OPTIMIZATION OF THE THERMO-MECHANICAL FUSING PROCESS

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Abstract: *The thermo-mechanical fusing (TMF) process is one of the main technological processes in the garment industry. Research and analysis of it is especially important for the quality of garments. Some investigations were made to determine the effect of individual parameters on the TMF process. In order to achieve optimal quality indicators for TMF with energy and time saving, is create a mathematical model of the function connecting the output parameter with the input factors. This model describes the influence of the pressure, the temperature of the pressing plates and the mass per unit area of the basic textile materials on the duration of the TMF process. Obtaining an adequate mathematical model of the process creates real conditions for its optimization. The aim of the present work is to investigate and optimize the function describing the relationship between the output parameter and the input factors in TMF.*

Keywords: *optimization; thermo-mechanical fusing process.*

1 INTRODUCTION

The thermo-mechanical fusing (TMF) process is one of the main technological processes in the garment industry. Research and analysis of it is especially important for the quality of garments. From the study conducted, it can be summarized that some investigations were made to determine the effect of individual parameters on the TMF process [1-3]. The time for the implementation of the TMF process was studied [2, 4, 5]. The time-temperature dependence for different textile materials was investigated [4]. The conditions for feedback implementation with the processed textile materials at TMF were analyzed [4, 6]. However, the combined influence of the controllable factors, such as 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 order to achieve optimal indicators for 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*) [7-9]. This requires conducting experiments with simultaneous variation of the studied factors [10]. In the work process [11] a mathematical model of the TMF process was created. This model describes the influence of the pressure, the temperature of the pressing plates and the mass per unit area of the basic textile materials on the duration of the TMF process [11]. Obtaining an adequate mathematical model of the process creates real conditions for its optimization [12, 13].

The present work aims to investigate and optimize the function describing the relationship between the output parameter and the input factors in TMF.

2 RESEARCH WORK

2.1 Conditions for conducting the study

In order to achieve the set goal, it is necessary to optimize the mathematical model (1).

Such values for the input parameters *X1, X2, X3* are sought for, for which the output parameter (function)

$$\begin{aligned} &Y(X_1X_2X_3)= \\ &=22{,}4375-1{,}4375X_1-5{,}8125X_2+ \\ &+6{,}9375X_3-1{,}8125X_2X_3\rightarrow \min \end{aligned} \tag{1}$$

subject to:

$$\begin{cases} If\quad X_1=\{-1;0;1\}\ \ then\ \ X_2,X_3\geq 0; \\ If\quad X_2=\{-1;0;1\}\ \ then\ \ X_1,X_3\geq 0; \\ If\quad X_3=\{-1;0;1\}\ \ then\ \ X_1,X_2\geq 0, \end{cases} \tag{2}$$

where: $Y(X_1, X_2, X_3)$ - the time for implementation of the TMF process, which is a criterion for productivity; X_1 - coded value of the input parameter - pressure *P* [N/cm^2]; X_2 - coded value of the input parameter - temperature of the pressing plates *T* [°C]; X_3 - coded value of the input parameter - mass per unit area of basic textile materials *M* [g/m^2].

The levels of the input factors are given in Table 1 [11].

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	

Function (1) was studied at different combinations of input factor levels. The nine options listed in Table 2 were examined. In each option, one of the input factors is chosen to be a constant. The optimal value of the output parameter *Y* is sought by varying the other two input factors. Each factor taken as a constant, successively accepts the following levels: (+1), (0), (-1). The search for the optimal value is related to determining the minimum and maximum value of *Y*. The output parameter is the time for which the TMF process takes place. Therefore, the optimal value for *Y* will be Y_{min}.

2.2 *Methods*

Mathematical methods for analysis and evaluation are usually used to optimize technological processes [14-16], and their numerical realization is conducted with specialized software.

In the present article, the numerical realization of the proposed model of the optimization problem was rendered in software environments in the software product Maple. With its help the process of thermo-mechanical fusing is analyzed.

3D models of thermo-mechanical fusing process are designed in the environment of Maple. They illustrate the optimal options for carrying out this process.

2.3 *Materials*

When creating the mathematical model (1) [11] materials produced by the company NITEX-50 - Sofia were used for basic textile materials. They are 100% wool fabrics:

article EKSELSIOR, mass per unit area 173 g/m^2, warp threads count 52/2 Nm, weft threads count 37/1 Nm, warp threads density 122 pcs/10 cm, weft threads density 230 pcs/10 cm;

article RITZ, mass per unit area 193 g/m^2, warp threads count 52/2 Nm, weft threads count 37/1 Nm, warp threads density 175 pcs/10 cm, weft threads density 263 pcs/10 cm;

article KARDINAL, mass per unit area 213 g/m^2, warp threads count 52/2 Nm, weft threads count 37/1 Nm, warp threads density 370 pcs/10 cm, weft threads density 232 pcs/10 cm [11].

Material produced by the company Kufner-B121N77 was used for an auxiliary TM (interlining). The auxiliary TM is fabric, with mass per unit area 63 g/m^2, warp threads 100% PES, weft threads 100% PES [11].

3 RESULTS AND DISCUSSION

3.1 *Research results*

Research of the function (1) was performed for 9 options given in Table 2. While studying the first option, the function (1) acquires the form (3):

$$\begin{aligned} Y_{(X_2,X_3)} &= 22.4375 - 1.4375 - 5.8125X_2 + \\ &+ 6.9375X_3 - 1.8125X_2X_3 = \\ &= 21.0000 - 5.8125X_2 + 6.9375X_3 - \\ &- 1.8125X_2X_3 \end{aligned} \quad (3)$$

The three-dimensional image of the function (3) is given in Figure 1, where: X2є[(-1)÷(+1)] and X3є[(-1)÷(+1)].

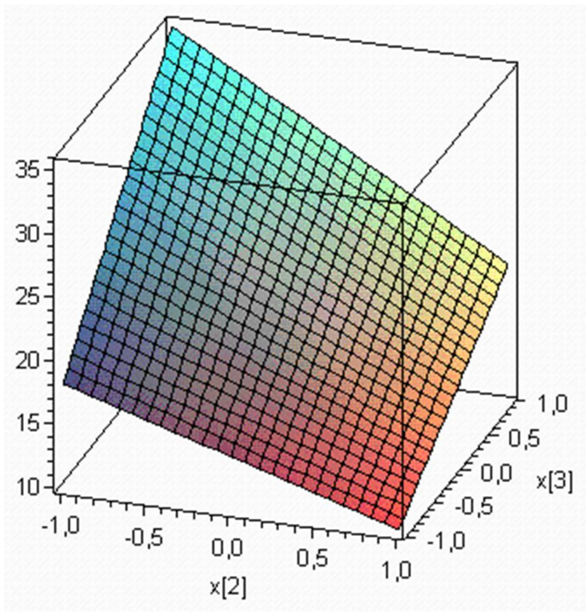

Figure 1 3D model of the function (1)

After the research it was found:

$$Y_{1max} = 35.5625 = f\,[X_2 = (-1),\ X_3 = (+1)] \quad (4)$$

$$Y_{1min} = 10.0625 = f\,[X_2 = (+1),\ X_3 = (-1)] \quad 5)$$

Figure 2 illustrates Y_{1max} and Y_{1min}.

The optimal value of Y_1 for the present study is Y_{1min}.

Therefore, the optimal levels of input factors for TMF in option 1 are: $X_1=(+1)$, $X_2=(+1)$, $X_3=(-1)$.

In a similar way, function (1) was studied for the other 8 options. The research results are given in Table 2. In Table 2 the function (1) is denoted by $Y_i = f\ (X_1,\ X_2,\ X_3)$, where $i=(1\div9)$. Figures 3-10 illustrate the 3D models and the optimal values of the function (1) for the options 2-9.

3.2 Discussion of the research results

From the analysis of the obtained results it can be generalized that the function $Y_i(X_1, X_2, X_3)$ has an optimal value in option 1. The optimal value of function (1) is $Y_i(X_1, X_2, X_3)=10.0625$ *s* with natural values of the input factors: X_1=*40 N/cm*^{2}, X_2=*150°C* and X_3=*213 g/m*^{2}.

Table 2 Optimal values of the function Y_i

Option №	Value of the input factor that is selected as a constant	$Y_i\ (X_1, X_2, X_3)$	$Y_{i\ max}$, [s]	$Y_{i\ min}$, [s]
1	$X_1=(+1)$	$Y_{(X_2,X_3)} = 21.0000 - 5.8125X_2 + 6.9375X_3 - 1.8125X_2X_3$	35.5625=f[X_2=(-1), X_3=(+1)]	10.0625=f[X_2=(+1), X_3=(-1)]
2	$X_1=0$	$Y_{(X_2,X_3)} = 22.4375 - 5.8125X_2 + 6.9375X_3 - 1.8125X_2X_3$	37.0000=f[X_2=(-1), X_3=(+1)]	11.5000=f[X_2=(+1), X_3=(-1)]
3	$X_1=(-1)$	$Y_{(X_2,X_3)} = 23.8750 - 5.8125X_2 + 6.9375X_3 - 1.8125X_2X_3$	38.4375=f[X_2=(-1), X_3=(+1)]	12.9375=f[X_2=(+1), X_3=(-1)]
4	$X_2=(+1)$	$Y_{(X_1,X_3)} = 16.6250 - 1.4375X_1 + 5.1250X_3$	23.1875=f[X_1=(-1), X_2=(+1)]	10.0625=f[X_1=(+1), X_2=(-1)]
5	$X_2=0$	$Y_{(X_1,X_3)} = 22.4375 - 1.4375X_1 + 6.9375X_3$	30.8125=f[X_1=(-1), X_2=(+1)]	14.0625=f[X_1=(+1), X_2=(-1)]
6	$X_2=(-1)$	$Y_{(X_1,X_3)} = 28.2500 - 1.4375X_1 + 8.7500X_3$	38.4375=f[X_1=(-1), X_2=(+1)]	18.0625= =f [X_1=(+1), X_2=(-1)]
7	$X_3=(+1)$	$Y_{(X_1,X_2)} = 29.3750 - 1.4375X_1 - 7.6250X_2$	38.4375=f[X_1=(-1), X_2=(-1)]	20.3125=f[X_1=(+1), X_2=(+1)]
8	$X_3=0$	$Y_{(X_1,X_2)} = 22.4375 - 1.4375X_1 - 5.8125X_2$	29.6875=f[X_1=(-1), X_2=(-1)]	15.1875=f[X_1=(+1), X_2=(+1)]
9	$X_3=(-1)$	$Y_{(X_1,X_2)} = 15.5000 - 1.4375X_1 - 4.0000X_2$	20.9375=f[X_1=(-1), X_2=(-1)]	10.0625=f[X_1=(+1), X_2=(+1)]

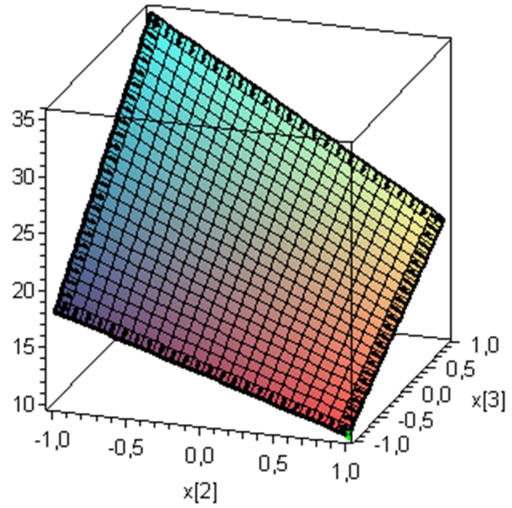

Figure 2 Optimal value of function (1) for option 1

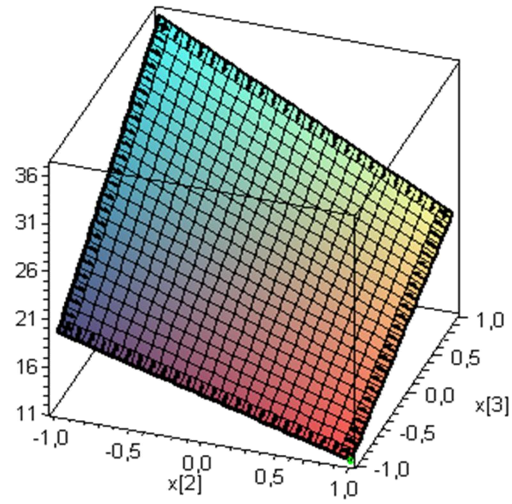

Figure 3 3D model and optimal value of function (1) for option 2

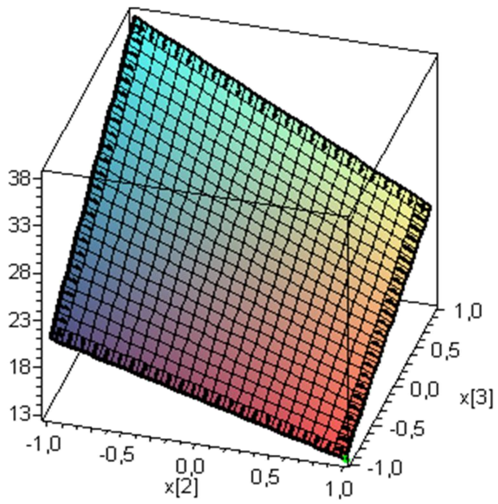

Figure 4 3D model and optimal value of function (1) for option 3

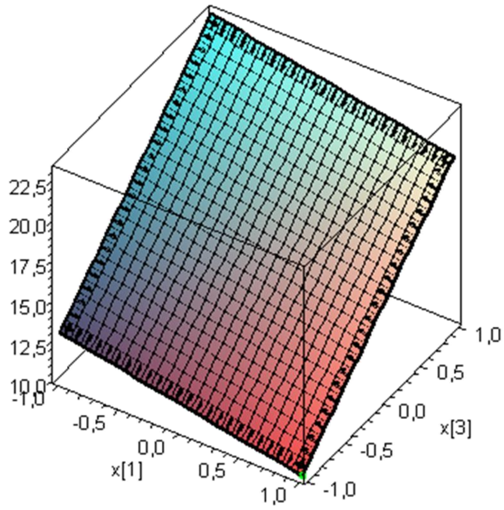

Figure 5 3D model and optimal value of function (1) for option 4

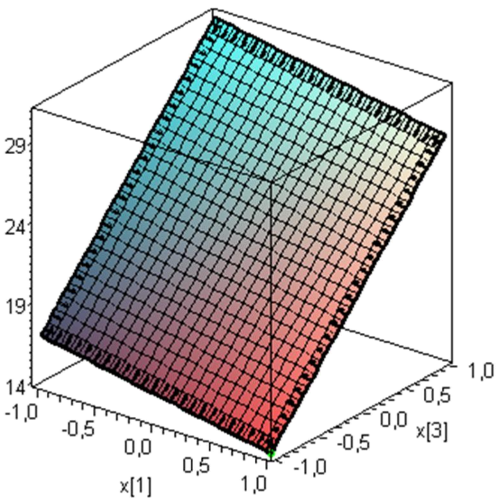

Figure 6 3D model and optimal value of function (1) for option 5

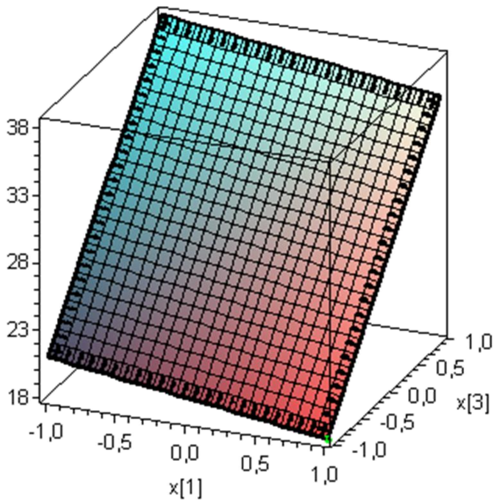

Figure 7 3D model and optimal value of function (1) for option 6

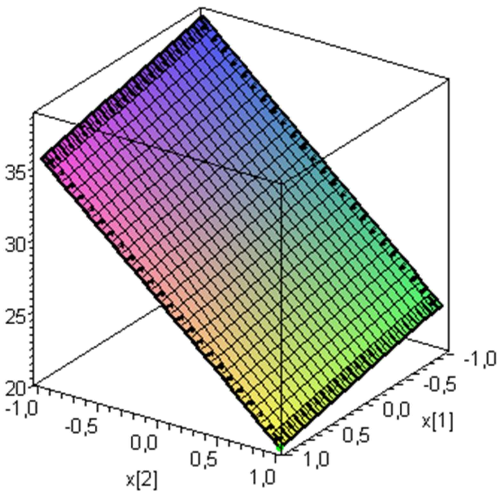

Figure 8 3D model and optimal value of function (1) for option 7

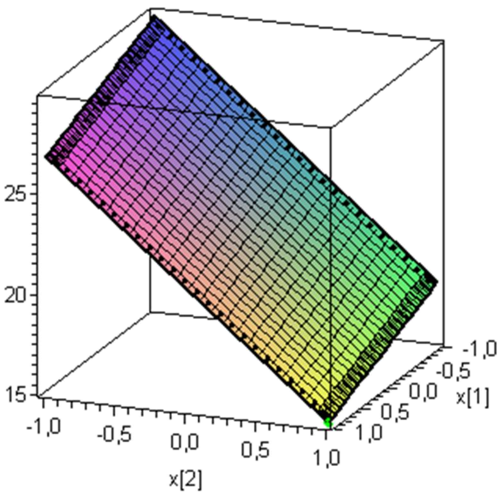

Figure 9 3D model and optimal value of function (1) for option 8

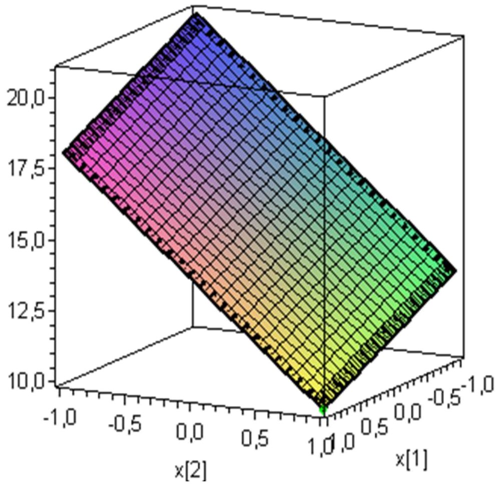

Figure 10 3D model and optimal value of function (1) for option 9

4 CONCLUSIONS

This work investigates the function connecting the output parameter with the input factors of the TMF process. A produce criterion is selected for the output parameter. This is the duration for the implementation of the TMF process.

Nine different options have been investigated. For each option one factor is selected, which is accepted as a constant, and the other factors change at a certain interval. The optimal values of the output parameter are determined for each option.

It was found that the optimal value of the output parameter (for the studied 9 options) $Yi=10.0625$ *s* is reached at the following values of the input factors: the pressure $P=40\ N/cm^2$, the temperature of the pressing plates $T=150°C$ and the mass per unit area of basic textile materials $M=213\ g/m^2$.

3D images of the combinations of factor levels and the corresponding value of the output parameter for each option are designed. This makes it possible to easily and quickly find optimal combinations of input factors and the output parameter of the TMF process.

The present study has a wide applied-scientific significance. The application of mathematical methods for analysis, evaluation and optimization makes the conducted research scientifically based. The designed 3D images of the mathematical model of the process allow for making quick and efficient technological decisions in real production conditions.

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