OPTIMIZING A FUNCTION LINKING AN QUALITY CRITERION TO INPUT FACTORS ON THE THERMO-MECHANICAL FUSING PROCESS

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Abstract: *The subject of research in the present work are technological processes in the garment industry. Different quality criteria are established for each technological process. One of the major technological processes in the sewing industry is the process of thermo-mechanical fusing (TMF). Its optimization is not an easy task. This is due to the extreme complexity of the process. As a result of numerous studies, a mathematical model of TMF has been created. The model gives the relationship between input factors and a process quality parameter. The present work aims to optimize the function describing the relationship between the quality criterion and the input factors in TMF. A 3D graphical interpretation of the optimization has also been made.*

Keywords: *thermo-mechanical fusing process, optimizing.*

1 INTRODUCTION

The quality criteria in the garment industry are extremely many and varied [1]. Their research and optimization are important for the final look of the sewing product. Different quality criteria are established for each technological process. One of the major technological processes in the sewing industry is the process of thermo-mechanical fusing (TMF). A number of studies and analyzes of this process have been conducted. Various indicators have been used as quality criteria. For example, the compressibility of textile material (TM) during TMF is an important quality criterion [2-4]. In modern sewing technology, however, this problem is now very easy to overcome. For this purpose, the so-called "rough" cutting is used. The thermo-mechanical fusing process is carried out. Then the detail is cut fine (exactly). This ignores the problems with the compressibility of the TM during the TMF process. There is another significant problem with the TMF process. In case of incorrect setting of the process parameters, the color shade of the main textile material subjected to TMF changes. This change in the color shade of the individual parts will impair the quality of the sewing product as a whole. Therefore, it is appropriate to use the change in the specific color shade as a quality criterion after TMF. To achieve optimal indicators for the quality and productivity of a technological process, it is necessary to create a mathematical model of the function connecting the output parameter (*Y*) with the input factors (*X*) [5, 6]. This requires conducting experiments with the simultaneous variation of the studied factors.

In the works [7, 8] mathematical models of the TMF process are created. The mathematical model [7] describes the influence of input factors on a productivity criterion of the TMF process. The mathematical model [8] describes the influence of the pressure, the temperature of the pressing plates, and the mass per unit area of the basic textile materials on a quality criterion of the TMF process.

The present work aims to investigate and optimize the function describing the relationship between a quality criterion and the input factors in TMF. The change of the color shade of the textile material after TMF is used as a quality criterion.

Table 1 Levels of factors

Factors	**X_1 - Pressure [N/cm^2]**		**X_2 - Temperature of the pressing plates T [°C]**		**X_3 - Mass per unit area of basic textile materials M [g/m^2]**	
Levels	***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	

2 RESEARCH WORK

2.1 Conditions for conducting the study

As a result of numerous studies [2, 8, 9], the function connecting the quality criterion with the input factors of the TMF process has been created. This function is represented by (1):

$$Y(X_1, X_2, X_3) = 1{,}255 + 0{,}3225.X_1 + \\ + 0{,}21.X_2 + 0{,}155.X_3 - 0{,}0175.X_1.X_2 - \\ - 0{,}04.X_2.X_3 + 0{,}0175 X_1.X_2.X_3 \quad (1)$$

The optimization of the function is related to finding those values of X_1, X_2, and X_3 for which $Y(X_1, X_2, X_3)$ has a minimum or maximum value subject to:

$$\begin{cases} X_1 = \{-1;0;1\}; \\ X_2 = \{-1;0;1\}; \\ X_3 = \{-1;0;1\}, \end{cases} \quad (2)$$

where: $Y(X_1, X_2, X_3)$ - the change in the specific color shade of the textile material after TMF (a quality criterion); X_1 - the coded value of the input parameter - pressure P [N/cm^2]; X_2 - the coded value of the input parameter - the temperature of the pressing plates T [°C]; X_3 - the coded value of the input parameter - mass per unit area of basic textile materials M [g/m^2].

The coded and natural levels of input factors are given in Table 1 [8].

The study of function (1) was performed for 9 different options. The options are illustrated in Table 2. In each option, one of the input factors is assumed to be constant, and the other two factors vary (in the range of values given in Table 1). Each factor is taken as a constant and successively accepts the following levels: (+1), (0), (-1). The optimal values (minimum and maximum) of the output parameter Y for each option are sought. The output parameter is the change in the specific color shade of the textile material after TMF. In light of the above, Y_{min} is the optimal value of Y.

2.2 Methods

Statistical methods of analysis and evaluation are used to optimize a mathematical model [10-14]. In the present work, the optimization is performed with a specialized software product Maple. A 3D graphical interpretation of the model (1) in the environment of Maple was also made.

2.3 Materials

Materials produced by the company NITEX-50 - Sofia were used for basic textile materials. They are 100% wool fabrics: article EKSELSIOR; article RITZ; article KARDINAL, described in detail in [7].

The material produced by the company Kufner-B121N77 was used for interlining textile material (auxiliary textile material) [8].

3 RESULTS AND DISCUSSION

3.1 Research results

Function (1) is investigated for 9 different combinations of input factor levels. These 9 combinations (options) are illustrated in Table 2. When studying the first option:

- it is assumed that the coded value of $X_1=(+1)$, then the natural values of X_2 and X_3 fulfil condition (3):

$$X_2, X_3 \geq 0 \quad (3)$$

- function (1) acquires the form (4):

$$Y_1(X_2, X_3) = 1{,}255 + 0{,}3225.(+1) + 0{,}21.X_2 + \\ + 0{,}155.X_3 - 0{,}0175.(+1).X_2 - 0{,}04.X_2.X_3 + \\ 0{,}0175(+1).X_2.X_3 = 1{,}5775 + 0{,}1925 X_2 + \\ + 0{,}155 X_3 - 0{,}0225 X_2.X_3 \quad (4)$$

The 3D graphical interpretation of the mathematical model (4) is given in Figure 1, in which on the abscissa and the ordinate are given the coded values of X_2 and X_3, for which the condition (5) is fulfilled:

$$X_2 \epsilon [(-1) \div (+1)], \quad X_3 \epsilon [(-1) \div (+1)] \quad (5)$$

For the first option, the respective maximum and minimum values of the output parameter Y are obtained:

$$Y_{1max}=1.9025=f[X_2=(+1), X_3=(+1)] \quad (6)$$

$$Y_{1min}=1.2075=f[X_2=(-1), X_3=(-1)] \quad (7)$$

The optimal value of the output parameter Y for the first option is Y_{1min}. The optimal value of the function (1) for option 1 is given in Figure 2.

From the study, it can be concluded that the optimal levels of input factors for the TMF process for option 1 are: $X_1=(+1)$; $X_2=(-1)$; $X_3=(-1)$.

Function (1) is investigated and analyzed in a similar way for the other options.

The results of the studies are given in Table 2. In Table 2 the function (1) is denoted by $Y_i=f(X_1, X_2, X_3)$, where i – option number.

In Figures 3-10 illustrates the 3D models and the optimal values of the function (1) for the options 2-9.

3.2 Discussion of the research results

For each of the considered options the natural levels of the factors at which the quality criterion has optimal values are presented (Table 3). Therefore, it can be generalized that function (1) has an optimal value for option 3, option 6 and option 9.

The optimal value of the function (1) is $Y_i(X_1, X_2, X_3)=0.4975$ at natural values of the input factors: $X_1=10$ N/cm^2, $X_2=120$°C, $X_3=173$ g/m^2.

Table 2 Optimal values of the function Y_i

Option №	Value of the input factor that is selected as a constant	$Y_i (X_1, X_2, X_3)$	$Y_{i\ max}$	$Y_{i\ min}$
1	X_1=(+1)	$Y_{(X_2,X_3)} = 1,5775 + 0,1925X_2 + 0,155X_3 - - 0,0225X_2X_3$	1.9025=f[X_2=(+1), X_3=(+1)]	1.2075=f[X_2=(-1), X_3=(-1)]
2	X_1=0	$Y_{(X_2,X_3)} = 1,255 + 0,21X_2 + 0,155X_3 - - 0,04X_2X_3$	1.58=f[X_2=(+1), X_3=(+1)]	0.85=f[X_2=(-1), X_3=(-1)]
3	X_1=(–1)	$Y_{(X_2,X_3)} = 0.9325 + 0,2275X_2 + 0,155X_3 - - 0,0575X_2X_3$	1.2575=f[X_2=(+1), X_3=(+1)]	0.4925=f[X_2=(-1), X_3=(-1)]
4	X_2=(+1)	$Y_{(X_1,X_3)} = 1.465 + 0.305X_1 + 0.115X_3 + + 0.0175X_1X_3$	1.9025=f[X_1=(+1), X_3=(+1)]	1.0625=f[X_1=(-1), X_3=(-1)]
5	X_2=0	$Y_{(X_1,X_3)} = 1.255 + 0.3225X_1 + 0.155X_3$	1.7325=f[X_1=(+1), X_3=(+1)]	0.7775=f[X_1=(-1), X_3=(-1)]
6	X_2=(–1)	$Y_{(X_1,X_3)} = 1.045 + 0.34X_1 + 0.195X_3 - - 0.0175X_1X_3$	1.5625=f[X_1=(+1), X_3=(+1)]	0.4925=f[X_1=(-1), X_3=(-1)]
7	X_3=(+1)	$Y_{(X_1,X_2)} = 1.41 + 0.3225X_1 + 0.17X_2$	1.9025=f[X_1=(+1), X_2=(+1)]	0.9175=f[X_1=(-1), X_2=(-1)]
8	X_3=0	$Y_{(X_1,X_2)} = 1.255 + 0.3225X_1 + 0.21X_2 - - 0.0175X_1X_2$	1.77=f[X_1=(+1), X_2=(+1)]	0.705=f[X_1=(-1), X_2=(-1)]
9	X_3=(–1)	$Y_{(X_1,X_2)} = 1.1 + 0.3225X_1 + 0.25X_2 - - 0.035X_1X_2$	1.6375=f[X_1=(+1), X_2=(+1)]	0.4925=f[X_1=(-1), X_2=(-1)]

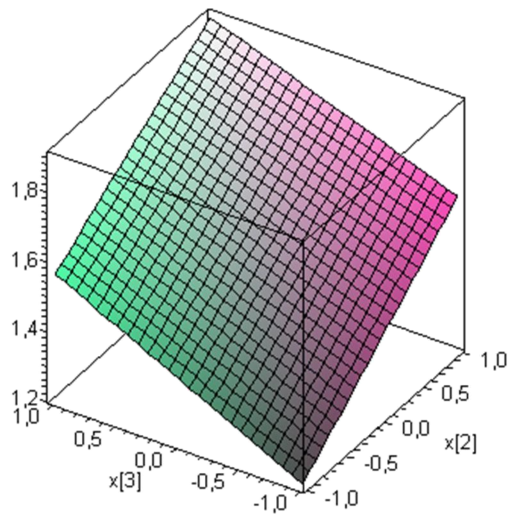

Figure 1 3D model of the function (4)

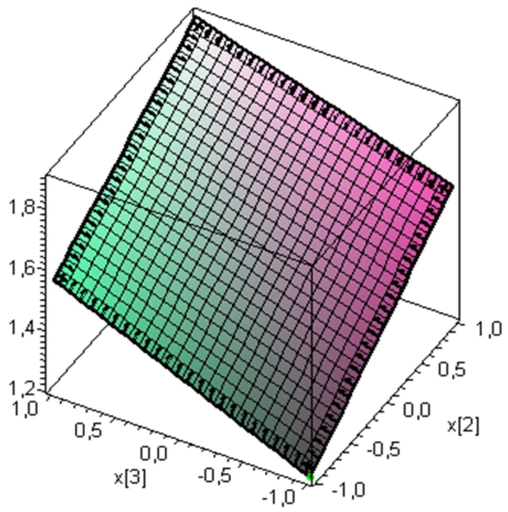

Figure 2 Optimal value of function (1) for option 1

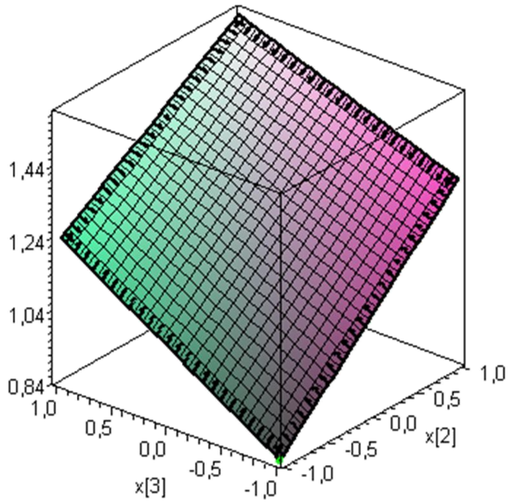

Figure 3 3D model and optimal value of function (1) for option 2

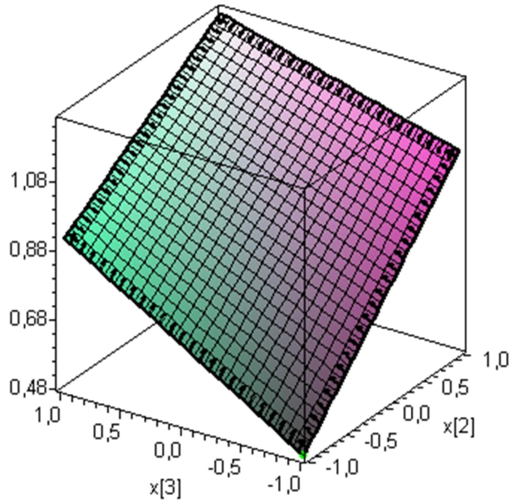

Figure 4 3D model and optimal value of function (1) for option 3

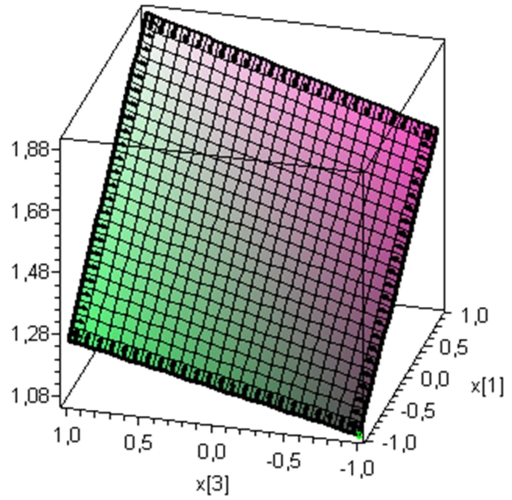

Figure 5 3D model and optimal value of function (1) for option 4

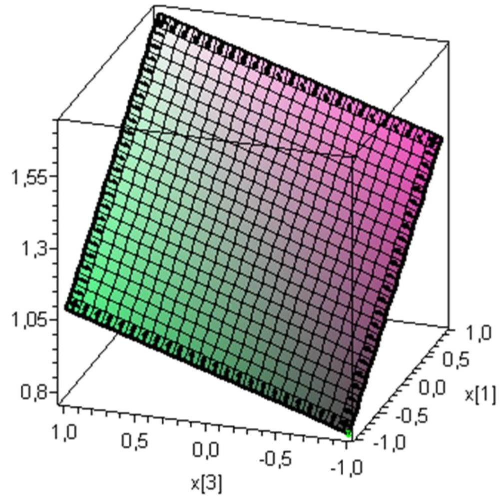

Figure 6 3D model and optimal value of function (1) for option 5

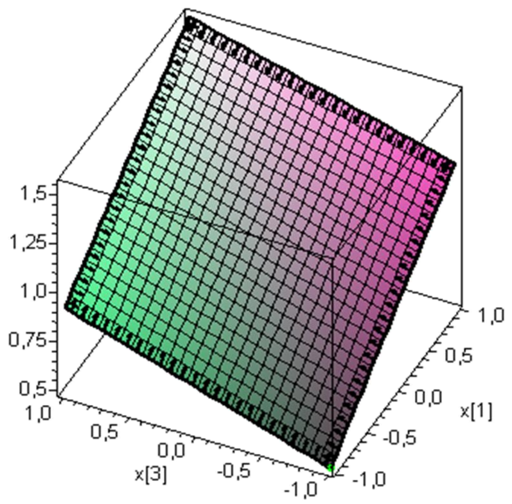

Figure 7 3D model and optimal value of function (1) for option 6

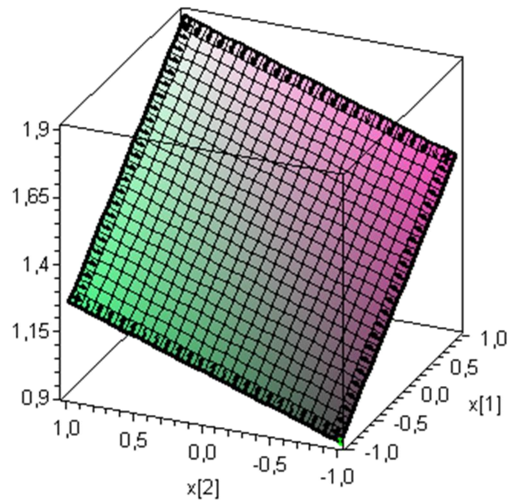

Figure 8 3D model and optimal value of function (1) for option 7

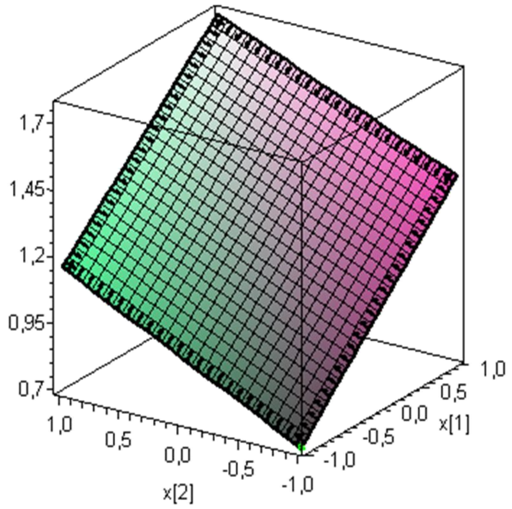

Figure 9 3D model and optimal value of function (1) for option 8

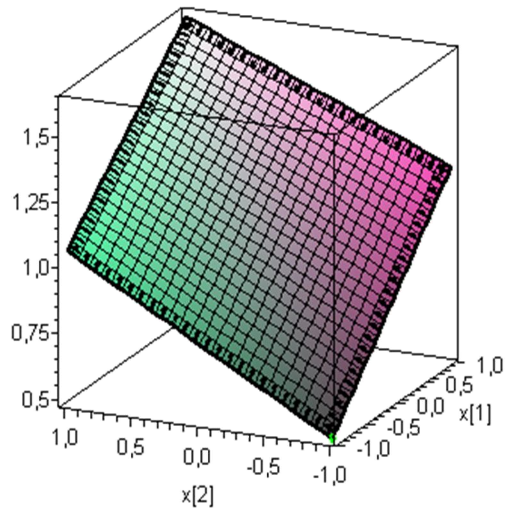

Figure 10 3D model and optimal value of function (1) for option 9

4 CONCLUSIONS

In the present work, the function connecting the output parameter with the input factors of the TMF process is investigated. A quality criterion is selected for an output parameter.

The change of the color shade of the main TMs after TMF was chosen as a quality criterion. The study aims to find those values of the input factors at which the output parameter has an optimal value. Nine different options of combinations of input factors were studied.

Table 3 Optimal combinations of the natural factor levels and the output parameter

Option №	Optimal values of the quality criterion $Y_i(X_1, X_2, X_3)$	X_1 [N/cm^2]	X_2 [°C]	X_3 [g/m^2]
1	1.2075	40	120	173
2	0.85	25	120	173
3	0.4925	10	120	173
4	1.0625	10	150	173
5	0.7775	10	135	173
6	0.4925	10	120	173
7	0.9175	10	120	213
8	0.705	10	120	193
9	0.4925	10	120	173

The following conditions are met for each option:

- one of the factors is considered a constant;
- the other factors belong to the range of values for which the mathematical model of the TMF process has been created;
- each factor, which is taken as a constant, sequentially takes the coded values: (+1), (0), (-1) (in three different options).

The optimal values of the quality criterion are determined for each option. The optimization is performed with a modern specialized software product Maple. The levels of the input factors at which the output parameter is optimal for the studied options are established. The optimal value of the selected quality criterion *Yi=0.4975* is reached at the following values of the input factors: the pressure *P=10 N/cm*^{2}, the temperature of the pressing plates *T=120°C* and the mass per unit area of basic textile materials *M=173 g/m*^{2}.

3D images of the combinations of factor levels and the corresponding value of the quality criterion for each option are designed.

The study illustrates the characteristics of the TMF process. Conditions are created for quick and easy finding of optimal combinations of input factors and output parameters in the real production. With the application of scientific methods, an effective solution to real technological problems in the garment industry has been proposed.

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