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Influence of Fusing Conditions on the Change of Colour Shade in the Production of Clothing

Vpliv pogojev fiksiranja na spremembo barvnega odtenka pri proizvodnji oblačil

Original scientific article/*Izvirni znanstveni članek*
Received/*Prispelo 5-2020* • Accepted/*Sprejeto 8-2020*

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Abstract
One of the major technological processes in the sewing industry is the process of thermo-mechanical fusing (TMF). This is a process in which the main textile material connects to an additional textile material (interlining) through a polymer binder. This ensures better resistance to the shape of the individual parts of the sewing article. The main factors that influence the process are the temperature of the pressing plates, and the pressure and the duration of the process. The process has not been sufficiently studied and therefore it is important to identify a function that connects the output parameter to the input factors of the TMF process. It is especially important to choose an optimisation criterion. After numerous preliminary studies, some changes in textile materials (TM) after TMF have been observed. For example, the incorrect adjustment of process parameters (e.g. pressure, temperature and duration) changes the colour shade of TM after TMF. This change in the colour shade of the individual parts will impair the quality of the sewing product as a whole. This encourages the selection of the quality criterion. In light of the latter, the purpose of this paper was to derive a mathematical model of the TMF process that describes the influence of input factors on the quality criterion: changing the colour shade of TM after TMF.
Keywords: thermo-mechanical fusing process, change of colour shade

Izvleček
Eden glavnih tehnoloških procesov v konfekcijski industriji je termomehanski postopek fiksiranja. To je postopek, pri katerem se osnovni tekstilni material poveže z dodatnim tekstilnim materialom (medvlogo) s polimernim lepilnim termoplastom. S tem se poveča obstojnost oblike posameznih delov šivanega izdelka. Glavni dejavniki, ki vplivajo na postopek, so temperatura stiskalnih plošč, tlak in časovni potek postopka. Sam postopek fiksiranja še ni bil v celoti raziskan z vidika funkcijske odvisnosti med vhodnimi dejavniki termomehanskega taljenja z izhodnimi parametri. Še zlasti je pomembna možnost izbire optimalnih kriterijev. Po številnih predhodnih študijah so bile opažene nekatere spremembe tekstilnih materialov po termomehanskem taljenju. Na primer, nepravilna nastavitev parametrov (tlaka, temperature in časa) spremeni barvni odtenek tekstilnega materiala po fiksiranju. Takšna sprememba barvnega odtenka posameznih oblačilnih delov poslabša kakovost oblačila kot celote. To narekuje pravilno izbiro kriterijev kakovosti, zato je v članku izpeljan matematični model termomehanskega fiksiranja, ki opisuje vpliv vhodnih dejavnikov na enega od kriterijev kakovosti – spreminjanje barvnega odtenka tekstilnega materiala končnega izdelka.
Ključne besede: termomehanski postopek fiksiranja, sprememba barvnega odtenka

1 Introduction

One of the major technological processes in the sewing industry is the process of thermo-mechanical fusing (TMF). This is a process in which the main textile material connects to an additional textile material (interlining) through a polymer binder. This ensures better resistance to the shape of the individual parts of the sewing article. The main factors that influence the process are the temperature of the pressing plates, and the pressure and the duration of the process. From the study conducted, it can be summarised that some investigations were made to determine the effect of individual parameters on the TMF process [1–4]. However, the combined influence of controllable factors, for example to satisfy the quality and performance criteria, has not been sufficiently studied.
Globally, many elite companies have conducted research in this area, but their studies are commercial or confidential. In this context, it is necessary to derive a mathematical model of the TMF process through research and analysis with the help of modern control and measuring equipment. It is especially important to choose an optimisation criterion.
Optimisation criteria (i.e. output parameters) can be quality criteria or performance criteria. In industrial technology, time is often used as a criterion for productivity [5–8]. In one study [9], a mathematical model of the TMF process was created to describe the relationship between the duration of the process and input factors. In any scientific study, it is especially important to define an effective quality criterion, as well. Quality assurance and quality control represent a complex area of the apparel industry. Quality assurance is not quality control, but quality control is an aspect of quality assurance. Quality assurance builds quality into each step of the manufacturing process [10]. Therefore, it is especially important to study the influence of TMF conditions on the quality of the sewing product [11]. From the literature review, it can be concluded that this issue has not been sufficiently investigated. After numerous preliminary studies, some changes in textile materials (TM) after TMF have been observed. For example, the incorrect adjustment of process parameters (e.g. pressure and temperature) changes the colour shade of TM after TMF. For some technological processes, colour change is a desired effect. It is especially fashionable to generate faded effects on indigo dyed denim fabric [12]. For the TMF technological process, however, the change of the colour shade of the main textile materials is an entirely undesirable effect.
The change in the colour shade of individual parts will impair the quality of the sewing product as a whole. This encourages the selection of the quality criterion. In this work, the colour change after TMF is used as a quality criterion. The conditions for carrying out the TMF process are also especially important. In recent years, the sewing industry has used an increasing number of new and different textile materials. Each of them has a different composition and structure. It is rare to find two fibres or textile materials at random that exhibit the same characteristics [13]. This determines their different properties [5, 9, 14, 15]. In light of the latter, it is important to choose a manageable factor that is related to the type and structure of the studied textile materials. One study [16] illustrates the relationship between the mass per unit area, the composition and the structure of the respective type of textile material.
The purpose of this paper was to derive a mathematical model of the TMF process that describes the influence of the input factors (e.g. pressure, the temperature of the pressing plates and the mass per unit area of basic textile materials) on the quality criterion: changing the colour shade of TM after TMF.

2 Experimental work

When carrying out experimental work it is important to take into account the reflective properties of the TM. These properties depend on many factors. They include colour, dye concentration, composition and structure of TM and many others. For this reason, TMs of the same colour are used in the experiment. On the other hand, this ensures the reproducibility of the process.

2.1 Methods

In formulating the conditions and methods for conducting the experiment, the principles of the morphological method for analysis and synthesis of methods were applied [17]. It is important to determine the method for quantifying the change in colour shade of TM after TMF. This quantification in the present work was carried out using a modern objective method. The DATA COLOR measurement system was used for colour measurement. That system comprises a spectrophotometer and a computer.

The device used was highly sensitive. The method was carried out over a short time frame, with a sufficient degree of accuracy. It is reproducible, versatile and affordable. The studies were performed with monochromatic TMs, coloured in black.
The full factorial experiment (FFE) method was used to create a mathematical model. It implements all possible combinations of two levels of factors. The number of these combinations for n factors is N = 2n [5, 18].
The basic elements for the compilation of the mathematical model were determined using the methodology for the implementation of FFE [5, 18].

2.2 Conditions for conducting the experiment

In order to determine the conditions for conducting the experiment, it was also necessary to select manageable factors.
The following were selected for controllable (manageable) factors: X_1 representing the pressure of the pressing plate, P (N/cm^2); X_2 representing the temperature of the pressing plates, T (°C); and X_3 representing the mass per unit area of basic textile materials, M (g/m^2). The main factor levels and intervals of variation are given in Table 1 [9].
The temperature between the basic TM and the auxiliary TM (interlining) was T_M (material temperature).
After conducting a number of preliminary studies, the following conditions for conducting the experiments were selected:

- an ATLAS - I. BALA - 4-93 fusing machine (stationary press type "drawer"); and
- the TM temperature (T_M) was recorded with a computer integrated measurement system [19].

The temperature (T_Q) is assumed to be the temperature required for quality bonding when working with the textile materials described.
The fusing process was finalised when T_M reached T_Q [4].
After numerous preliminary experiments, it was found that T_Q = 112 °C for the studied T_M.

2.3 Materials

Materials produced by the company NITEX-50 (Sofia) were used for basic textile materials.
They were 100% wool fabrics: article EKSELSIOR with a mass per unit area 173 g/m^2, warp threads density of 122 pcs/10 cm and weft threads density of 230 pcs/10 cm; article RITZ with a mass per unit area of 193 g/m^2, warp threads density of 175 pcs/10 cm and weft threads density of 263 pcs/10 cm; and article KARDINAL with a mass per unit area 213 g/m^2, warp threads density of 370 pcs/10 cm and weft threads density of 232 pcs/10 cm [9].
Material produced by the company Kufner-B121N77 was used for interlining textile material (auxiliary textile material). The interlining TM is tissue with a mass per unit area of 63 g/m^2, warp threads of 100% PES and weft threads of 100% PES.

3 Results and discussions

3.1 Experimental results

The design of the experiment is given in Table 2.
The number of factor levels is k = 2; the number of factors is n = 3 (I, l and p representing the sequences numbers of factors), therefore [5, 18] N = 8.

3.2 Discussion of experimental results

It is necessary to carry out a process reproducibility check, which is reduced [5, 18] to a variance perseverance check (using Cochran's C test).
The results for the calculated and tabulated value of the Cochran's C test are:

$$G_C = \frac{S^2_{j\max}}{\sum_{j=1}^{N} S_j^2} = 0{,}125 \quad (1)$$

$$G_T\{f_1 = m\text{-}1;\ f_2 = N;\ r = 0.05\} = 0.6798, \quad (2)$$

where: "r" represents the significance level and "f_1" and "f_2" represent degrees of freedom.

Table 1: Factor levels

Factors levels	X_1 – P (N/cm^2)		X_2 – T (°C)		X_3 – M (g/m^2)	
	Natural	Coded	Natural	Coded	Natural	Coded
$X_{oi} + J_i$	40	+ 1	150	+ 1	213	+ 1
X_{oi}	25	0	135	0	193	0
$X_{oi} - J_i$	10	– 1	120	– 1	173	– 1
J_i	15		15		20	

Table 2: Design of the experiment

№	X_0	X_1	X_2	X_3	X_1X_2	X_1X_3	X_2X_3	$X_1X_2X_3$	$\bar{Y}_J$	Y_{jC}
1	+	–	–	–	+	+	+	–	0.5	0.4925
2	+	+	–	–	–	–	+	+	1.2	1.2075
3	+	–	+	–	–	+	–	+	1.07	1.0625
4	+	+	+	–	+	–	–	–	1.63	1.6375
5	+	–	–	+	+	–	–	+	0.91	0.9175
6	+	+	–	+	–	+	–	–	1.57	1.5625
7	+	–	+	+	–	–	+	–	1.25	1.2575
8	+	+	+	+	+	+	+	+	1.91	1.9025

The number of repetitions of the jth test (j = 1÷N) is m = 2.
The results of the experiments () are also given in Table 2.

Therefore, the intra-group variance does not differ statistically and the process is reproducible.
Regression coefficients were determined using formulas (3) to (12) [5, 18]:

$$b_o = \frac{1}{N}\sum_{j=1}^{N}\bar{Y}_j = 1{,}255 \quad (3)$$

$$b_i = \frac{1}{N}\sum_{j=1}^{N}x_{ij}\bar{Y}_j \quad (4)$$

$$b_1 = 0{,}3225 \quad (5)$$

$$b_2 = 0{,}21 \quad (6)$$

$$b_3 = 0{,}155 \quad (7)$$

$$b_{il} = \frac{1}{N}\sum_{j=1}^{N}x_{ij}x_{lj}\bar{Y}_j \quad (8)$$

$$b_{12} = \frac{1}{N}\sum_{j=1}^{N}x_{1j}x_{2j}\bar{Y}_j = (-0{,}0175 \quad (9)$$

$$b_{13} = 0{,}0075 \quad (10)$$

$$b_{23} = (-0{,}04) \quad (11)$$

$$b_{ilp} = b_{123} = \frac{1}{N}\sum_{j=1}^{N}x_{1j}x_{2j}x_{3j}\bar{Y}_j = 0{,}0175 \quad (12)$$

The output parameter variance was defined according to (13) [5, 18]:

$$S_j^2(Y) = \frac{1}{m-1}\sum_{u=1}^{m}(Y_{ju} - \bar{Y}_j)^2 \quad (13)$$

The variance of reproducibility was determined according to (14) [5, 18]:

$$S_R^2 = \frac{1}{N}\sum_{j=1}^{N}S_j^2(Y) = 0{,}0002 \quad (14)$$

The variances of the regression coefficients were determined according to (15) [5, 18]:

$$S_{(Bi)}^2 = \frac{S_{(Y)}^2}{N(m-1)} = 0{,}000025 \quad (15)$$

The significance of the calculated regression coefficients was verified. Student's t-test was used. Only those coefficients were significant for which the following was valid [5, 18]:

$$t_C > t_T, \quad (16)$$

where: t_C represents the calculated coefficient; t_T represents the table value of Student's t-test, with the selected significance level of r = 0,05 and the degree of freedom of f = N (m–1) = 8.
The value of Student's t-distribution was defined as: $t_T = 2.31$.
t_C was determined according to (17) [5, 18]:

$$t_C = \frac{|B_i|}{S_{(B_i)}} \quad (17)$$

Therefore: $t_{C(b0)} = 251$; $t_{C(b1)} = 64.5$; $t_{C(b2)} = 42$; $t_{C(b3)} = 31$; $t_{C(b12)} = 3.5$; $t_{C(b13)} = 1.5$; $t_{C(b23)} = 8$; $t_{C(b123)} = 3.5$.

The only insignificant coefficient was b_{13}, the absolute value of which was smaller than the critical value. After eliminating the insignificant coefficient, the model took the following form:

$$Y_C = 1{,}255 + 0{,}3225 \cdot x_1 + 0{,}21 \cdot x_2 + 0{,}155 \cdot x_3 - 0{,}0175 \cdot x_1 \cdot x_2 - 0{,}04 \cdot x_2 \cdot x_3 + 0{,}0175 \cdot x_1 \cdot x_2 \cdot x_3 \quad (18)$$

Verification of model adequacy:

- the adequacy variance was established (19) [5, 18]:

$$S^2_{ad.} = \frac{m}{f} \sum_{j=1}^{N} (\overline{Y}_j - \overline{Y}_{jC})^2 = 0{,}0009 \quad (19)$$

where: f = N–M=1, Y_{jC} represents the value calculated by the mathematical model (Table 2) and M represents the number of significant regression coefficients.

- the expected Fisher's F-test was calculated according to (20) [2, 18]:

$$F_C = \frac{S^2_{ad.}}{S^2_{(Y)}} = 4{,}5 \quad (20)$$

- the table value of Fisher's distribution was:

F_T {r = 0.05; f_1 = N–M = 1; f_2 = N(m-1) = 8} = = 5.32 [5, 18].

As F_C = 4.5 < 5.32= F_T, the model is adequate [5, 18]. Therefore, the hypothesis that a mathematical model of the type (18) is adequate can be accepted with a confidence probability of P = 0.95.

4 Conclusion

After a thorough analysis of the nature and characteristics of the technological TMF process of a stationary press type "drawer", a full factorial experiment was planned to make a mathematical model of the process. The change in the colour shade of the sewing parts after TMF was selected as a quality criterion. A mathematical model of the TMF process was created for the corresponding experimental conditions. It showed how the output quality parameter is linked to the input factors, i.e. the pressure P (N/cm^2), temperature T (°C) and mass per unit area of basic textile materials M (g/m^2).

The conducted research has an applied-scientific character. The mathematical model obtained creates the conditions for quickly finding another combination of inputs that satisfies the quality criterion. This helps to quickly solve real production problems and optimise the process.

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