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The Perception of Plain Woven Fabrics' Performance Using Regression Analysis

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ABSTRACT

Due to the high computation in the market, the weaving factory had to attain the customers' demands based on samples or fabric performance at minimum time. The fabric performance is mostly determined on theoretical bases, which need experiments to meet the factory working conditions; this tends to loss of time and high expensive recycled wastes.

Understanding the fabrics performance is important to investigate the working process. The fabric properties depend to a great extent on constructional parameters, methodology and machines conditions. Due to that the factory data base can help attaining the buyer requirement in a shorter time.

This paper predicts the behaviors of, cotton and cotton/polyester, plain woven fabric during performance from constructional parameters to be available at database in textile industry. The work is carried on analytical and experimental procedures while varying fabric construction specifications. The fabric performance was based on fabric tearing, bursting, and tensile strength, elongation, abrasion, thickness, porosity. Fabric porosity was obtained theoretically, by air permeability and image processing.

Significant regression equations were determined to predict various fabric properties, and identify the most significant factors influencing the fabric properties. This can quickly attain the needed performance based on constructional parameters alone with sufficient accuracy.

Variations in count, densities of ends and picks, and crimp have a significant effect on fabrics properties. These results should be incorporated into the design phase of fabric properties for any woven product.

KEYWORDS: *Constructional Parameters, Porosity, Fabrics Properties, Regression, Image Processing.*

INTRODUCTION

In today's competitive marketplaces, profitability is not only depends on increasing sales but also just as importantly on reducing cost and improving the quality[16]. Textiles are applied from apparel to technical textiles; to compete with different markets, the quality has the greater influence. This implies that the quality has to be built in the production process [8].

Tensile strength, percent elongation, Tear, Thickness and air permeability are the most important fabric propertied which determine its performance. Fabrics properties are affected by fabric parameters, methodology, processing and environment. Raw material, fabric construction (yarn structure, fabric density and fabric structure), working conditions, setting and condition of machines are the factors which influence on fabric properties [1, 4, 6, and 9]. Optimum operation condition to attain the required propertied can be attained based on theoretical or experimental methods. Relationship between these parameters and fabric properties can enable the designer to create fabric for diverse applications [11]. In the main time different fabric behavior, required for end use, impose a challenge to the industry for determining a complex fabric attribute with a simple parameter which can describe to great extant the behavior of fabrics to a specific application [8]. On the basis of relative rate of individual structural interlacing models as well as yarn parameters fabric behavior can been defined [15]. From literature it is possible to detect that fabric strength depends on type of raw materials, yarn structure and properties, spinning system, fabric geometry, yarn crimp during processing, weaving conditions (such as temperature, humidity and yarn tensions during weaving) as well as fabric finishing treatments [1, 4, 9, 12]. While fabric thickness is affected by yarn diameter, thread waviness and fabric structure [15]. The air permeability is related to fabric density, yarns linear densities and the weave [6]. Also the analysis fabric stress-strain curves can help in predicting its behavior [14].

Researchers in the last year in an attempt to obtain effective relations between fabric properties and fabric parameters include as factors both fabric thickness and porosity, because of the steadily growing interest on technical textiles and composites [5, 3] both of them depends on fabric and yarns constructions. They are determined

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from either fabric geometry or from experiments. Porosity model from an open area and based on fabric geometry is as follows:

$$\mathbf{Ps = 1 - CF = 1 - (do\ Do + du\ Du - do\ du\ Do\ Du)} \qquad \textbf{(1)}$$

where: Ps fabric Porosity, CF cover factor, do, du diameters of warp and weft yarn respectively [Tex], and Do, Du sets of warp and weft yarns respectively [1/m] [7, 2].
The porosity can be determined from its correlation with air permeability or from the percentage of light transmission by image processing [10]. Porosity is defined by different relevant quantities such as pore size, pore size distribution, pore diameter [13]

Theoretical relationship between fundamental mechanics of woven fabrics or fabric parameters and fabric properties was proposed to enables the designer to create fabric for diverse applications. These equations in most cases don't fail but difficult to attain the optimum engineering attributes [11]. This is due to the large numbers of factors on which the behavior of the fabric depends also the model requires a large number of assumptions the approximations to handle the model [17]. For that the optimum operating conditions are always determined in the industry on experimental bases, which mean a lot of trails [7].

The excessive number of trails carried to attain the required quality or the non convenient fabric for the markets excess a higher stress on the environment since the fabrics are in most cases sized and colored. For that it is better to obtain the needed product with the minimum experiments and lesser excess.

Experimental Plan
The following stages will be considered according to the following:
Fabric selection ➔ Fabric testing ➔ Data modeling ➔ Result & Discussion.
The data were extracted from different fabric tests. The results were analyzed and formed in models using regression analysis.

Fabric selection

An available number of commercial plain weave fabrics produced in an Egyptian mill were collected for experimental study. All of these fabrics were produced from warp and weft yarns of similar characteristics (count and raw materials for each fabric). The constructional parameters of these fabrics are given in Table (1).

Table 1. The range and variations in the fabric constructional parameters

Material (X_2)	Yarn count Ne (X_1)	Fabric Density Ends/cm(X_3)	Picks/cm(X_4)	Crimp% Warp(X_5)	Weft (X_6)	Fabric Mass gm/mt^2
100% Cotton	14-60	19.5-57	15.5-36	0.8-7.3	8-21	82-184
50%Cotton 50% Polyester	14-60	26-48	22.8-32	1.0-3.8	2.5-10.5	111-185
Percentage Variation C	124.3	98.0	79.6	160.5	89.7	76.7
Percentage Variation C/P	124.3	59.5	33.6	116.7	123.1	50

Fabric Testing

Various measurements were taken to investigate the relationship between fabric constructional parameters and fabric performance. Standard specifications were applied for testing fabric properties; they consist of fabric strength i.e. bursting, tearing (using Elmendorf tester), tensile and elongation (using Instron tester), abrasion resistance (using Martindale tester), fabric thickness, weight while fabric porosity is determined from Eq. (1) , by transmitted to light (image processing) and transmitted to air (air permeability test).

The images of fabric samples for image processing were taken through a digital camera, under which the sample was placed in a black box over a constant light source in order to obtain a regular light transparency. Schematic diagram for the applied instrument is shown in Fig. (1).

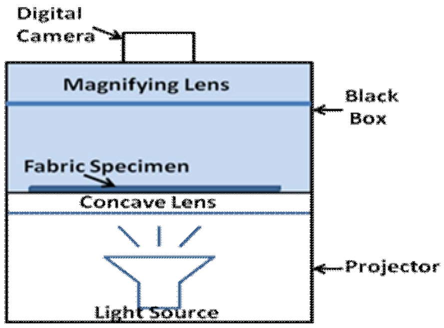

Figure 1: Image processing method for measuring porosity by transmitted light

Data Modeling Technique

Modeling of the collected data was based on multiple regression analysis. A significant second order regression equation between the fabric construction parameters and the measured properties, which are of the main features for the characterization of woven fabric quality and fabric performance, of the following form was proposed.

$$y = a + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n}\sum_{j>i}^{n} b_{ij} x_i x_j + \sum_{i=1}^{n} b_{ii} x^2_{ii} + \varepsilon \qquad (2)$$

Were y- Fabric properties, $x_{i,}$ $x_{j\,,}$ are the factors under study ,x^2_{ii} square of factors under study, a, $b_{i,}$ $b_{ij\,,}$ b_{ii} constants of the equation

Using stepwise regression analysis a significant regression was attained .This regression is accepted if the significant level of the factor is lesser than 0. 1 and the F-statistics of the equation is lesser than 0.01. Also the validity of these models was tested.

RESULTS AND DISCUSSIONS

The coefficients of the significant regression equations obtained between the factors under study and the tested parameters are shown in *Table (2).* From statistical analysis R^2 ranges (from 0.72 to 0.96) and Significance F values are between (**0.**004 and 8E-11**)** for the obtained models. The influences of the interaction between factors are higher for both bursting and warp tearing and lower for both thickness and weft tearing. Successful predictions of fabric properties by this model are attained.

The relationships obtained of these models can help in guiding the direction for moderating fabric parameters. The main relationships could be summarized as follows:

- Increasing the thickness of yarn (X_1) is decreasing air permeability of the fabrics and increasing fabric thickness, bursting, tearing and tensile strength, abrasion resistance and elongation in warp direction. Non-linear relationships between yarn count and air permeability, abrasion resistance, stress and elongation in weft direction are indicated. Figures (2, 3 and 4) indicate the relation between yarn count and the air permeability, porosity, and bursting of fabrics with different weft densities of picks from cotton and C/P yarns.
- Fabrics produced of cotton /polyester yarns (X_2) have higher fabric porosity by image processing and tearing strength in both directions beside to elongation in weft direction. However they have lower elongation in warp direction compared to cotton fabrics.
- It is evident from the coefficients that density of warp ends (X_3) has a positive effect on most fabric properties except fabric thickness which has negative effect on it.
- The fabrics produced of higher density of picks (X_4) have the higher values of stress in fabric directions. However air permeability and tearing strength are decreased by increasing the weft density. The effect of X_4 on thickness and elongation in warp direction is not linear
- The higher ratio of crimp in warp yarns (X_5) leads to decreasing fabric porosity, air permeability and tearing strength in warp direction however the bursting strength of fabric, elongation in warp direction, and tearing and stress in weft direction are increased.
- The ratio of crimp of weft yarns (X_6) have a negative effects on tearing strength, abrasion resistance, air permeability and stress in warp direction and positive effect on fabric thickness but this effect is not linear.

Table 2. The Statistical Result Models for Fabric Properties Using Regression Analysis

	Thickness (mm*100)	Air Permeability cm3/cm^{2}sec	Porosity Light trans. (%)	Abrasion (No. of Turns)	Bursting (Kg/ cm2)	Tearing		Stress Kgf/mm^2		Elongation (mm)	
						Warp	Weft	Warp	Weft	Warp	Weft
Inter	62.21	188.9	9.35	1044.7	7.45	190.4	114.26	1.47	0.55	-56.12	24.28
X_1	-0.33	8.88		-74.95	-2.33	-1.82	-0.48	-0.09	-0.06	-0.55	
X_2			9.48			10.25	4.43			-28.29	37.09
X_3	-0.12		2.53	34.62	1.50	1.35		0.07		3.48	0.64
X_4	-1.93	-3.35				-8.12	-3.27	0.01	0.05		
X_5		-52.54	-4.43		5.70	-13.0	3.25		0.36	3.72	
X_6	0.87	-4.72		-35.09		-2.93	-3.61	-0.07			
X_1*X_5			0.12		0.15	-0.87			-0.02		
X_2*X_6			-1.25	-29.61	-0.18	-0.91		-0.02			
X_3*X_4		-0.18	-0.08							-0.13	
X_4*X_6			0.09		-0.05		0.16				
X_5*X_6		2.07			-0.23						
X_1*X_2				-20.2				0.01			
X_1*X_6					0.05	0.10		0.003			
X_2*X_4										1.21	-2.27
X_1*X_4					0.02	0.06					
X_2*X_3				25.24							0.76
X_3*X_5					-0.21				0.005		
X_2*X_5		4.95									
X_4*X_5						1.62					
X_1^2		-0.04		0.58					9E-04		-0.01
X_4^2	0.04									0.11	
X_5^2		4.86									
X_6^2	-0.03		-0.13								0.15
Sign. F	8E-11	6E-07	3E-08	3E-05	2E-04	0.004	5E-04	3E-08	2E-06	0.002	7E-06
R^2	0.96	0.94	0.95	0.84	0.88	0.83	0.72	0.93	0.86	0.72	0.84

Where: X_1 is Yarn Count(Ne), X_2 Fibre type of yarns (cotton, C/P), X_3 density of warp (ends/cm), X_4 Weft density (picks/cm), X_5 Warp Crimp %, and X_6 Weft Crimp%

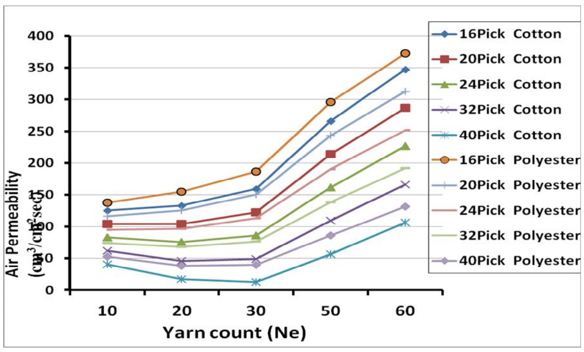

Figure 2 . Predicted Relation between Yarn Count and Air Permeability

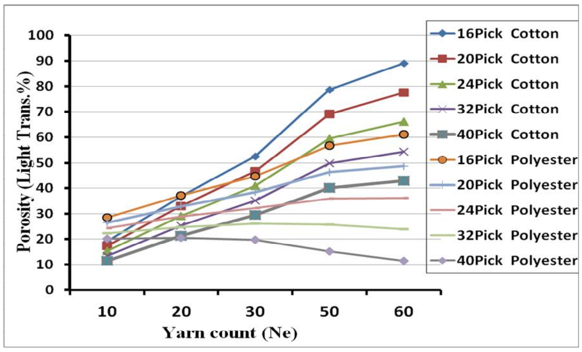

Figure 3. Predicted Relation between Yarn Count and Fabric Porosity

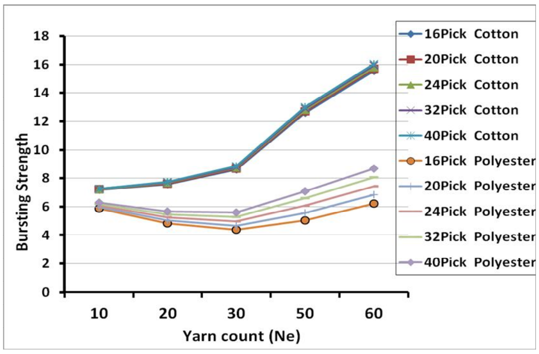

Figure 4. Predicted Relation between Yarn Count and Bursting Strength

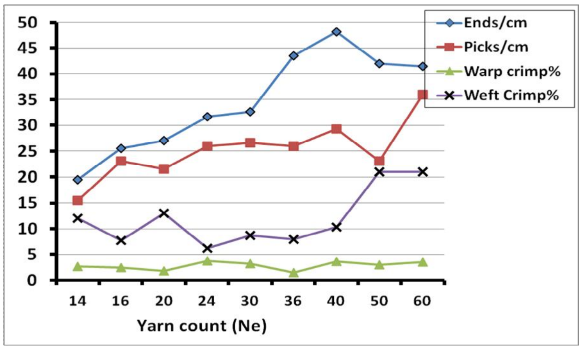

Figure 5. Practical Relation between Yarn Count and other Parameters

The correlations between different constructional parameters

The coefficient of correlations between fabrics parameters are presented in Table (3). This indicates that an increase in yarn count leads to an increase in warp and weft densities as presented in figure (5). It means that a change in yarn count tends to a change in fabric density due to market demands Also the change weft density demands an increase in warp density to attain an acceptable fabric for the market. Also the crimp % cotton yarns differ from that of (50% cotton /50% polyester) yarns.

Table 3. Correlation between constructional Parameters and Each Other

		Ne (X_1)	*yarn type* (X_2)	*Fabric Density*		*Crimp%*	
				Warp (X_3)	*Weft* (X_4)	*Warp* (X_5)	*Weft* (X_6)
Ne (X_1)		1.0					
Yarn Type(X_2)		-0.1	1.0				
Fabric Density	**Warp(X_3)**	0.8	0.1	1.0			
	Weft(X_4)	0.8	0.1	0.8	1.0		
Crimp%	**Warp(X_5)**	0.3	-0.3	0.4	0.4	1.0	
	Weft(X_6)	0.3	-0.7	0.1	0.1	-0.04	1.0

The correlation between fabric properties

The coefficients of correlation between the studied fabric properties were determined with the aim to attaining the possibility of reducing the number of predicted properties when designing specified fabrics. The coefficients of correlations between fabrics properties are presented in Table (4), from which the fabric weight has a higher correlation with all the tested fabrics properties (from 0.5 to 0 .8) except the fabric elongation in both directions.

Table 4. Correlation between Fabric Properties

	Math Porosity	**Image Porosity**	**Air Permeability**	**Weight**	**Thickness**	**bursting**	**Abrasion**	**Tear Warp**	**Tear Weft**	**Stress Warp**	**Stress Weft**	**Elong*.Warp**
Image Porosity	-0.3	1.0										
Air permeability	0.1	0.3	1.0									
Weight	0.6	-0.4	-0.5	1.0								
Thickness	0.8	-0.5	-0.1	0.8	1.0							
Bursting	0.2	-0.05	-0.6	0.5	0.2	1.0						
Abrasion	0.3	-0.4	-0.3	0.6	0.2	0.4	1.0					
Tear Warp	0.7	-0.2	0.1	0.6	0.5	0.4	0.3	1.0				
Tear Weft	0.6	-0.3	0.1	0.6	0.6	0.3	0.3	0.9	1.0			
Stress Warp	0.02	0.1	-0.6	0.6	0.1	0.7	0.3	0.3	0.2	1.0		
Stress Weft	0.3	-0.5	-0.6	0.8	0.6	0.5	0.6	0.4	0.6	0.5	1.0	
Elong*. Warp	-0.3	-0.2	-0.6	0.1	-0.2	0.4	0.4	-0.1	-0.1	0.3	0.4	1.0
Elong*. Weft	-0.2	0.04	0.1	-0.1	-0.1	-0.03	-0.4	0.1	0.1	0.03	-0.2	-0.5

Elong.* = Elongation (mm)

Since the fabric weight depends on all the constructional parameters, so the fabric weight can be replaced by fabric porosity, which was assessed by three different methods. Their correlations with fabric properties are demonstrated in table (4). While the fabric porosity determined by image give a significant regression equation with the factors under study, its correlation coefficients with fabric properties is at the third place. This can be due to the lesser number of trails or carrying other measuring in image processing. A further study has to be carried to overcome this situation. Yarn type effect significantly the fabric porosity as determined the image processing, a case is not included in mathematical determination of fabric porosity, from that the further studies has to take into consideration not only the yarn material but also its construction.

These results will assist designers and engineers in selecting the constructional parameters for specific applications and provide a better understanding of the behavior of woven fabric.

Conclusion

Significant regression equations describing the relation between the six proposed constructional parameters and the eleven tested fabric properties were obtained with an R^2 ranging from 0.72 to 0.96. While the F- statistics of the obtained regression is lesser than 0.004 and attain a value of 8E-11. All the studied factors has an effect on one or more fabric properties this exist for both first order and interactions, while yarn count, weft density, warp crimp and weft crimp have quadratic effect on some fabric properties.

Ranking the factors by their existence in the equations the yarn count is in the first place, so that yarn count is the most important factor affecting the fabric properties, followed by weft crimp, weft density. Warp crimp, warp density and material type are in the last position. From the obtained regressions it is obvious that the weft crimp and the warp crimp had a considerable effect on the obtained fabric properties. These factors are highly affected by the processing tension and both of the machine types and settings. Due to that greater attention had to be given to them when designing fabrics.

This study has many benefits for textile manufacturers to create models quickly based on fabric parameters alone with sufficient accuracy to be used in predicting various fabric properties that help in producing fabric with specification from the first time. The obtained models will be able to predict the fabric properties easily and determined the most significant parameters' before manufacturing. The correlation between fabric properties were determined, this will help the designer to suggest with the aid of regression equations the procedure taken for producing the needed fabrics. More work had to be carried for better understanding the effect of porosity on fabric properties.

Using this technique for interval values of constructional parameters is providing reasonable ways for the perception of woven fabric properties that are most significant influences in application that leads weaving company towards improving quality and remains competitive.

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