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Cite as: AIP Conference Proceedings **2430**, 050003 (2022); https://doi.org/10.1063/5.0077307
Published Online: 24 January 2022

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Estimation of Hygroscopicity of Knitted Fabrics

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Abstract. The creation of new types of textile-based consumer goods requires solving the problems of designing their properties. Hygroscopic properties are important physical and mechanical characteristics of textile materials because these materials have to provide comfort in contact with the human body. In this work, the different types of knitted fabrics were researched. The statistical analysis of experimental data of dependence of hygroscopic properties on time has been carried out. As a result of the analysis, mathematical models have been developed to describe the experimental data. On the basis of the models, a method for the express estimation of the hygroscopicity of knitted fabric is proposed. Specialists who design the properties of new types of clothing and textile materials can use the results obtained in this work.

INTRODUCTION

The creation of new types of textile-based consumer goods requires solving the problems of designing their properties. Hygroscopic properties [1] are important physical and mechanical characteristics of textile materials because these materials have to provide comfort in contact with the human body [2-4]. Medical hygiene and underwear products are examples of consumer goods using such materials [5-8]. Two-layer hybrid knitted fabrics are often used for their production. They are a double knitted fabrics of combined stitch patterns that knitting using two systems of threads. First one is used for the formation of loops of the face side. Second one is used for the formation of loops of the backing side. The yarns of the one of the sides aren't used on the other side [9].

Thus, the task of estimation and prognosing the hygroscopicity of two-layer hybrid knitted material is actual for the purposes of designing new medical hygiene and underwear products.

MATERIALS AND METHODS

In this work, the hygroscopic properties of samples of two-layer hybrid knitted fabrics of plated structure was investigated [10]. The samples were made of several raw materials with different linear density. They were produced on a circular knitting machine with a cylinder diameter of 3.34 inches, class 16. The samples parameters are shown at table 1.

International Conference on Textile and Apparel Innovation (ICTAI 2021)
AIP Conf. Proc. 2430, 050003-1–050003-6; https://doi.org/10.1063/5.0077307
Published by AIP Publishing. 978-0-7354-4175-0/$30.00

TABLE 1. Raw materials for the samples

Variant number	Face side raw material	Backing side raw material
1	Linen yarn with linear density 30 tex	Linen yarn with linear density 30 tex
2	Cotton yarn with linear density 36 tex	Cotton yarn with linear density 36 tex
3	Polyester yarn with linear density 16.7 tex x2 (288 filaments)	Cotton yarn with linear density 36 tex
4	Polyester yarn with linear density 16.7 tex x2 (288 filaments)	Polyester yarn with linear density 16.7 tex x2 (288 filaments)

Photographs of the enlarged surface of the samples using a microscope were made. Figure 1a shows sample No.1 face side. Figure 1b shows sample No.1 backing side. The look of the rest of the samples is similar to that shown in Fig.1.

To measure the hygroscopic properties, the mass of the samples was measured before the experiment. The samples were then placed in a sealed container with water. The water temperature was 90º. The mass of the samples was measured after 1, 5, 10, 30 and 60 minutes after the start of the experiment. Hygroscopic property was defined as the ratio of the mass of moisture absorbed by the sample to the mass of the dry sample. To find a statistically significant value of hygroscopic properties, 10 measurements were made for each sample.

RESULTS AND DISCUSSION

As a result of statistical analysis of the data, a mathematical model was developed. The model can be used to describe the dependence of hygroscopic properties of knitted fabric samples on time. The model describes the experimental data with a high degree of validity of approximation. The model is in accordance with the following theoretical preconditions:

– at the beginning of moistening the actual hygroscopic property of knitted fabrics is equal to zero;

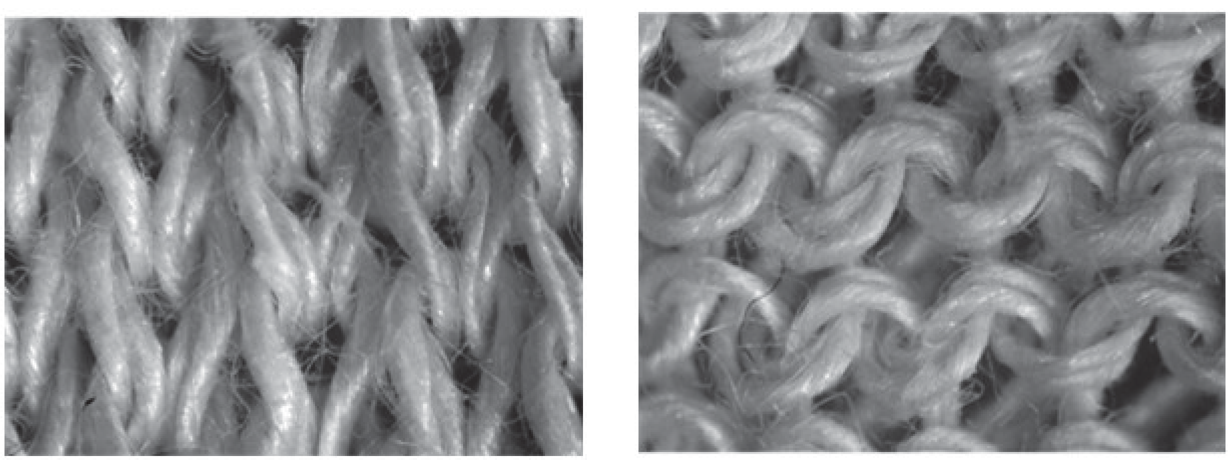
– actual hygroscopic property of knitted fabrics asymptotically tends to a constant value (the limit of actual hygroscopic property);

– the growth velocity of actual hygroscopic property is maximum at the start;

– the growth velocity tends to zero with the passage of time.

The described requirements are satisfied by the function [11]:

$$W_{\mathrm{A}} = \frac{t}{b_0 + b_1 t} \quad (1)$$



(a) (b)

FIGURE 1. Photographs of the enlarged surface of the samples using a microscope

W_A– actual hygroscopic property; t – absorption time; b_0 and b_1 – some model parameters.

A physical interpretation of the model parameters is desirable. For this purpose, by dividing the numerator and denominator of expression (1) by t and substituting $t \to \infty$ we find the asymptote (the limit of actual hygroscopic property):

$$W_L = \frac{1}{b_1} \tag{2}$$

By differentiating expression (1), we get the initial growth velocity of actual hygroscopic property:

$$V_{W_\mathrm{A}} = \frac{\partial W_\mathrm{A}}{\partial t} = \frac{1}{b_0 + b_1 t} - \frac{t b_1}{(b_0 + b_1 t)^2} \tag{3}$$

The growth velocity of actual hygroscopic property is maximum at the start. It can be found by estimating the parameter b_0 of the model (1):

$$V_S = \frac{1}{b_0} \tag{4}$$

Substituting (2) and (4) into (3) we obtain a model of the growth velocity of actual hygroscopic property with coefficients that have a physical interpretation:

$$V_{W_\mathrm{A}} = \frac{1}{\frac{1}{V_S} + \frac{t}{W_L}} = \frac{\frac{t}{W_L}}{\left(\frac{1}{V_S} + \frac{t}{W_L}\right)^2} = \frac{V_S W_L^2}{(W_L + t V_S)^2} \tag{5}$$

After linearizing the model (1) by replacing the variable $y = \frac{t}{W_L}$:

$$y = b_0 + b_1 t \tag{6}$$

After linearizing the model (1) estimates of model parameters b_0 and b_1 can be found by the ordinary least squares method [12]. After applying the formulas for finding an estimate of the actual moisture limit were obtained:

$$V_{W_\mathrm{A}} = \frac{1}{\mathrm{b}_1} = \frac{\overline{\mathrm{t}^2} - \bar{\mathrm{t}}^2}{\overline{\left(\frac{t^2}{W_A}\right)} - \bar{t}\,\overline{\left(\frac{t}{W_A}\right)}} \tag{7}$$

The initial growth velocity of actual hygroscopic property was also obtained:

$$V_S = \frac{1}{\mathrm{b}_0} = \frac{1}{\overline{\left(\frac{t}{W_A}\right)} - \left(\frac{\bar{t}}{W_S}\right)} \tag{8}$$

Thus, the possibility of linearization of the model allows to obtain point and interval estimates of the limit of actual hygroscopic property and the start growth velocity of actual hygroscopic property. It also allows to obtain the confidence intervals for the entire sorption curve using regression analysis methods.

The statistical analysis of experimental data of dependence of hygroscopic properties on time has been carried out using Julia language [13, 14]. Figure 2 shows results of hygroscopic properties measurements of the sample No.3 (Table 1). One point is a mean value of ten measurements. Based on the experimental data in accordance with the model (1), an approximating curve of the dependence of hygroscopic properties on time of the sample was plotted.

Figure 3 shows the dependence of hygroscopic properties on time of all samples.

To estimate the parameters of the linearized model (7) it is enough to carry out experiments for two different time intervals t_1 and t_2. This makes it possible to realize the method of express estimation of the sorption properties of knitted fabric by two short-term experiments.

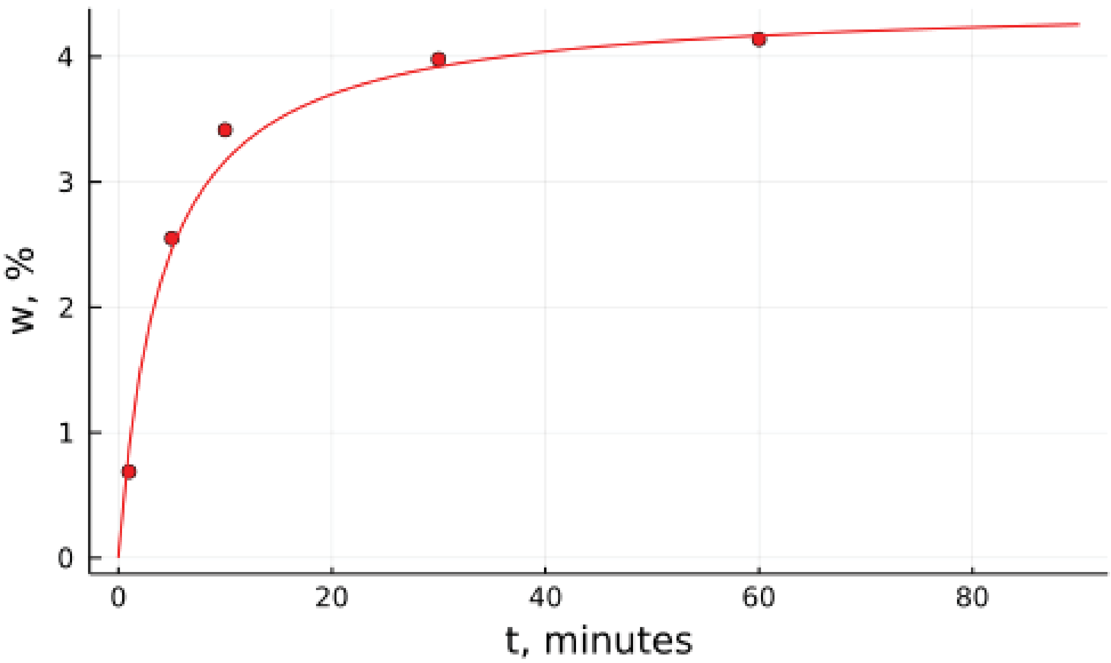


FIGURE 2. Results of hygroscopic properties measurements

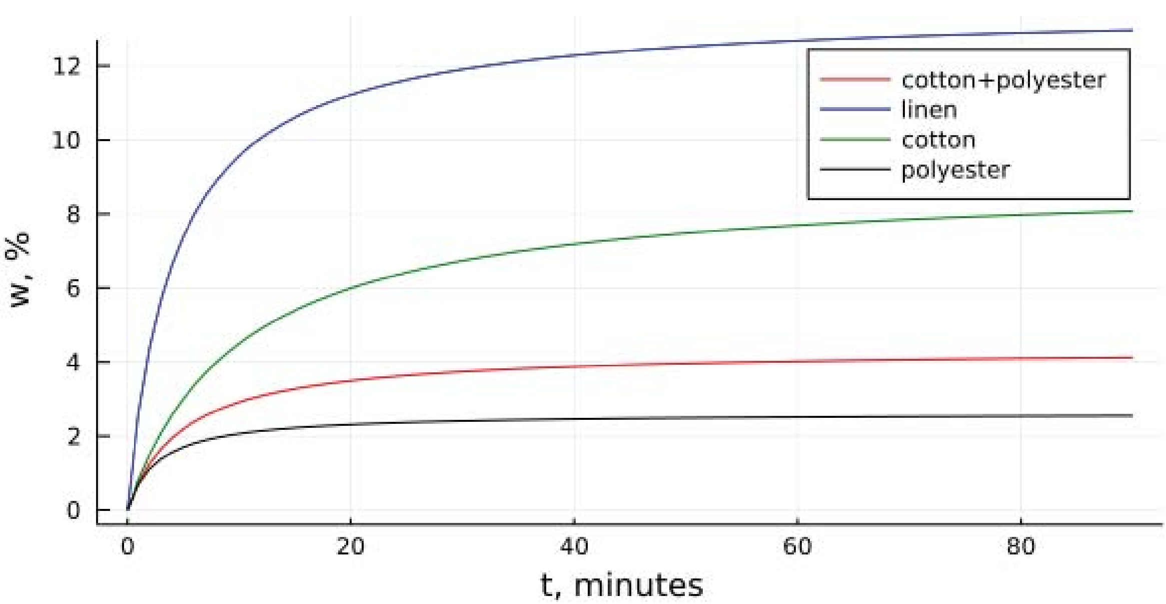


FIGURE 3. Dependence of hygroscopic properties on time

Figure 4 shows the estimation of the sorption curve of knitted fabrics by experiments for two different time intervals: $t_1 = 0..5$ min, $t_2 = 0..30$ min. The further in time the extrapolation is made, the wider the confidence intervals and the lower the reliability of the predictive estimate.

Point estimates of the sorption model parameters for the knitted fabrics are shown in Table 2.

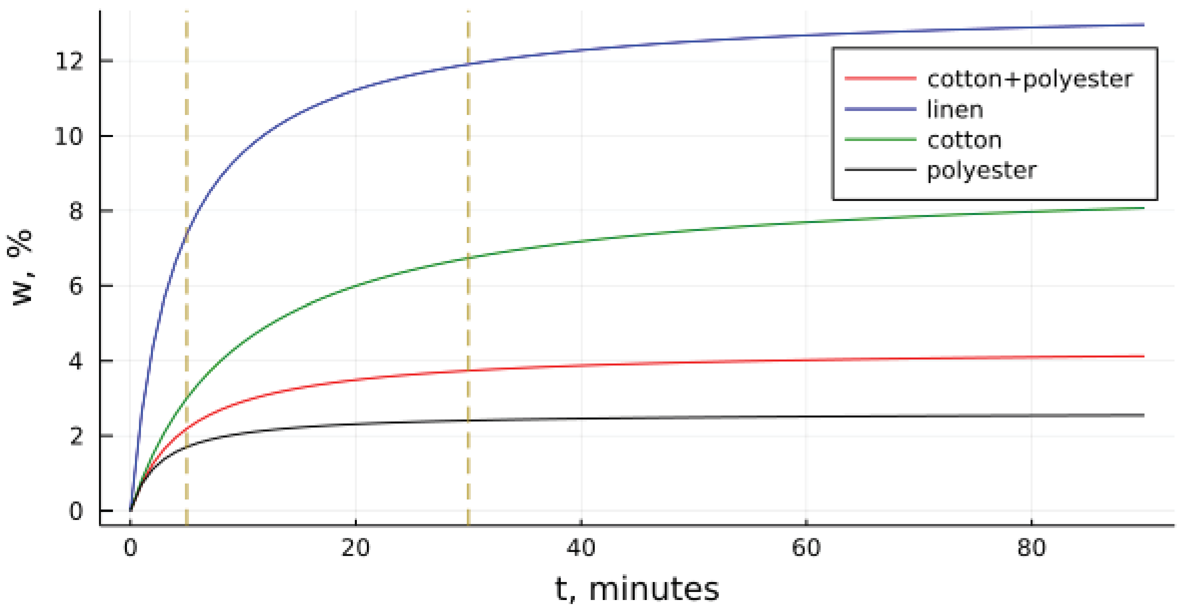


FIGURE 4. Express-estimation of hygroscopic properties

TABLE 2. Point estimates of the sorption model parameters for the knitted fabrics

Variant number	Limit of actual hygroscopic property	Initial growth velocity of actual hygroscopic property
1	13,561	3,245
2	8.965	0.903
3	4,353	0,883
4	2.624	0.966

As a result of the experimental research carried out the following has been discovered:

– linen knitted fabric has the maximum limit of actual hygroscopic property 13,5%;

– cotton knitted fabric has the maximum limit of actual hygroscopic property 8,9%;

– polyester multifilament knitted fabric has the maximum limit of actual hygroscopic property 2,6%;

– knitted fabric with polyester yarns on the backing side and cotton yarns on the face side has the maximum limit of actual hygroscopic property 3,5% that is between actual moisture limit values of polyester sample and cotton sample.

The results obtained can be used in the design of new types of textile products using knitted fabrics of different raw materials.

CONCLUSION

A mathematical model has been developed. The model makes it possible to implement the method of express estimation of the curve of dependence of hygroscopic properties of hybrid two-layer knitted fabrics from different raw materials on time (table 1). The developed mathematical model makes it possible, using the results of hygroscopic properties measurements for two different time intervals, to estimate limit of actual hygroscopic property and initial growth velocity of actual hygroscopic property. The results obtained can be used in the design of new types of textile products using knitted fabrics of different raw materials.

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