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Experimental Investigation of Effects of Fabric Thickness, Loop Shape Factor, Fabric Tightness Factor and Aerial Weight on Air Permeability of Pique Cotton Knitted Fabric

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***Abstract*—** The present study tries to navigate the effects of fabric aerial weight, loop shape factor, tightness factor and thickness on air permeability of pique knitted fabric made with 100% cotton yarn. Samples used for experimentation are purchased from market. For assessing the factor effects statistical analysis is made using Design expert software and for computation (BBD) is followed. 30 experimental runs have been made and for point prediction of the response, a confidence level of 0.95 is used. Thus, a calculated correlation coefficient of 76.37% is found. The analysis proves fabric aerial weight, thickness and fabric tightness factor significantly affects air permeability of pique fabric made with 100% cotton yarn. Thus, the study shows fabric aerial weight, fabric thickness and tightness factor affect air permeability negatively but significantly.

***Keywords*—** Pique, fabric aerial weight, thickness, loop shape factor, tightness factor, air permeability, BBD

I. INTRODUCTION

Air permeability in a textile fabric refers to a rate at which air flows perpendicularly in a specified area. [1-4]
Pore behavior influences the flow of air through the textile material. The pore size is influenced by count, diameter, thread densities, etc. Additionally, materials used for treating the fabric also affects air permeability.

Air permeability of a knitted fabric has an influence on the fabrics' comfort behavior. While a wearer is exposed to the outside atmosphere, it is better for the fabric to have an optimum air permeability so as to protect the wearer from wind. [5-8]

The loop length affects density, aerial weight, porosity, width, dimensional stability, etc. [9]

The fabric thickness is one of the main factors influencing air permeability characteristics. The other main factor is fabric tightness factor which determines this property.
Knitted fabrics are more permeable to air. This is useful quality for underwear whereby the garment next to skin can 'breathe'. [10]

Athirah et al reported in their studies that air permeability has an inverse relation with fabric aerial weight and thickness. They also studied that loop shape factor loosely and negatively affect air permeability behavior of a knitted fabric. They stressed that porosity has a significant effect on the stated parameter. [11]

S.S. Bhattacharya et al reported that air permeability varies with change of fabric porosity. They studied that the two are directly correlated. This is entertained by changing of the fabric tightness factor. Here it is also reported that fabrics made with coarser yarn exhibit lower air permeability values. Fabrics with a lower thickness and aerial weight also show higher air permeability. [12]

In this research it is planned to see the stated effects on air permeability of pique knitted fabrics made with 100 % cotton. Design expert software is used for analyzing the significance of the stated factors. For analysis Box Behnken design is used.

II. RELATED WORK

Neway has reported that one of the factors stated in this paper & affecting air permeability properties of knitted fabric, i.e. fabric aerial weight (GSM) is significantly affected by control of input yarn tension. He has used one-way ANOVA for analysis of the experiment. [13]. Using the same design of experiment analysis, he has also found the significant effect of mechanical yarn stretch % in sizing on warp yarn breakage cmpx values. [14]

Neway has used Box Behnken design and also reported that the factors have significant effects on water vapor permeability property of single jersey polyester knitted fabrics. [15]

In addition the author has reported that the stated factors have significant effects on thermal conductivity of plain single jersey cotton knitted fabrics. [16]

III. METHODOLOGY

For conducting the experiment, pique designed single jersey fabric is collected from market. All the samples are made with 100% cotton yarn.

Below is a table showing the properties of the sample fabrics.

Table 1 Characteristic of the sample fabrics

S.no	Experimental code	Fabric composition	Count (Ne)	Sample fabric structure	Wales/inch	Course/inch	Fabric aerial weight (GSM)	Thickness (mm)	Loop length (mm)	Fabric tightness factor ($tex^{1/2}$/loop length in mm)	Loop shape factor (CPI/WPI)
1	S_1CP	100% cotton	64	Pique single jersey	40	48	158.5	5.5	2.4	1.27	1.2
2	S_2CP	100% cotton	19	Pique single jersey	30	42	128.7	5.5	2.8	1.98	1.385
3	S_3CP	100% cotton	64	Pique single jersey	30	42	158.5	6.1	2.4	1.27	1.385
4	S_4CP	100% cotton	19	Pique single jersey	40	48	158.5	5.5	2.8	1.98	1.2
5	S_5CP	100% cotton	40	Pique single jersey	28	44	158.5	4.9	2.4	1.625	1.57
6	S_6CP	100% cotton	40	Pique single jersey	40	48	158.5	6.1	2.4	1.625	1.2
7	S_7CP	100% cotton	64	Pique single jersey	28	44	158.5	5.5	2.4	1.27	1.57
8	S_8CP	100% cotton	19	Pique single jersey	28	44	158.5	5.5	2.8	1.98	1.57
9	S_9CP	100% cotton	40	Pique single jersey	30	42	188.3	4.9	2.4	1.625	1.385
10	S_{10}CP	100% cotton	19	Pique single jersey	30	42	158.5	6.1	2.8	1.98	1.385
11	S_{11}CP	100% cotton	64	Pique single jersey	30	42	188.3	5.5	2.4	1.27	1.385
12	S_{12}CP	100% cotton	40	Pique single jersey	28	44	128.7	5.5	2.4	1.625	1.57
13	S_{13}CP	100% cotton	40	Pique single jersey	30	42	158.5	5.5	2.4	1.625	1.385
14	S_{14}CP	100% cotton	40	Pique single jersey	30	42	188.3	6.1	2.4	1.625	1.385
15	S_{15}CP	100% cotton	64	Pique single jersey	30	42	158.5	4.9	2.4	1.27	1.385
16	S_{16}CP	100% cotton	40	Pique single jersey	30	42	128.7	6.1	2.4	1.625	1.385
17	S_{17}CP	100% cotton	19	Pique single jersey	30	42	158.5	4.9	2.8	1.98	1.385
18	S_{18}CP	100% cotton	40	Pique single jersey	40	48	158.5	4.9	2.4	1.625	1.2
19	S_{19}CP	100% cotton	40	Pique single jersey	30	42	128.7	4.9	2.4	1.625	1.385
20	S_{20}CP	100% cotton	19	Pique single jersey	30	42	188.3	5.5	2.8	1.98	1.385
21	S_{21}CP	100% cotton	40	Pique single jersey	28	44	158.5	6.1	2.4	1.625	1.57
22	S_{22}CP	100% cotton	64	Pique single jersey	30	42	128.7	5.5	2.4	1.27	1.385
23	S_{23}CP	100% cotton	40	Pique single jersey	28	44	188.3	5.5	2.4	1.625	1.57
24	S_{24}CP	100% cotton	40	Pique single jersey	40	48	188.3	5.5	2.4	1.625	1.2
25	S_{25}CP	100% cotton	40	Pique single jersey	40	48	128.7	5.5	2.4	1.625	1.2

SCP describes sample made with cotton and having pique structure.

Experimental

The stated samples are tested for composition, count, thread densities, aerial weight, thickness, loop length.

The samples are conditioned for 24 hr. with a temperature of 22^0c & a relative humidity of 63%

prior to testing. Then, the conditioned specimens are tested for:

Fabric GSM: using GSM cutter and electronic balance following ASTM D 3776 with a specimen size of 100cm2

Fabric composition: test is made with ISO 1833:2012 test method with MLR ratio of 1g of fabric: 200 ml of (75% conc. H_2SO4)

Fabric thickness test: fabric thickness is one of the basic parameters determining the fabrics' warmth, bulkiness and performance characteristics. The test is conducted following ASTM D 1777.

Loop length: of a knitted fabric is measured and calculated by using the formula:

Loop length=course length/No. of loops (1)

Tightness factor: It is the relative tightness or looseness of knitted fabrics. The higher the factor shows the fabric is tighter. It is highly or solely dependent on loop or stitch length. It is an important fabric property which has an influence on fabric durability, drape, handle, strength, abrasion resistance, dimensional stability, air permeability, water vapor permeability, thermal conductivity, etc.

It is calculated with the formula:

Fabric tightness factor=$tex^{1/2}$/loop length (2)

Loop shape factor: The factor determines the dimensions of the knitted fabrics. It determines the variability between the yarn densities. It is determined with:

Loop shape factor=CPI/WPI (3)

IV. RESULTS AND DISCUSSION

After testing and analyzing the above internal properties, the sample fabrics are tested for their air permeability characteristics and in below table results are discussed.

Air permeability test: TEXTEST FX3300 air permeability tester is used following ASTM D 1776 test method. The specimen size is 5.93 in^2.

Fig. 1 TEXTEST FX3300 air permeability tester

The tested samples are now analyzed for their statistical significance and fitness of model with design expert software.

For analysis Box Behnken design is used,

File Version	**11.0.3.0**		
Study Type	Response Surface	**Subtype**	Randomized
Design Type	Box-Behnken	**Runs**	30
Design Model	Quadratic	**Blocks**	No Blocks
Build Time (ms)	388.00		

Table 2 Experimental runs and results for air permeability

		Factor 1	Factor 2	Factor 3	Factor 4	Response 1
Std	**Run**	**A:Fabric aerial weight**	**B:Fabric thickness**	**C:Tightness factor**	**D:Loop shape factor**	**Air permeability**
		GSM	**mm**	**-**	**-**	**$cm^3/cm^2/s$**
5	1	158.5	5.5	1.27	1.2	112
19	2	128.7	5.5	1.98	1.385	104
14	3	158.5	6.1	1.27	1.385	109
6	4	158.5	5.5	1.98	1.2	110
23	5	158.5	4.9	1.625	1.57	114
22	6	158.5	6.1	1.625	1.2	105
7	7	158.5	5.5	1.27	1.57	115
8	8	158.5	5.5	1.98	1.57	99
2	9	188.3	4.9	1.625	1.385	104
16	10	158.5	6.1	1.98	1.385	95
18	11	188.3	5.5	1.27	1.385	112
11	12	128.7	5.5	1.625	1.57	110
25	13	158.5	5.5	1.625	1.385	115
4	14	188.3	6.1	1.625	1.385	101
13	15	158.5	4.9	1.27	1.385	125
27	16	158.5	5.5	1.625	1.385	117
3	17	128.7	6.1	1.625	1.385	112
15	18	158.5	4.9	1.98	1.385	110
21	19	158.5	4.9	1.625	1.2	114
1	20	128.7	4.9	1.625	1.385	128
20	21	188.3	5.5	1.98	1.385	94
30	22	158.5	5.5	1.625	1.385	108
29	23	158.5	5.5	1.625	1.385	115

		Factor 1	Factor 2	Factor 3	Factor 4	Response 1
Std	**Run**	**A:Fabric aerial weight**	**B:Fabric thickness**	**C:Tightness factor**	**D:Loop shape factor**	**Air permeability**
		GSM	**mm**	**-**	**-**	**$cm^3/cm^2/s$**
24	24	158.5	6.1	1.625	1.57	112
28	25	158.5	5.5	1.625	1.385	112
17	26	128.7	5.5	1.27	1.385	138
12	27	188.3	5.5	1.625	1.57	102
10	28	188.3	5.5	1.625	1.2	104
9	29	128.7	5.5	1.625	1.2	128
26	30	158.5	5.5	1.625	1.385	113

Table 3 Analysis of variance

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	2047.67	4	511.92	20.20	< 0.0001	significant
A-Fabric aerial weight	884.08	1	884.08	34.88	< 0.0001	
B-Fabric thickness	310.08	1	310.08	12.23	0.0018	
C-Tightness factor	816.75	1	816.75	32.22	< 0.0001	
D-Loop shape factor	36.75	1	36.75	1.45	0.2398	
Residual	633.70	25	25.35			
Lack of Fit	584.37	20	29.22	2.96	0.1160	not significant
Pure Error	49.33	5	9.87			
Cor Total	2681.37	29				

The ANOVA analysis shows the developed model is significant and lack of fitness is insignificant. Thus, the model is adequate and fit. F-value of 20.20 shows the model's significance.

In the experiment P-values indicates that fabric aerial weight, thickness and fabric tightness factor significantly affects air permeability of pique single jersey fabric made with 100% cotton yarn.

From the experiment it is found that when aerial weight increases, air permeability decreases. This is because as GSM increases the fabric gets denser and bulkier and the air space in the fabric (inter-yarn space) decreases as it is occupied by fibers. Thus, the study shows fabric aerial weight negatively but significantly affects air permeability. The experimental analysis proves that fabric thickness is having an inverse relation with air permeability. Highest thickness exhibits lower value of air permeability. This is because as thickness increases, it takes more time for air passage & it will be trapped by the fibrous material in the fabric structure.

The other factor significantly affecting the air permeability is fabric tightness factor. The samples with the lowest tightness factor results in the higher value of air permeability. This is because; as the fabric is getting tighter its porosity will reduce thus lower air permeability. Tightness factor is directly correlated with coarseness of yarns. Since coarser yarns are more hairy they tend to block the air space in the fabric. Tightness factor is negatively influenced by loop length. As stitch density increases, the fabric becomes denser and lower air permeability will occur. Hence, the experiment shows tightness factor is inversely affecting air permeability.

For point prediction confidence level of 95% is used. It is clearly indicated in the plot below that the values are scattered around the regression line. The coefficient shows that the actual values are 76.37% correlated with the predicted values.

Std. Dev.	**5.03**	**R^2**	**0.7637**
Mean	111.23	**Adjusted R^2**	0.7259
C.V. %	4.53	**Predicted R^2**	0.6446
		Adeq Precision	16.3796

Fig. 3 below shows a 3D surface graph for showing effects of fabric thickness and aerial weight on air permeability values. Factors used for experimentation are 4, but the other 2 factors of; loop shape factor and tightness factor are held constant with values of 1.385 & 1.625 respectively. Thus, the surface graph shows different colors of mesh for the air permeability values. Blue depicts the lowest value & red shows the highest values. When the fabric thickness value is highest (6.1mm), the mesh color for the air permeability is blue & vice versa. This shows the inverse relation between fabric thickness and air permeability. For the highest fabric aerial weight value of 188.3 GSM, the mesh color shown is blue, resulting in the lowest value of the response. In contrast, lowest aerial weight, i.e. 128.7 GSM, the mesh color shown is yellowish. This results in higher value of air permeability.

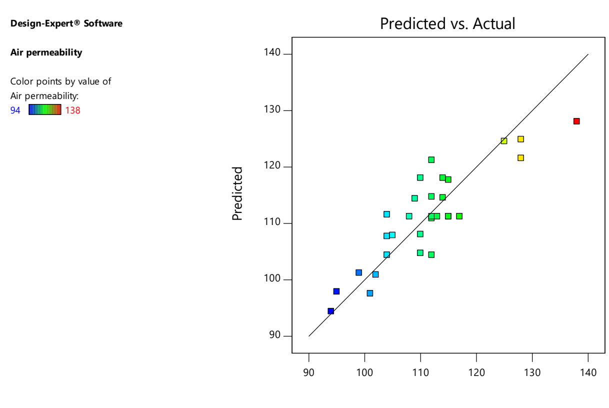

Fig. 2 Plot for predicted vs. actual values of the air permeability

Regression Equation in Terms of Actual Factors

Air permeability	=
+254.34896	

-0.288031	*Fabric aerial weight
-8.47222	*Fabric thickness
-23.23944	*Tightness factor
-9.45946	*Loop shape factor

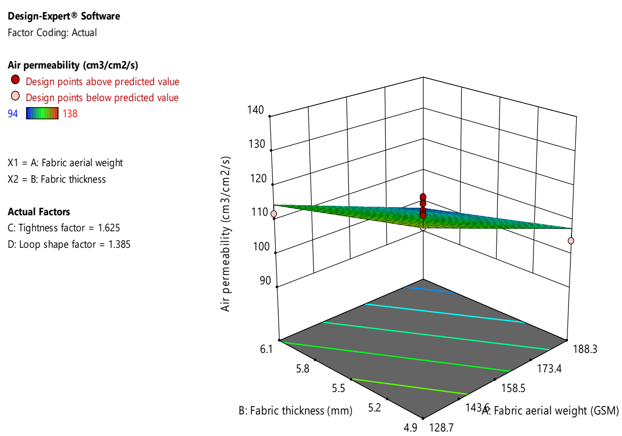

Fig.3 3D surface for showing the factor effects on air permeability.

V. CONCLUSION

The study shows all the 4 factors significantly affects air permeability of pique fabric made with 100% cotton yarn. The factors are inversely related with the response behavior. For the experiment, prediction of air permeability values is made with confidence level of 95%. Thus, the correlation coefficient between the actual and the predicted air permeability values is found to be 76.37%.

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