thickness (T_r), mm	Compression parameter (α)	R^2	Recovery parameter (β)	R^2	Resiliency %
1	0.460	0.266	0.338	0.264	0.995	0.0846	0.989	34.8
2	0.358	0.228	0.292	0.213	0.988	0.0886	0.989	43.4
3	0.638	0.312	0.470	0.390	0.988	0.1398	0.996	42.2
4	0.490	0.266	0.404	0.308	0.987	0.1479	0.991	54.6
5	0.472	0.262	0.356	0.285	0.994	0.1136	0.986	44.2
6	0.522	0.280	0.412	0.309	0.990	0.1297	0.987	48.5
7	0.350	0.212	0.262	0.226	0.988	0.0926	0.991	40.7
8	0.385	0.222	0.290	0.264	0.994	0.1024	0.990	42.8
9	0.592	0.306	0.438	0.354	0.992	0.1190	0.979	38.5
10	0.454	0.262	0.370	0.272	0.981	0.1236	0.979	50.2
11	0.446	0.258	0.320	0.256	0.985	0.0848	0.986	33.2
12	0.374	0.232	0.308	0.228	0.993	0.0878	0.989	43.4
13	0.302	0.194	0.228	0.185	0.976	0.0660	0.983	35.9
14	0.446	0.248	0.342	0.286	0.990	0.1160	0.989	44.6
15	0.434	0.256	0.328	0.260	0.993	0.1021	0.986	42.6
16	0.546	0.288	0.430	0.305	0.987	0.1342	0.996	48.6
17	0.478	0.268	0.350	0.286	0.987	0.0940	0.984	35.8
18	0.396	0.242	0.322	0.240	0.972	0.1025	0.982	47.2
19	0.604	0.306	0.444	0.372	0.990	0.1306	0.993	40.2
20	0.458	0.258	0.382	0.292	0.983	0.1370	0.989	53.4
21	0.412	0.248	0.314	0.238	0.978	0.0898	0.989	40.2
22	0.570	0.300	0.448	0.328	0.994	0.1400	0.986	50.2
23	0.270	0.178	0.210	0.172	0.996	0.0606	0.986	33.8
24	0.440	0.248	0.342	0.275	0.993	0.1089	0.984	43.4
25	0.456	0.252	0.344	0.280	0.993	0.1105	0.981	43.2
26	0.445	0.252	0.338	0.273	0.996	0.1090	0.982	42.7
27	0.436	0.248	0.330	0.260	0.986	0.1078	0.985	44.3
28	0.444	0.250	0.336	0.264	0.984	0.1082	0.982	44.0

comparable across independent variables due to being scaled in the same standardized matrix.

On the basis of analysis of variance, the sum of square for each individual model component was defined. The per cent of contribution for each individual term was calculated (Table 4). The expression for calculation of per cent contribution with the help of sum of squares is given below:

$$\text{Per cent contribution} = \frac{\text{Sum of square of individual term}}{\sum \text{Sum of square}} \times 100$$

3 Results and Discussion

To analyze the effect and contribution of feed yarn denier per filament and selected air-texturing parameters on textured yarn fabric properties, normalized values of properties are plotted in Figures 2-5 against the coded values of independent variables. The X-axis shows the coded levels of the linear density per filament and selected texturing variables used for the study, and Y-axis shows the normalized value of the textured yarn fabric properties after it has been scaled from 0 to 100.

Table 3 — Regression coefficient of fabric properties based on coded value of input parameters

Factor	Coefficients	Initial thickness (T_o), mm	Compression parameter(α)	Recovery parameter (β)	Resiliency %
-	C_0	+0.4453	+0.2693	+0.10888	+43.557
X_1	C_1	-0.0573	-0.0308	+0.00288	+5.631
X_2	C_2	+0.0745	+0.0467	+0.02459	+4.407
X_3	C_3	+0.0421	+0.0245	+0.01261	+2.313
X_4	C_4	-0.0631	-0.0304	-0.01488	-2.877
$X_1 * X_2$	C_5	-0.0115	-0.0077	+0.00103	+0.943
$X_1 * X_3$	C_6	-0.0160	-0.0085	-0.00052	+0.456
$X_1 * X_4$	C_7	+0.0165	+0.0135	-0.00040	-0.344
$X_2 * X_3$	C_8	-0.0080	-0.0140	-0.00448	-0.692
$X_2 * X_4$	C_9	+0.0030	+0.0033	-0.00048	-0.112
$X_3 * X_4$	C_{10}	0.0038	+0.0035	-0.00158	-0.569
X_1^2	C_{11}	+0.0418	+0.0244	+0.00492	-0.189
X_2^2	C_{12}	-0.0059	-0.0070	-0.00280	-0.515
X_3^2	C_{13}	-0.0025	+0.0038	+0.00248	+0.775
X_4^2	C_{14}	-0.0158	-0.0091	-0.00601	-1.157
R^2 value -		0.951	0.915	0.886	0.938

X_1= DPF, X_2= Overfeed , X_3= Air-pressure and X_4 = Texturing speed.

Table 4 — Significance of different compontents of quadratic model on properties of air-jet textured yarn fabrics

Factor	Normalized regresssion coefficient				Sum of square				Per cent contribution			
	Initial thickness (T_o)	Compression parameter (α)	Recover parameter (β)	Resiliency	Initial thickness (T_o)	Compression parameter (α)	Recovery parameter (β)	Resiliency	Initial thickness (T_o)	Compression parameter (α)	Recovery parameter (β)	Resiliency
X_1	-0.44	-0.41	+0.09	+0.68	0.03945	0.01135	0.00010	380.5	20.7	18.2	0.8	47.6
X_2	+0.58	+0.62	+0.75	+0.53	0.06660	0.02613	0.00726	233.1	35.0	41.9	58.2	29.2
X_3	+0.33	+0.33	+0.38	+0.28	0.02125	0.00720	0.00191	64.2	11.2	11.5	15.3	8.0
X_4	-0.49	-0.41	-0.45	-0.35	0.04775	0.01110	0.00266	99.3	25.1	17.8	21.3	12.4
$X_1 * X_2$	-0.06	-0.07	+0.02	+0.08	0.00053	0.00024	0.00000	3.6	0.3	0.4	0.0	0.4
$X_1 * X_3$	-0.08	-0.08	-0.01	+0.04	0.00102	0.00029	0.00000	0.8	0.5	0.5	0.0	0.1
$X_1 * X_4$	+0.09	+0.12	-0.01	-0.03	0.00109	0.00073	0.00000	0.5	0.6	1.2	0.0	0.1
$X_2 * X_3$	-0.04	-0.12	-0.09	-0.06	0.00026	0.00078	0.00008	1.9	0.1	1.3	0.6	0.2
$X_2 * X_4$	+0.02	+0.03	-0.01	-0.01	0.00004	0.00004	0.00000	0.1	0.0	0.1	0.0	0.0
$X_3 * X_4$	-0.02	+0.03	-0.03	-0.05	0.00006	0.00005	0.00001	1.3	0.0	0.1	0.1	0.2
X_1^2	+0.22	+0.22	+0.10	-0.02	0.01050	0.00358	0.00015	0.2	5.5	5.7	1.2	0.0
X_2^2	-0.03	-0.06	-0.06	-0.04	0.00021	0.00029	0.00005	1.6	0.1	0.5	0.4	0.2
X_3^2	-0.01	+0.03	+0.05	+0.06	0.00004	0.00009	0.00004	3.6	0.0	0.1	0.3	0.5
X_4^2	-0.08	-0.08	-0.12	-0.09	0.00150	0.00050	0.00022	8.0	0.8	0.8	1.7	1.0

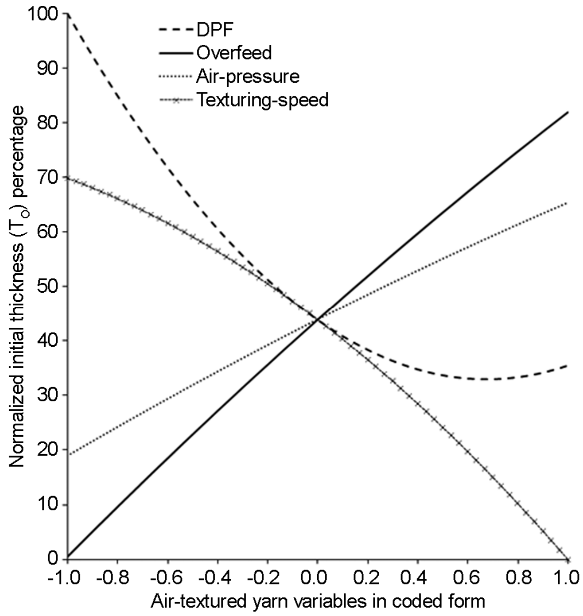

Fig. 2 — Individual effect of feed yarn denier per filament and different air-jet texturing variables on normalized initial thickness of air-jet textured yarn fabrics

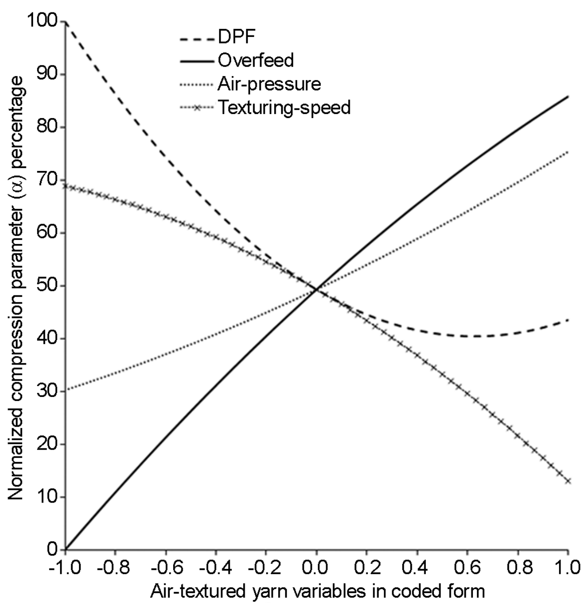

Fig. 3— Individual effect of feed yarn denier per filament and different air-jet texturing variables on normalized compression parameter of air-jet textured yarn fabrics

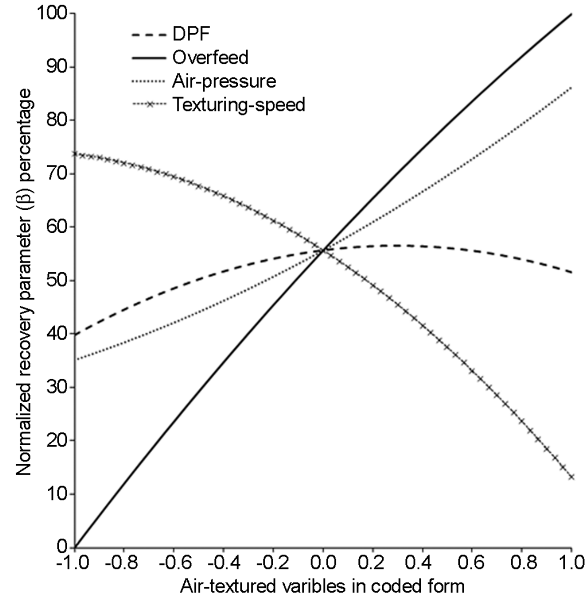

Fig.4 — Individual effect of feed yarn denier per filament and different air-jet texturing variables on normalized recovery parameter of air-jet textured yarn fabrics

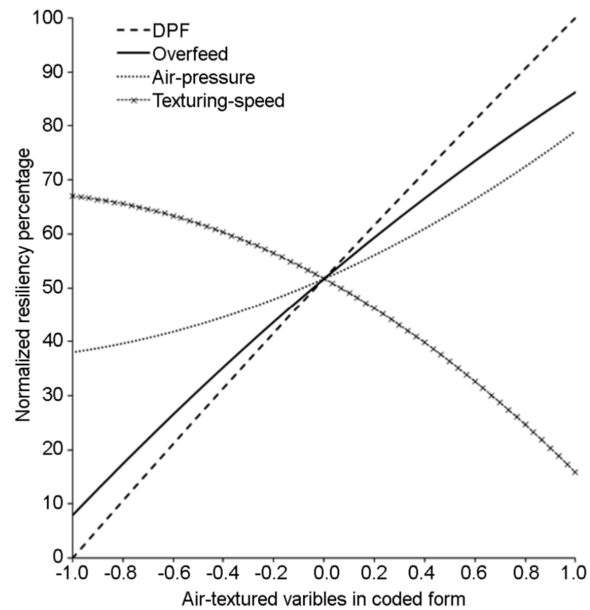

Fig. 5 — Individual effect of feed yarn denier per filament and different air-jet texturing variables on normalized resiliency of air-jet textured yarn fabrics

Figures show the percentage change in the textured yarn fabric properties corresponding to the changes in the variable studied from low to high levels.

3.1 Effect of Linear Density per Filament

Figures 2-5 show that the increase in linear density per filament in parent yarn causes decrease in air-textured yarn fabric thickness and compression parameter, however recovery parameter and resiliency of textured yarn fabric increase.

For a constant total yarn linear density, the number of filament will be higherfor lowerlinear density per filament yarn. The flexural rigidity of filament also varies directly with square of its linear density[10], so the finer filaments will tend to bend easily as compare to the coarser filaments. The textured yarn made of finer filament poses higher loop frequency and lower loop height. The smaller loops are more resilient to deformation than the larger loops hence textured fabric made of finer filament shows higher thickness and compressibility as compare to coarser filament fabric.

The higher loop density and smaller loops of textured yarn leads to more number of filament entanglement in the core of finer filaments and also due to easy bending increases the frictional area of contact within the yarn matrix. Hence, the chances of retention of original filament position after withdrawal of loading force decreases the recovery parameter and resiliency of thefiner filament yarnfabrics.

It is clear from Figs 2-5 that linear density per filament shows significant influence on all air-jet textured yarn fabric properties. On the basis of values of normalized regression coefficient and per cent contribution (Table 4), we can say that linear density of filament in parent yarn is the most important variable to explain variability in fabric resiliency and the second most important variable to explain remaining fabric properties was studied.

3.2 Effect of Overfeed

It can be seen from Figs 2-5 that there is a sharp increase in all textured yarn fabric properties with an increase in overfeed percentage of feed yarn.

The increase in fabric thickness with increase in overfeed can be because of the fact that textured yarn physical bulk enhances with the increase in overfeed. With the increase in overfeed, compactness of the yarn core reduces although number of loops increases

Figures 2-5 show that for all experimental combinations, overfeed percentage tends to display substantially sharp changes in air-jet textured fabric properties, from low to high level of overfeed. From Table 4, it is observed that the normalized regression coefficient and percent contribution show highest value against overfeed percentage in case of thickness, compression parameter and recovery parameter, and the second most influencing variable in case of resiliency means that air-jet textured fabric properties are influenced most by changes in the overfeed.

3.3 Effect of Air Pressure

Figures 2-5 show that with the increase in air pressure, all fabric properties increases. The increase in air pressure enhances the turbulence and formation of the more number of loops and this leads to higher physical bulk of the resultant air-jet textured yarn. The higher physical bulk of yarn results in an increase in fabric thickness and compressibility.

The increase in air-pressure leads to more compact core of yarn structure. Due to formation of compact core, higher recovery in fabric thickness on unloading is observed. Higher values of recovery on unloading and resiliency can be seen with the increase in air pressure.

As the values of normalized regression coefficient and percent contribution (Table 4) correspond to air pressure, this indicates a positive influence on all the textured yarn fabric properties.

3.4 Effect of Texturing Speed

Fabric thickness shows a sharp decrease with an increase in texturing speed (Fig. 2). With an increase in texturing speed, a given length of filament will be exposed to the air flow for a shorter duration, resulting in less intense entanglement and increase in yarn instability. So, as the yarn is subjected to higher process stress during subsequent weaving operation, this diminishes the texturing effect of the yarn. This results in lower values of thickness and compression parameter.

At higher filament speed (due to higher machine speed), the relative velocity between filaments and surrounding air flow reduces, thus reducing the forces and torque exerted on the individual filaments. Hence, a mutual displacement between the filaments, and a consequent decrease in loop formation tendency are observed. Also, with the increase in process speed yarn has lesser time in air stream, resulting in less effective texturing and leading to lower values of resiliency and recovery parameter.

From the values of normalized regression coefficient and per cent contribution of texturing speed in Table 4, it can be concluded that texturing speed is the second most influencing factor in case of initial thickness and recovery parameter while it has a significant contribution in case of compression parameter and fabric resiliency.

4 Conclusion

Based on the results of multiple regression model and contribution analysis of the different air-jet texturing variables on textured yarn fabric properties, the following conclusions can be drawn.

Overfeed percentage is an important factor in determining the air-jet textured fabric compression properties. A steep increase is visible in all textured yarn properties with the increase in overfeed percentage. The second most influential variable among the four variables studied is linear density per filament. Linear density per filament of parent yarn affect the fabric resiliency, thickness, compression parameter and recovery parameter significantly. Although airpressure affects fabric properties the least among variables studied but it has significant contribution to all fabric properties.

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