

Modeling Surface Roughness for prediction and evaluation of Bed-Sheet woven Fabric

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Abstract

Nowadays, evaluating fabric touch can be a great interest in the industry in order to match the quality needs of the consumer and the parameters for the manufacturing process. Modeling helps to determine how the structural parameters of the fabric affect the surface of a fabric and also identify the way they influence fabric properties. Moreover, it is helpful for estimating and evaluating without complexity and time-consuming experimental procedures, and even before the production of the fabric and the results available quickly, tangible, accurate and reliable, and project relevant. In this research prepare the regression model was developed that utilized for prediction and evaluation surface roughness of bed-sheet fabric and various types of woven fabric. The model was developed based on nine different half-bleached plain bed-sheet fabrics with three weft Yarn count 42TEX (14Ne), 29.5 TEX (20Ne) & 14.76 TEX (40Ne) and three weft thread density (18ppc, 21ppc & 24ppc) and then the surface roughness of bed-sheet fabric was tested by using Kawabata (KES-FB4) testing instrument. The Design-Expert®11 software was used for developing model equation and analysis of variance (ANOVA). Central Composite Design (CCD) with two independent variables (factors) was applied to investigate the effect of weft yarn count and linear density of weft yarn and each factor with three different levels on the surface roughness of fabrics. The effects of count and density on the roughness of bed-sheet fabric were found statistically significant at the confidence interval of 95%. The effect of weft yarn count on surface roughness values of fabrics was observed that surface roughness values increase with weft yarn count coarseness increase, while it decreases as the weft yarn get finer and finer. The surface roughness of the fabrics was decreased as the pick density of the fabrics increases and the vice versa. The correlation between the measured value by KES-FB4 and the calculated value by the model equation show that how they are strongly correlated at 95% (R^2 OF 0.97). This model can be used to select a suitable fabric for various end use applications and it was also, used for testing and predicting surface roughness of woven fabrics.

Keywords- Surface Roughness, Regression Modeling, Design Expert, Prediction, Bed-sheet, and Structural Paramete

I. INTRODUCTION

Nowadays, consumers demand clothing which not only looks good but also feels comfortable. Consumers choose comfort as the most important attribute that they seek in apparel products, which is followed by easy care and durability. As comfort is definitely an individualistic sense it is very difficult to define, design or determine it [1]. Evaluating fabric touch can be a great interest in the industry in order to match the quality needs of the consumer and the parameters for the manufacturing process [2]. One of the most important characteristics of the fabric which affects the comfort properties of cloth is the constructional specification. Parameters such as thickness, weight per square meter, the pattern of weave thread density, crimp%, and yarn count can be counted as the most effective parameters [2].

Roughness is a descriptive term for a fabric surface which has the feel of sandpaper (ASTM-D123-09, 2009). Smoothness and roughness of fabric materials are important fabric tactile properties for engineering design of many textile products including medical textiles, hygiene and healthcare products, sportswear, underwear, bed-sheet, lingerie, and other consumer products having special requirements is sensitive surface tactile properties[3-5].

Modeling of the process of perception of textiles by the skin fills the gap between two contemporary existing solutions: objective and subjective assessment of handling properties of fabrics [6]. Numerous mathematical models involving the human body, clothing, and environment provide useful tools for identifying key parameters in material design and for predicting clothing performance under extreme environmental conditions[2]

The evaluation of fabric surface roughness is possible by using either contact or non-contact methods. In this regard, many devices and techniques have been developed and employed. The Kawabata Evaluation System for Fabrics (KESF), Fabrics Analysis by Simple Tests (FAST), and Fabric Touch Tester (FTT) systems are available for measuring the fabric handle related characteristics under the contact methods. But, as far as the tactile responses are concerned, all the low-stress mechanical characteristics directly or indirectly stimulate the touch, pressure, roughness and other mechanoreceptors of human skin[6-8] .

The measurement, quantification, and analysis of surface roughness have been the subject of many research works, due to the decisive role of these parameters in the selection of an appropriate fabric for different technical and clothing end-uses. Many studies have focused on the measurement of fabric surface roughness by objective and subjective methods.

Recent years have seen huge advances in the accuracy, realism, and predictive capabilities of tools for the theory and simulation of materials. Predictive modeling has now become a powerful tool which can also deliver real value through application and innovation to different industries. It forms an essential part of the research and development effort of many of the world's leading organizations and can be incredibly valuable for businesses. By using modeling, it is possible to identify the effective aspects of bed-sheet fabric structure on surface roughness and also discover the way that they influence the property of surface roughness of bed-sheet fabrics. Used in a combination of good analysis and experimentation, materials modeling can drive progress, saving time, cost, effort and resource. Results are tangible, available quickly and project relevant. Materials modeling can be used to solve real issues and problems and push cutting edge research.

Most of the researchers were focused on experimental methods for characterizing the surface roughness of fabrics but, their focus on modeling the roughness of a commonly used bed-sheet fabric is limited and hence most industries are suffering to knowing the level of surface roughness of their product. In this research, a regression model was developed based on the geometrical parameter of fabrics. Thereby the designers in the weaving looms have the ability to design a bed sheet and various types of woven fabrics with specific surface roughness; simply by applying changes in fabric structural parameters (such as weft yarn density and

weft yarn linear density) and a laboratory personnel can simply calculate surface roughness of a given fabrics by identifying structural parameter and using the regression model equations. The model is a guide to select a suitable fabric for various end uses and a way to test and predict surface roughness of any kind of woven fabrics.

II. MATERIALS AND METHODS

A. Materials

Nine 100% cotton plain woven fabrics were produced with different structural parameters by Picanol air jet loom in; with three different weft density (ppc) and three different weft yarn linear density (weft count) while the other parameters are kept in constant such as warp density, warp count, tension, speed, and RH% as shown in Table 1. The warp tension force is 1.58KN and the speed of the loom is 500 RPM. All the fabric specification is mentioned as shown in below Table 3. Then each fabric was treated with combined pretreatment process. The chemicals used were sodium hydroxide 3%, hydrogen peroxide 4%, sodium silicate 2%, wetting agent 0.5% and EDTA 0.5 on the weight of the fabric and one to ten liquor ratio.

B. Experimental design

A central composite design (CCD) was selected to determine the experimental conditions as the inclusion of axial experimental points allow for a larger spread of conditions to be examined, which is beneficial when the required complexity of the model is not known for accurate predictions to be made. Central composite design (CCD) is an efficient technique for experimentally exploring relationships between investigated factors and system response. Central composite design experiments need a minimum numbers of trials for estimating the main effect, require less number of runs, allow sequential experimentation, which provides flexibility and time saving in running the experiment and analysis's[9]. The experiment has 8 non-center and 5 center points and the total run is 13 with five numbers of replications as shown in the Table 2.

C. Experimental procedure

Five test specimens 20.0 × 20.0 cm are prepared for measuring surface roughness by Kawabata Evaluation System (KES-FB4) from each produced samples and conditioned at $65 \pm 2\%$ relative humidity and $20 \pm 2^\circ\text{C}$ for a minimum of 24hr before testing according to ASTM-D1776 practice for conditioning and testing textile materials[10].

D. Developing an empirical model

Several statistical approaches are now available to researchers to analyze multiple outcomes or

informants. With multiple informants, researchers can jointly model the associations between informant and outcome using a modeling approach available in standard software packages [11]. Design Expert provides prediction equations (model) in terms of actual units and coded units. The coded equations are determined first, and the actual equations are derived

from the coded. To get the actual equation each term in the coded equation is replaced with its coding formula.

$$X_{coded} = \frac{X_{actual} - \bar{X}}{(X_{High} - X_{Low})/2} \dots \dots \dots (1)$$

Table 1 Construction parameters of bed-sheet woven fabric

Fabric code	Weave type	Warp density (EPC)	Warp count (Ne)	Weft density (PPC)	Weft count (Ne)
FK_1	Plain	24	20	18	14.76
FK_2	Plain	24	20	21	14.76
FK_3	Plain	24	20	24	14.76
FK_4	Plain	24	20	18	29.5
FK_5	Plain	24	20	21	29.5
FK_6	Plain	24	20	24	29.5
FK_7	Plain	24	20	18	42
FK_8	Plain	24	20	21	42
FK_9	Plain	24	20	24	42

Assumptions:

- ✚ All the fibers have the same properties.
- ✚ The fabric is produced with a constant tension force.
- ✚ The fabric is produced with the same warp count and density.
- ✚ The effect of fabric surface hairiness is ignored (neglected).
- ✚ Normal yarn elongation % is maintained
- ✚ The cross-section of yarns is regarded as a circle.
- ✚ The twist factor of the yarn is maintained as per the standards.

The experimental results from the forming trials performed according to the matrix by central composite are tabulated in Table 9. These values are feed to the Design Expert software for developing the surface roughness of the fabric by only considering the count and density of the bed-sheet fabric.

$$SMD = \beta_0 + \beta_1 A + \beta_2 B \dots (2)$$

E. Model validity test

It is always necessary to examine the fitted model to ensure that it provides an adequate approximation to the true system and verifies that none of the least squares regression assumptions are violated. Proceeding with the exploration and optimization of a fitted response surface will likely give poor or misleading results unless the model provides an adequate fit [9, 12].

F. Model test

A plain fabric consists of the different structural parameter which has different weft densities and weft counts were used for model test against surface roughness measured values by KES-FB4. Structural parameter analysis (density, count and crimp %) will be done for the fabrics which are used for model validation purpose. The count of weft yarn from the fabric is measured according to ISO 7211-5; density of weft yarn will be measured by using ISO 7211-2 standard [13], [14]. Finally, the average value of each measurement was used for calculating surface roughness of the fabrics by developed SMD model equation as shown in Table. 4. The surface roughness of the fabrics was also measured by Kawabata KES-FB4 instrument. Finally, the calculated and the measured value were checked their correlations by plotting graphs.

III. RESULTS AND DISCUSSION

A. Effects of count and density on the surface roughness

The data's which were collected from the KES-FB4 instrument of surface roughness values in Table 9 under the response column is normally distributed as shown in Fig. 1. From the box plot in Fig. 2, it is observed that the collected data have no out layers either an upper limit or lower limit. This implies that the collected data are normal and it can be used for further statistical analysis.

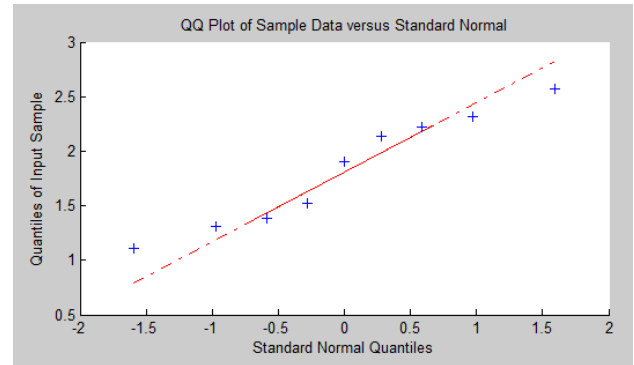


Fig. 1. The QQ-plot of the input data Vs. standard normal.

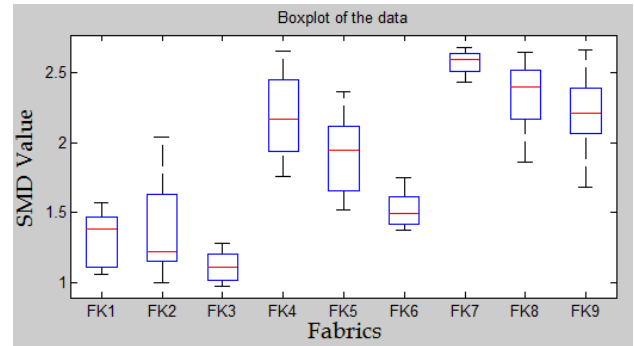


Fig. 2. The box plot of the data.

Table 2 The experimental design with two factors and three levels.

Code	Run	Factor 1 Count (Ne)	Factor 2 Density (PPC)	Response1 SMD
FK_2	1	14.76	21	1.31542
FK_5	2	29.5	21	1.90625
FK_8	3	42	21	2.32167
FK_1	4	14.76	18	1.38958
FK_5	5	29.5	21	1.90625
FK_5	6	29.5	21	1.90625
FK_9	7	42	24	2.32167
FK_5	8	29.5	21	1.90625
FK_4	9	29.5	18	2.13792
FK_5	10	29.5	21	1.90625
FK_3	11	14.76	24	1.11375
FK_6	12	29.5	24	1.52
FK_7	13	42	18	2.56625

ANOVA results of the linear models presented in Table 3 indicates that the model can adequately be used to describe the surface roughness of the fabrics based on the fabric parameters viz. count and density of weft yarn. The F-value is 166.83 ($P < 0.0001$) which implies that the model is significant for surface roughness. There is only a 0.01% chance that an F-value this large could occur due to noise. A P-value is the indicator of the significance of the test. Values of less than 0.05 ($P < 0.05$) indicate the significance of the model terms. Both the model terms count and density is statistically significant at 95% of the confidence interval, since they have a P-value of 0.0001 and 0.0002 respectively. The Predicted R^2 of 0.9407 is in reasonable agreement with the Adjusted R^2 of 0.9651; i.e. the difference is less than 0.2, which ensures a satisfactory adjustment of the model to the experimental data.

A smooth fabric surface provides a bigger contact area with the human body, while a rougher fabric surface has less contact area when it gets contact with the human bodies [2]. The effect of weft yarn count on surface roughness values of fabrics was observed that surface roughness values increase with weft yarn count (coarser), while it decreases as the weft yarn get finer and finer as shown in Fig. 3. Also, the surface smoothness of the fabrics increases as the pick density of the fabrics increases and the surface roughness of the bed-sheet fabric increases as the weft thread

density decreases as shown in Fig. 3. This was due to the fact that as the thread density of weft yarn increases the pick and valley on the fabric surface decreases which was resulted during the interlacement of warp and weft yarns.

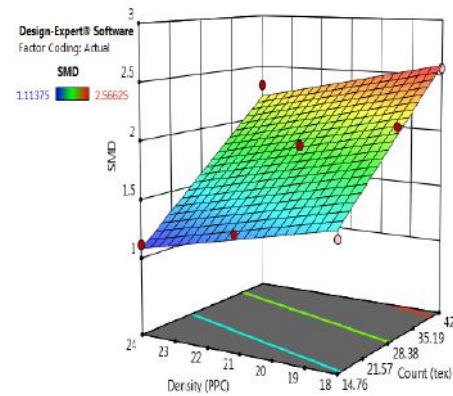


Fig. 3. The effects of both density and count on the surface roughness of the fabric.

B. Model equation for surface roughness

The actual model equation was developed by using surface roughness values of the nine samples which were measured by KES-FB4 instrument. The equation in terms of actual factors (count and density) can be used to make predictions about the response (surface roughness) for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

$$SMD = +1.98837 + 0.041492 * \text{Count} - 0.063241 * \text{Density} \dots \dots \dots (14)$$

C. Model validity test

The model validation test was done by checking the correlation between the measured data obtained from the experimental method (KES-FB4) and the calculated (estimated) data obtained from the developed actual model equations (SMD). As it is shown in Fig. 4, the proposed model equation can properly correlate the experimentally measured data from (KES-FB4) at the confidence interval of 95% (R^2 of 0.97).

TABLE 3 ANOVA table for linear model

Source	Sum of Squares	df	Mean Square	F-value	p-value	Decision
Model	2.14	2	1.07	166.83	P < 0.0001	Significant
Count	1.92	1	1.92	299.98	P < 0.0001	Significant
Density	0.2160	1	0.2160	33.69	P < 0.0002	Significant
Residual	0.0641	10	0.0064			
Lack of Fit	0.0641	6	0.0107			Not-significant
Pure Error	0.0000	4	0.0000			
Cor Total	2.20	12				

TABLE 4 Samples for model test

Fabric code	Weave type	Warp density (EPC)	Warp count (Ne)	Weft density (PPC)	Weft count (Ne)	Measured (SMD)	Calculated (SMD)
MT ₁	Plain	32	28	32	28	1.25	1.12644
MT ₂	Plain	20	20	20	20	1.437	1.5533
MT ₃	Plain	21	36	21	36	2.277	2.154
MT ₄	Plain	28	18.5	28	18.5	1.023	0.9859

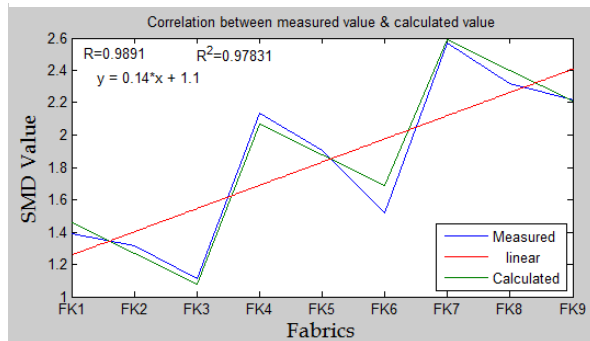


Fig. 4. The correlation between the measured SMD values by KES-FB4 and the calculated SMD value by the model equation.

C. Model test

The model efficiency was tested by using three different fabrics which are not used for the model equation extraction. The fabric's properties were studied and identified the weft density and count

by using the ISO 7211-5 and ISO 7211-2 standard.

The fabric's properties of the fabric that were used for the model test which was 100% cotton half-bleached and parameter of construction was as shown in Table.4. The correlation between the surface roughness values from KES-FB4 and the surface roughness values from the developed model equation were found strongly correlate at the 95% degree of freedom as shown in Fig. 5. The model can be used for prediction and evaluation of bed-sheet and other woven fabrics which is hundred percent cotton fabrics.

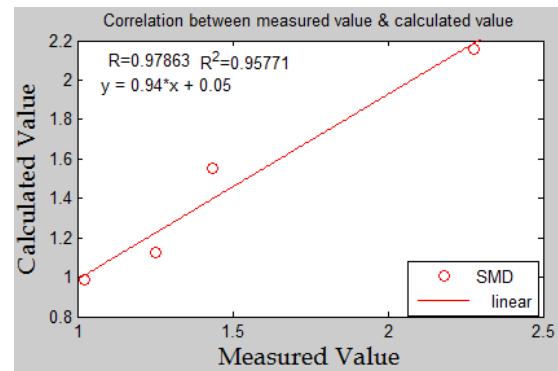


Fig. 5. The correlation between the measured SMD values by KES-FB4 and the calculated SMD value by the model equation for model testing fabrics.

VI. CONCLUSION

Even though there were different structural parameters that affect the surface properties of the fabrics, it is possible to control the surface behavior of the fabric with the developed model. The surface roughness of bed-sheet fabric was mainly affected by weave type, thread density, weft, and warp linear density. The weft count and density were used for the model equation which can be used prediction and evaluation of surface roughness of woven fabric. The model statistically significant and can adequately be used to describe the surface roughness of the fabrics. The surface roughness increases with count increases and the surface roughness decrease as the density of the weft thread increases. In order to produce fabrics with smooth surface properties yarn density should be increased and weft yarns fineness should also increase. The model was validated and tested the correlation between measured by KES-FB4 and calculated by the developed model equation reveals that the model was strongly correlated with the confidence interval of 95% (R^2 of 0.95).

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