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Using Taguchi Methodology to Optimize Woven Fabrics Air Permeability

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Abstract

Woven fabric's breathability is one of the most important characteristics concerning fabrics used as tents, raincoats and uniform shirtings. It is mainly evaluated and compared significantly via fabric air permeability. This study aimed to optimization of the fabric parameters influencing the woven cotton fabrics' air permeability. Twenty seven different fabric combinations using a 33 full factorial design were diminished to only nine fabric samples according to L9 Taguchi's orthogonal design. These fabric samples were produced, tested and evaluated. Using S/N ratios, the best combinations of factor levels which yield the highest value of fabric air permeability were detected efficiently.

Keywords: Taguchi methodology; Woven fabric; Air permeability; Orthogonal array; Optimization

Introduction

Woven fabrics have found various and many application in our daily life and also in the industry because of their strength, flexibility, air permeability and other functional properties. In general, the air volume (in cm^3) passes through one square centimeter of the woven fabrics in a time of one second at a pressure difference of one centimeter of water is termed as fabric air permeability[1]. This functional property, is often used in determining and comparing the coated and uncoated fabric's breathability for several end uses. The performance of raincoats, tents, uniform shiting, parachutes, air bags, etc. was evaluated and assessed using their air permeability [2-4].

Clothing comfort which includes three main aspects, namely psychological, thermal and tactile comfort related mainly to ability of fabric to control the temperature of the skin through heat and moisture transfer [5]. Since moisture vapors transfer from the skin to surrounding atmosphere based mainly on the air permeability, it is considered the most important parameter in evaluating woven fabrics' comfort [6]. It was reported that fabrics' air permeability is considered one of six major factors in the consideration of comfortable apparel [7].

Woven fabrics' air permeability is significantly influenced by different factors such as, fiber, yarn and fabric parameters. Generally, basic fabric structure, fiber type, yarn and fabric constructions are considered the major effects on the outerwear garment air permeability; and finishing techniques were found to be the secondary influence [8]. Construction factors of spun yarns such as yarn diameter, crimp and twist level significantly affect warmth, and appearance of the woven fabrics [9].

Woven fabric porosity is affected by its weave structure, warp and weft yarn crimp. The higher the more spacing is covered by the yarns, the lower is the air permeability. Increasing twist level of ring spun yarns diminishes the yarn diameter and lead it to be more compact and dense, which in turn increases the fabrics' air permeability [10]. Type of the yarn or spinning method has a great influence on fabric air permeability. It was found that open-end yarn fabrics are more permeable to air than those made from ring spun yarns [10].

Many research works have been conducted on the prediction and evaluation of physical and mechanical properties of woven fabrics [10-18], while minor ones operated on the optimization of these properties. The purpose of this study is to optimize woven fabrics' air permeability using Taguchi's approach.

Experimental Work

According to the Taguchi orthogonal array which has been selected for this study, nine different woven fabrics were produced. These fabrics were woven from warp yarns of count 40 Ne and weft yarns with different three counts. The warp yarn density for these woven fabrics was kept at 60 ends/inch for all samples, while weft yarns have three different twist multipliers and densities. All fabric samples were woven on Tsudakoma Air-Jet weaving machine with running speed 580 rpm.

Throughout this study, woven cotton fabrics' air permeability is selected from among many quality characteristics as a research quality characteristic. Air permeability was measured according to ASTM standard D737-04 using Textest FX 3300 air permeability tester. Then, the larger the better of the Taguchi method is used to analyze the air permeability. Weft yarn linear density, twist factor and No. of picks per inch were used as control factors in this analysis. Each factor has been set at three levels.

1. Weft yarn count can be set at 30Ne, 40 Ne and 50 Ne. In general, the higher the yarn count, the lower is the yarn diameter, which in turns increasing the fabric air permeability.

2. The three levels of twist factor of the weft yarns are, 3.9, 4.1 and 4.3, respectively. Increasing yarn twist factor diminishes yarn diameter which increases the pore size in fabric structure, then increases air permeability.

3. The weft yarn density may be 50, 60 and 70 ppi, respectively. The higher the weft yarn density, the lower the fabric air permeability.

Depending to the control factors, the total number of freedom is equal to six (5 × (3-1)=6); and the orthogonal array of $L_9(3^4)$ was chosen for this experiment. The different levels of the control factors were listed in Table 1.

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Control factors	Levels		
	1	2	3
Weft yarn count (N_e)	20	30	40
Weft yarn twist factor (α_e)	3.9	4.1	4.3
Weft yarn density (ppi)	55	65	75

Table 1: Levels of the experimental (control) factors.

Experiment NO.	Control factors levels		
	Count of weft yarn (N_e)	Twist factor of weft yarn (α_e)	Weft density (ppi)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 2: L_9 (3^3) Orthogonal array used in this study.

Using the software MINITAB version 16, the S/N ratios were calculated for the selected orthogonal array of the control factors.

In the present work, an L_9 (3^3) Orthogonal Array table was used. There are three control factor each of which has three levels, so to investigate all possible factor – level combinations, a total of twenty seven (3^3) full factorial experiments would be demand. The experiments will consume much effort and cost in the case of full factorial design. Therefore, the Orthogonal Array of L_9 (3^3) is required urgently because of nine experiments will be conducted and it is displayed in Table 2.

There are three main characteristics categories upon which the S/N ratio will be calculated. These are as following:

Higher- the- better:

$$\frac{S}{N} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right] \quad (1)$$

Lower–the-better:

$$\frac{S}{N} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}y_i^2\right] \quad (2)$$

Nominal–the-best:

$$\frac{S}{N} = 10\log\left[\frac{\bar{y}^{2}}{S^2}\right] \quad (3)$$

Where,

n=Observations numbers,

y_i=i^{th} Experimental measured value,

$\bar{y}$ =Arithmetic mean of the observed data, and

S^2=Variance of the observed data.

Results and Discussion

Shortly, the following steps summarize the concept of optimization using Taguchi's methodology:

(1) S/N ratio measure the measurement accuracy scale for predicting abnormal conditions. It is expressed in decibels (dB). The lower error of the prediction is characterized by the higher value of S/N ratio. Generally, S/N ratios are very important to enhance the measurement accuracy and diminish the cost of the analysis.

Eqn. (1) was used to calculate S/N ratios. The values of S/N ratios were analyzed using ANOVA to disclose the factors that have a significance influence. After that the S/N ratio with highest value corresponding to the level of significant factor is chosen as the optimum level.

S/N ratios are calculated by eqn. (1) correspond to of woven fabric air permeability for each experimental run are listed in Table 3.

(2) Determining the average value of the influence of each variable on fabric quality characteristic, namely air permeability, is the second step in Taguchi's methodology.

Table 4 displays the average of each factor influence at their different levels in relation to S/N ratio. In this table, the optimum level of each factor was marked using an asterisk.

The optimum level is that one which corresponds to the maximum average influence e of the factor. Table 4 displays the average influence of each factor; and Figure 1 depicts the plot of the main effect for S/N ratios.

The difference between larger and lower values of S/N ratios is termed as delta or the gain in this ratio. Generally, the positive gain refers to the useful variable. This means that the factor change affects the fabric air permeability significantly.

From Figure 1, it is shown that the weft density of the woven cotton fabrics has a higher main effect compared to the other control factors, i.e., count and twist factor of the weft yarn. In this graph, the highest value of S/N value which is preferred for each factor is marked by a red circle. We can deduce from this figure that $A_3B_2C_1$ is the combination which satisfies the maximum air permeability. The corresponding factor levels which yield the maximum air permeability of woven fabrics are listed in Table 5.

Results of the analysis of variance (ANOVA)

ANOVA is considered a quantitative and efficient statistical

Experiment no.	Factors and their levels			Values of air permeability ($cm^3/cm^2.sec$)	Value of S/N ratio
	A	B	C		
1	1	1	1	26	28.31282
2	1	2	2	16.16667	24.17241
3	1	3	3	9.193	19.26915
4	2	1	2	15.7	23.89584
5	2	2	3	11.97333	21.5643
6	2	3	1	30.6	29.71443
7	3	1	3	13.3	22.47703
8	3	2	1	34.55	30.76896
9	3	3	2	20.08	26.05527

Table 3: L_9 (3^3) orthogonal array, average air permeability values and corresponding S/N ratios.

Control factors	Average S/N ratios			Delta
	Level1	Level 2	Level 3	(gain)
Weft yarn count	23.92	25.06	26.43*	2.51
Twist factor	24.9	25.50*	25.01	0.6
Weft density	29.60*	24.71	21.1	8.5

*Optimum factor level

Table 4: S/N ratios at different factor levels.

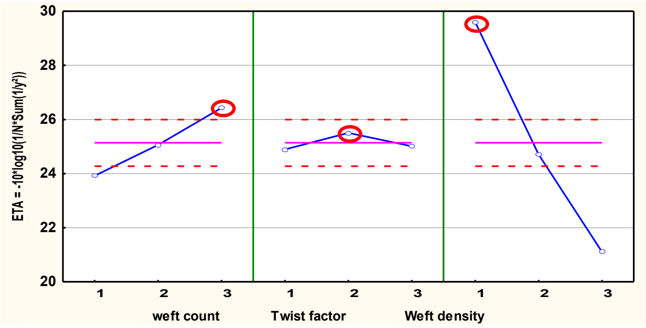

Figure 1: It shows that weft-density of woven cotton fabrics.

Level of con optimal control factors	value
A (3)	50 N_e
B(2)	4.1 α_e
C(1)	55 picks / inch

Table 5: Optimum value of factor and their levels.

Factor	SS	Degree of freedom	MS	F	p-value	% contribution
Weft count	137.99	2	69	41.878	0	26.9
Twist factor	30.27	2	15.14	9.187	0.001479	7.9
Weft density	1688.31	2	844.15	512.373	0	92.2
Error	32.95	20	1.65			
Total		26				

Table 6: ANOVA results.

analysis to measure and detect each control factor influence on the fabric quality characteristics, i.e., air permeability. From the results of such analysis, we can conclude the significant variables affecting air permeability. Also the importance and the contribution percentage of each factor effect on air permeability can be detected. This well known analysis was performed using SPSS version 17 software program. The significant factors were determined at significant level 0.05. The ANOVA results were presented in Table 6.

From this table and the statistical analysis it was depicted that weft density has the highest significant effect on fabric air permeability followed by weft yarn count and twist factor. The contribution of each control factor in influencing fabric air permeability in ascending order is as follows: twist factor (7.9%)<weft yarn count (7.9%)<weft density (92.2%).

Confirmation of the experiment

The optimum level of each control factor was determined depending on the results of the ANOVA and the average values of S/N ratios. As described before, the optimum combinations of factor levels that yield the highest air permeability were $A_3B_2C_1$. The final step in Taguchi's methodology is the confirmation of the experiment. The main object of experiment confirmation is to confirm that the optimum conditions derived from Taguchi method have indeed the projected improvement. S/N ratios at optimum factor levels (η_0) can be predicted according the following equation:

$$\eta_o = \eta_m + \sum_{i=1}^{j} (\eta_i - \eta_m) \qquad (4)$$

where,

η_0=optimum S/N ratio,

η_m=S/N ratio average value of the experimental runs,

j=control factors numbers, and

η_i=S/N ratio corresponding the optimum factor level.

Substituting different values in the above equation will yield the optimum S/N ratio. It was found that the value of optimum S/N ratio equal to 31.2 dB. This value is very close to the value obtained from design of experiment that is equal to 30.8. By substituting with η_0=31.2 in the eqn. (1), the obtained value of fabric air permeability is 36.5 (cm^3/cm^2.sec). That is the optimum air permeability predicted for such fabrics used in this study. The other combinations' air permeability values can be predicted from the same equation. Optimum fabric design was $A_3B_2C_1$.

The optimum fabric design was $A_3B_2C_1$, namely woven from weft yarn of count 40 Ne, with twist factor 4.1 and weft yarn density is 55 ppi. The average air permeability for this type of fabric was 34.7 cm^3/cm^2.sec (Table 7) which approaches the value predicted using Taguchi design (predicted by eqn. (1)) (36.5 cm^3/cm^2.sec).

Also, the S/N ratio for both initial and optimum fabric designs was calculated in order to detect the enhancement in the S/N ratio (Table 8). From this table, it is shown that the enhancement of S/N ratio due to the optimum design was 2.4. It is also shown that the improvement for predicted and verification results are close to each others which confirms the results. It is also calculated that the arithmetic mean value of initial fabric design's air permeability was 26 cm^3/cm^2.sec that is increased to 34.7 cm^3/cm^2.sec. This means that the increase in fabric air permeability using Taguchi's methodology is clearly observed.

The prediction of other fabric samples' air permeability which are not tested before can be forecasted efficiently using the Taguchi method. Using eqns. (1) and (4), the air permeability of fabrics that are not included in L_9 orthogonal array can be predicted. The air permeability predicted values of such fabrics compared to their corresponding experimental results were listed in Table 9. The relative error between experimental and predicted results was also shown in Table 9. Figure 2 illustrates the relevant results. It can be noticed from this figure that the predicted values are very close to the experimental air permeability and the error among them is very small.

Conclusion

The results of this study can be sum up as follows:

1) The optimum factors for maximizing cotton woven fabrics' air permeability can be evaluated and determined efficiently by simple and low-cost experiment using Taguchi' approach.

2) As conducting the cause and effect diagram, weft yarn count,

Fabric design	Air permeability values (cm^3/cm^2.sec)						Average air permeability	S/N ratio
Optimum (A_3B_2C1)	34.6	33.1	36.8	34.6	33.6	34.8	34.7	30.8
Initial ($A_1B_1C_1$)	26.04	26	26	26.3	26.2	25.5	26	28.3

Table 7: Air permeability results for optimum ($A_3B_2C_1$) and initial ($A_1B_1C_1$) fabric designs.

	S/N ratios	
	Predicted	Verified
Initial design	28.3	28.3
Optimum design	30.87	30.7
Improvement	2.48	2.4

Table 8: Verification experiment results.

Sample No.	A	B	C	Air permeability (cm³/cm², sec)		Relative error, %
				Experimental	Predicted	
1	1	1	2	13.7	14.5	5.84
2	1	3	2	18.5	17.6	4.86
3	2	2	1	29.5	28.7	2.71
4	2	3	3	13.5	14.1	6.82
5	3	2	2	19.8	21	6.06
6	3	3	3	13.7	14.1	2.92

Table 9: Experimental and predicated air permeability values.

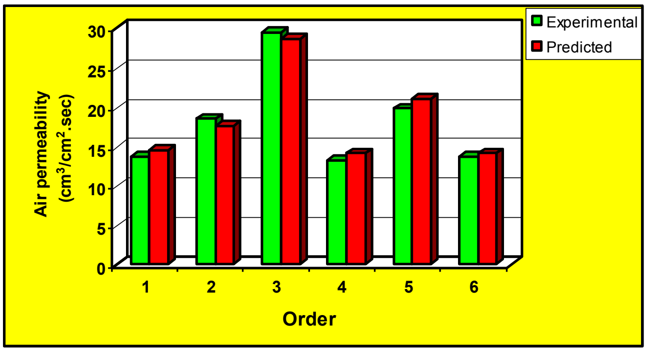

Figure 2: Experimental verses predicted air permeability values.

weft yarn twist factor and weft yarn density are determined as control factors influencing woven fabrics' air permeability.

3) In planning step of Taguchi's method, an L_9 (3^3) orthogonal array was used. The larger the better equation was also used to maximize air permeability.

4) Depending on S/N ratios and ANOVA results, the weft yarn density was determined as the most important control factor influencing fabric air permeability followed by weft yarn count.

5) The optimum level of control factors which yield the highest woven fabrics' air permeability were $A_3B_2C_1$. In other words, the optimum fabric sample which gives the highest value of air permeability composed of weft yarns of count 50 Ne, weft yarn twist factor 4.1 α_e and weft yarn density 55 ppi respectively.

6) Using Taguch's method, the product quality characteristic (Air permeability in this study) was improved significantly.

References

1. Textile Fabrics (1995) Determination of the permeability of fabrics to air. British Standard BS EN ISO 9237: 1999.
2. Ogulata RT (2006) Air permeability of woven fabrics. Journal of Textile and Apparel, Technology and Management 5: 1-10.
3. Ogulata RT, Koc E (2001) A theoretical model for air permeability of woven fabrics. Association for the Advancement of Modelling & Simulation Techniques in Enterprises 70: 39-48.
4. Tokarska M (2008) Analysis of impact air permeability of fabrics. Fibres & Textiles in Eastern Europe 16: 76-80.
5. Das A, Ishtiaque SM (2004) Comfort characteristics of fabrics containing twist-less and hollow fibrous assemblies in weft. Journal of Textile and Apparel, Technology and Management 3: 1-5.
6. Karaguzel B (2004) Characterization and role of porosity in knitted fabrics. Unpublished master's thesis, North Carolina State University, Raleigh, NC.
7. Wallenberger FT (1980) Dacron/Orlon Blends in Apparel-Product Value, Wear Comfort, Energy Savings, and Environmental Aspects. Textile Res J 50: 287-296.
8. Dhingra RC, Postle R (1977) Air Permeability of Woven, Double-Knitted Outerwear Fabrics. Textile Res.J 47: 630-631.
9. American Society for Testing and Materials (1979) (ASTM) Annual Book of Standards 32: 162.
10. Lord PR, Grady PL (1976) The Twist Structure of Open-End Yarn. Textile Res J 46: 123-129.
11. Ibrahima NA, Amr A, Eid BM, Almetwally AA, Mourad MM (2013) Functional finishes of stretch cotton fabrics. Journal of Carbohydrate Polymers 98: 1603-1609.
12. Cay A, Tarakcıoglu I (2007) Prediction of the air permeability of woven fabrics using neural networks. International Journal of Clothing Science and Technology 19: 18-35.
13. Almetwally AA, Mourad MM (2014) Effects of spandex drawing ratio and weave structure on the physical properties of cotton/spandex woven fabrics. The Journal of the Textile Institute 105: 235-245.
14. Urbas R, Kostanjsek K, Dimitrovski K (2011) Impact of structure and yarn colour on UV properties and air permeability of multilayer cotton woven fabrics. Textile Research Journal.
15. Almetwally AA, Idrees HF, Hebeish AA (2014) Predicting the Tensile Properties of cotton/ spandex core-spun yarns using Artificial Neural networks and regression models. The Journal of the Textile Institute 105: 1221-1229.
16. Mourad MM, Ahmed El-Salmawy, Almetwally AA (2011) Core spun yarn and the secret behind its popular appeal. Textile Asia 42: 41-43.
17. Pradhan AK (2013) Studies on multi-consistent nonwoven air filter media. (Doctoral dissertation). Indian Institute of Technology Delhi, New Delhi, India.
18. Rombaldoni F, Demichelis R, Mazzuchetti G, Ferri A, Banchero M, et al (2009) Effect of Carbon Dioxide Dry Cleaning on Low-stress Mechanical Properties, Air Permeability and Crease Pressing Performance of Men's Suit Fabrics. Textile Research Journal 79.