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Usage of proportions method for predicting percentage reflectance of woven structures in fabric design

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Effects of fabric constructional parameters on the prediction of percentage reflectance of woven polyester fabrics for different weft yarn densities have been investigated considering the same yarn count and weave pattern. Relationship among weft yarn density, fabric bulk density, fabric cover factor and percentage reflectance has been studied using the proportions method. The relationship between measured and proportionally predicted percentage reflectance values shows that proportional prediction method, according to fabric cover factors and using the same yarn count and the weave pattern but different yarn densities, gives the closest results to the measured ones. This could be used in estimation of fabric percentage reflectance for fabric design. Fabrics with different constructional parameters but having the same percentage reflectance could be produced by using proportions method under the conditions when appropriate beginning parameters are selected along with the fabric cover factors.

Keywords: Bulk density, Cover factor, Fabric constructional parameters, Polyester, Proportions method, Reflectance, Weft density, Woven fabric

1 Introduction

Light reflection from a cloth relies on the properties of yarns used and woven structures[1,2]. Taylor[3] explains the difference between the two similar fabric characteristics, namely cover factor and cover. Cover signifies the actual efficiency of the yarns in closing up the surface of cloth. The cover of a cloth may be judged by the appearance of the cloth when held up against the light, and it depends not only on the number of threads per cm and their linear density, but also on their regularity, hairiness, fibre composition, twist and cloth finishing processes. Any irregularity in construction, for example in the uniformity of the spacing of the threads, tends to reduce the level of cover. Cover factor is calculated from only two of these quantities (threads per cm and linear density) and, therefore, cannot provide a complete indication of cover[3].

Cover factor indicates the extent to which the area of a fabric is covered by one set of threads. For any fabric there are two cover factors, viz warp cover factor and weft cover factor. Cloth cover factor is obtained by adding the weft cover factor to the warp cover factor. Cover factors can be adjusted for yarns of different relative densities – either because of the yarn structure or because of the raw material used[4].

The composition of light and its interaction with the surfaces are still being studied. The proposed reflectance models have assumed microscopic facets to be specular or Lambertian in reflection, and most of them are based on geometrical optics[5-10]. A few researches are focused on woven cloth simulations[11-13] and material and weaving structure properties of cloth. Certain properties of different fabric structures woven from different fibre materials, related to percentage reflectance and surface characteristics, are presented in literature, considering their effects on the light reflecting and scattering by surfaces[14-22].

There are many parameters which are related to the physical forms of textile materials to be considered, for the research to be done upon light reflectance from fabric surfaces. These physical forms include properties of fibres, yarns and fabrics, usually taken into account in more than one dimension. A physical change which seems relatively unimportant among the others may affect the scientific results in a way that cannot be predicted. For that reason, surface and reflectance properties of woven fabrics comprise many parameters that have to be controlled independently[23].

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In order to perform scientific researches on the properties affected by the interaction of surfaces with light, some parameters need to be incorporated in a single parameter. Cover factor of woven fabrics incorporates yarn densities and yarn counts to establish the covered area by the yarns and it provides a valuable tool for considering the relation between surfaces and light[23].

Papers, relating to clothing and textile design approaches, reported the need for a better understanding of design through practice[24], tests for improvement of design skills[25], usage of computer and software technology in fabric printing and design[26], and colour attributes that affect colour preferences together with psychological colour references for apparel fabrics choice[27].

In this investigation, prediction of the effects of yarn density, fabric bulk density and fabric cover factor on percentage reflectance of fabric samples has been studied, considering the same yarn counts and weave pattern but different yarn densities. Prediction of percentage reflectance is made according to proportions method.

2 Materials and Methods

Fabrics comprising different yarn counts, filament numbers and fineness, yarn densities and weave patterns were used in the experimental part. Different constructional properties were considered to assess relationship between measured ($\%R_{measured}$) and proportionally predicted ($\%R_{proportionally\ predicted}$) fabric percentage reflectance. Fabrics were woven under controlled weaving conditions in order to obtain the exact constructional properties. Woven fabrics were then pre-treated [washed with a non-ionic agent (2 g/L) at 60°C for 30 min and later stentered without tension at 180°C for 60 s] under mill conditions. All fabrics were conditioned for a minimum of 24 h using the ASTM Test Method D1776-08 (20±2°C and 65±2% RH) before all measurements.

Constructional parameters of fabrics are shown in Table 1. Warp yarn properties and warp densities were kept the same for the corresponding sub-groups. In the first and the second groups of fabrics, warp yarns were composed of 70/36 and 75/36 denier/filament textured yarns respectively and they were woven to give fabrics with a warp density of 60 threads/cm. Weft yarn properties were kept different from each other in the corresponding sub-groups. These differences were weft yarn filament fineness/number and weft yarn density. Weft yarns were textured polyester yarns in all groups of fabrics. Fibres of warp and weft yarns were of round cross sectional shapes; they were semi-dull fibres.

The first group of fabrics was composed of weft yarns having the same count but different filament fineness/numbers. These fabrics were made from 100 denier polyester yarns constituting different numbers of filaments, namely 36 filaments (2.78 dpf), 48 filaments (2.08 dpf), and 144 filaments (0.69 dpf) respectively. Fabric samples were woven in two weave patterns, viz plain and 1/5 sateen.

The second group of fabrics was composed of weft yarns having the same count and the same filament fineness/numbers. Fabric samples were woven in three different weave patterns, viz plain, 1/3 twill and 1/7 sateen.

2.1 Measurement of Fabric Percentage Reflectance

Percentage reflectance of samples was measured on a Macbeth Reflectance Spectrophotometer (MS 2020+) between 400 nm and 700 nm (at 20 nm intervals) under D65/10° illuminant/observer and in SCI (Specular Component Included) mode. Percentage reflectance values were recorded according to AATCC Evaluation Procedure 6 (ref. 28). Samples were prepared as five replicas for reflectance measurements. Four reflectance measurements were made on each replica with a sample rotation of 90° and percentage reflectance of a sample was calculated by using total twenty measurements. Percentage reflectance measurements were made on ready to dye white polyester fabric samples at single fabric fold. Reflectance measurements of replicas were made on an achromatic black background (black background colour coordinates; average %R 4.88; average K/S 9.27; L^* 26.3; a^* 0.04; b^* -0.29; C^* 0.29; and h° 277.69).

2.2 Calculation of Cover Factors

For any fabric there are two cover factors, namely warp cover factor (K_{wa}) and weft cover factor (K_{we}). Cover factors in SI units are calculated using the following equation[29]:

$$K_{wa} = (3.3 \times n_1) / (Nm_1)^{1/2} \quad \ldots(1)$$

$$K_{we} = (3.3 \times n_2) / (Nm_2)^{1/2} \quad \ldots(2)$$

where n_1 and n_2 are the warp and weft yarn densities (thread/cm); and Nm_1 and Nm_2, the warp and weft yarn counts in Nm (metric count; length in meters of 1 g of yarn).

Table 1 — Constructional parameters and percentage reflectance values of all test fabrics

Fabric group	Weave	Weft yarn count den/filament	Weft density thread/cm	Fabric bulk density, g/cm^3	Fabric cover factor (K_f)	$\%R_{(measured)}$	$\%R_{(proportionally\ predicted)}$		
							A	B	C
First	Plain	100/36	15	0.31	19.42	**61.20**	–	–	–
			18	0.33	19.82	61.75	73.44	65.15	62.46
			20	0.35	20.08	61.96	81.60	69.10	63.28
	Plain	100/48	15	0.31	19.42	**61.61**	–	–	–
			18	0.34	19.82	62.18	73.93	67.57	62.88
			20	0.36	20.08	62.52	82.15	71.55	63.70
	Plain	100/144	15	0.30	19.42	**64.12**	–	–	–
			18	0.34	19.82	64.53	76.94	72.67	65.44
			20	0.37	20.08	65.00	85.49	79.08	66.30
	1/5 Sateen	100/36	15	0.20	19.42	**64.40**	–	–	–
			18	0.22	19.82	65.23	77.28	70.84	65.73
			20	0.23	20.08	65.82	85.87	74.06	66.59
	1/5 Sateen	100/48	15	0.20	19.42	**64.61**	–	–	–
			18	0.22	19.82	65.68	77.53	71.07	65.94
			20	0.23	20.08	65.84	86.15	74.30	66.81
	1/5 Sateen	100/144	15	0.20	19.42	**67.25**	–	–	–
			18	0.22	19.82	67.91	80.70	73.98	68.64
			20	0.25	20.08	68.88	89.67	84.06	69.54
Second	Plain	75/36	27	0.37	20.95	**57.00**	–	–	–
			32	0.45	21.49	58.07	67.56	69.32	58.47
			37	0.53	22.02	58.83	78.11	81.65	59.91
	1/3 Twill	75/36	27	0.25	20.95	**59.48**	–	–	–
			32	0.29	21.49	60.70	70.49	69.00	61.01
			37	0.33	22.02	61.76	81.51	78.51	62.52
	1/7 Sateen	75/36	27	0.20	20.95	**61.88**	–	–	–
			32	0.22	21.49	63.90	73.34	68.07	63.47
			37	0.25	22.02	65.00	84.80	77.35	65.04

A – Proportionally predicted results according to yarn density.
B – Proportionally predicted results according to fabric bulk density.
C – Proportionally predicted results according to fabric cover factor.
Bold values are taken as constant values in proportions method.

Calculation of fabric cover factor (K_f) given by Peirce[29,30] is presented below:

$$K_f = K_{wa} + K_{we} - ((K_{wa} \times K_{we}) / 28) \quad \ldots(3)$$

where *f* stands for fabric; *wa* stands for warp; and *we* stands for weft.

2.3 Calculation of Fabric Bulk Density

Fabric bulk densities were calculated according to following equation[31,32]:

$$\text{Fabric bulk density (g/cm}^3\text{)} = \text{Fabric unit weight (g/cm}^2\text{)} / \text{Fabric thickness (cm)} \quad \ldots(4)$$

The results are presented in Table 1. Polyester fibre density was taken 1.38 g/cm^3 in calculation[33].

2.4 Proportions Method

Fabrics with different constructional parameters were used in the experimental part and percentage reflectance values of these fabrics were measured with the reflectance spectrophotometer ($\%R_{measured}$). In proportions method, percentage reflectance values were predicted proportionally by computation ($\%R_{proportionally\ predicted}$) according to yarn density (A), fabric bulk density (B) and fabric cover factor (C) (Table 1). A, B and C were used as symbols to differentiate among the results. In prediction of percentage reflectance by proportions method, percentage reflectance ($\%R_{measured}$) of fabric sample which had the smallest yarn density of the fabric under estimation was taken into consideration as the beginning step and later proportioned with yarn density (A), fabric bulk density (B) and fabric cover factor (C) separately for the higher yarn density fabrics. An example of prediction calculation according to fabric cover factor (C column in Table 1) is discussed hereunder.

Percentage reflectance of plain woven fabric which belonged to the first group (including 100/36 dpf weft yarn, 15 weft/cm yarn density and fabric cover factor of 19.42; $\%R_{measured}$ 61.20 in Table 1) was taken as the beginning step for its sub-group of samples having 18 and 20 weft density. Predicted percentage reflectance of fabric (fabric cover factor 19.82), which could be woven with the same weft yarn and the same weave pattern but at 18 weft/cm weft density, was calculated using the following equation:

$\%R_{proportionally\ predicted}$: 61.20 × (19.82 / 19.42)

$\%R_{proportionally\ predicted}$: 62.46

While predicted percentage reflectance of fabric (fabric cover factor 20.08), which could be woven with the same weft yarn and the same weave pattern but at 20 weft/cm weft density, was calculated as follows:

$\%R_{proportionally\ predicted}$: 61.20 × (20.08 / 19.42)

$\%R_{proportionally\ predicted}$: 63.28

In this study, calculation of percentage reflectance values of new fabric surface after changing weft density (weave pattern, yarn count and yarn filament numbers being the same) was conducted by proportions method using three different approaches. In the first approach, calculation by using proportions method was conducted according to yarn densities (A). In the second approach, fabric bulk densities (B) calculated by Eq. (4) were used. In the third approach, calculation by using proportions method was conducted considering cover factors (C).

3 Results and Discussion

The measured ($\%R_{measured}$) and the proportionally predicted ($\%R_{proportionally\ predicted}$) percentage reflectance values are presented in Table 1. The predictions are made using three different approaches by the proportions method considering weft yarn density (A), fabric bulk density (B), and fabric cover factor (C).

The relationship among measured ($\%R_{measured}$) and proportionally predicted percentage reflectances ($\%R_B$ − prediction according to weft density; $\%R_B$−prediction according to fabric bulk density; and $\%R_C$ − prediction according to fabric cover factor), calculated by using the proportions method, is shown in Fig. 1 for the first group of fabrics that were woven in plain and 1/5 sateen patterns from the same yarn count but different filament number weft yarns at different weft densities.

The measured and proportionally predicted percentage reflectances of the second group of fabrics are presented in Fig. 2. The second group of fabrics are woven in plain, 1/3 twill and 1/7 sateen patterns from the same count and filament fineness weft yarns but different weft densities.

An overall consideration of figures shows that the closest results to the actual percentage reflectance values are obtained by prediction according to fabric cover factors in the proposed proportions method.

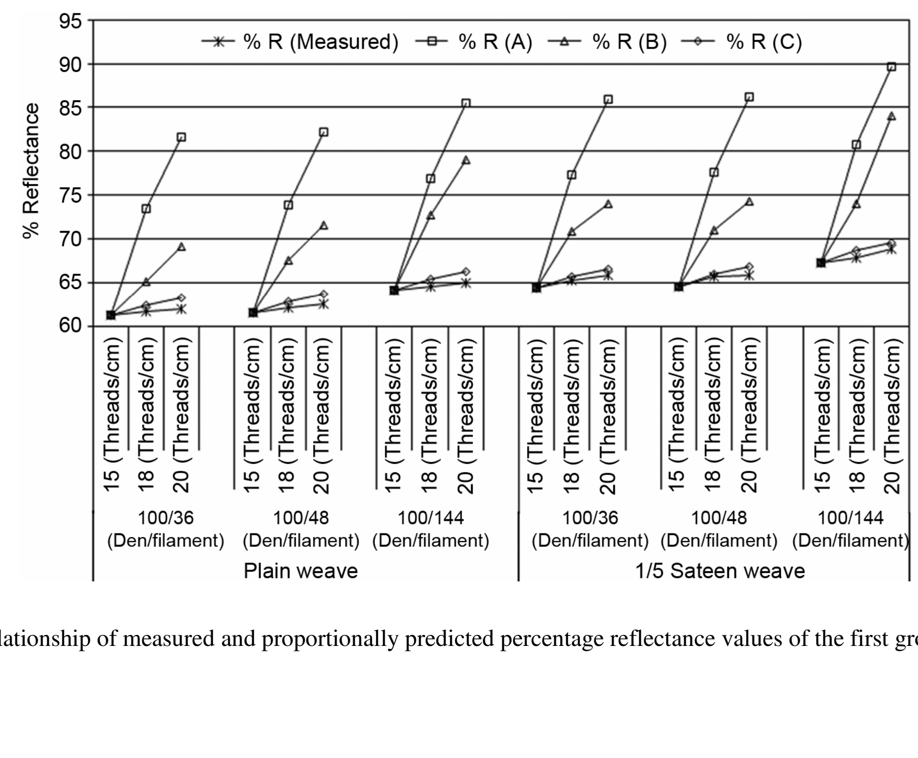

Fig.1 — Relationship of measured and proportionally predicted percentage reflectance values of the first group of fabrics

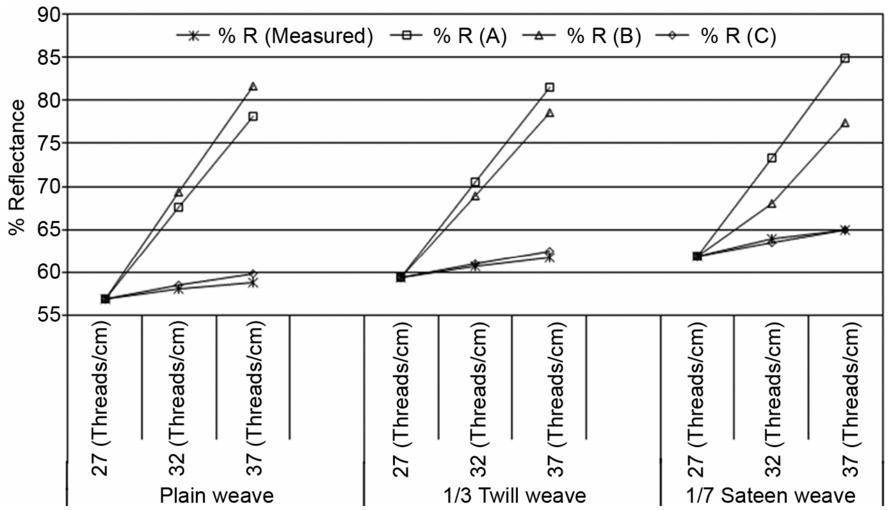

Fig. 2 — Relationship of measured and proportionally predicted percentage reflectance values of the second group of fabrics

Predicted results obtained according to yarn densities are found much different from the actual percentage reflectance values.

Proportions method according to fabric cover factors shows very close results regardless of fibre filament fineness and weave pattern. Especially the closest prediction is obtained in sateen patterns with finer filament fineness samples. Prediction according to yarn density and fabric bulk density shows changes with regard to yarn density and weave pattern in opposite terms for the two groups of fabrics.

In Figs 1 and 2, predicted reflectance value according to yarn density ($\%R_A$) increases as yarn densities and fibre filament fineness increase and also as weave pattern changes from plain to sateen. The highest predictions according to yarn density are obtained in fabric samples having the finest fibre filaments and woven in sateen pattern. In Figs 1 and 2, predicted results according to yarn density gradually increase as yarn densities and fibre filament fineness increase from plain to sateen pattern. However, predicted reflectance values according to fabric bulk density ($\%R_B$) change in different manners (Figs 1 and 2). In Fig. 1, predicted values ($\%R_B$) gradually increase as yarn densities and fibre filament fineness increase. But predicted values obtained in fabric samples containing the finest filaments (100/144 yarns; 0.69 dpf fibres) are found very much higher than the other ones, indicating that proportional prediction is dependent on the changes in fabric bulk density. Table 1 shows that fabric bulk densities decrease as weave patterns change from plain to sateen but increase as yarn densities increase. On the other hand, predicted percentage reflectance values ($\%R_B$) gradually decrease (Fig. 2) as yarn densities increase and weave patterns change from plain to sateen, although the fabric bulk densities change similarly as in first group of fabrics. Opposite changes in percentage reflectance prediction according to fabric bulk density are also obtained (Figs 1 and 2).

Prediction according to fabric cover factors gives the closest results to the actual percentage reflectance values. Especially, the estimations obtained in fabric samples with the finest filaments and with sateen pattern are found very close to the actual measured percentage reflectance.

Fabric cover factor could be considered as the best formula for reflectance estimation in which yarn densities and yarn count of fabric samples are taken into consideration to predict the cover of fabric samples based on reflection.

4 Conclusion

Results show that the percentage reflectance of woven fabrics changes mainly with fabric cover factors but not with yarn density and fabric bulk density when the proportions method is applied. The results show that percentage reflectance prediction of polyester woven fabrics could be made depending on changes in weft yarn density, which directly affects fabric cover factors. By using the same yarn count and the same weave pattern, percentage reflectance of polyester woven fabrics could be calculated according to the relation between weft yarn density and fabric cover factor. Prediction of percentage reflectance by proportions method gives reasonable results considering fabric cover factors under the rules of the same weave pattern and the same yarn count but different weft yarn densities.

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