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INVESTIGATION OF THE ENVIRONMENTAL FACTORS' INFLUENCE ON THE MECHANICAL PROPERTIES OF PLASTICS

Abstract:*A statistical method for the analysis of the experimental results obtained by tensile test on specimens made of high-density polyethylene is presented in this work. The two-factor experiment with three levels was used for statistical analysis of data. Specimens were tested at low temperatures at different tension speeds. By applying this method it can determine which factors have the greatest influence on the tensile strength of the tested specimens.*
Keywords:*statistical method, factor experiment 3^n, tensile testing, polyethylene*

1. INTRODUCTION

In engineering practice, the experiment is a research method or performing of professional work.Factor experiment is a statistical method for analysing of the experimental results when the test subject is affected by several factors with multiple levels [1].A large part of research in science and engineering and especially in the industry is empirical. The usage of statistical methods of experiments planning can significantly increase the efficiency of the experimentation process itself and lead to better and more reliable conclusions.

When researching the determined phenomenon, the greatest importance is single-factor experiment.In addition to the many phenomena that depend only on one factor, single-factor experiment, in the classical approach, is also used as the basis in experiments with multiple factors.The difference between the conventional and single-factor experiment is only in a randomization of factor level, whichisrequired at single-factor experiment. This causes that the external factors' effects, as random variables, are encompassed by an experiment's error. Factor experiment is denoted by the product of factor's level, which precisely shows how large is the total number of combinations of factor levels.

Polymeric materials are today among the most important technical materials.They are no longer used as a substitute for traditional materials (metal, wood, ceramics and glass), but are also used to create objects that have previously been produced from these traditional materials [2]. These materials are characterized by their mechanical properties, which are a combination of properties of solids and liquids. They are strong and capable of great mechanical elastic deformation. Properties of the polymer are conditioned by their internal structure.

Polyethylene is a macro-molecule hydrocarbon, and represents a very important material today. Industrially isproduced by polymerization of ethylene, and in a laboratory's conditions can be also obtained from diazomethane [3].

2. FACTOR EXPERIMENT 3^n

Factor experiment 3^n has n factors, each with three levels. In this experiment, the levels are fixed, and may be qualitative or quantitative[1]. This type of plan, because of its good features, is often a basis of complex plans, although it has a minor significance than 2^n plan for the same purpose.

There are two factors with three levels in the experiment 3^2, i.e. total of nine combinations of factor levels. The levels of factors are divided into three types: the bottom level (mark 0), the basic level (mark 1) and the upper level (mark 2). The mathematical model of this plan is, if there is no repetition on the same factor level, as follows:

$$x_{ij} = \mu + A_i + B_j + AB_{ij} + \varepsilon_{ij} , (1)$$

where:

μ - general value of all observations where there is no influence of the factors or error,

A_i - factor of level i,

B_j - factor of level j,

AB_{ij} - factor of interactions' existence and

ε_{ij} - the total experiment's error.

The previous expression shows that the error interferes with the interaction. If the reading is repeated $k = 1, 2, ..., n$ times for each combination of levels, the error of the experiment can be extracted, and the mathematical model is:

$$x_{ijk} = \mu + A_i + B_j + AB_{ij} + \varepsilon_{k(ij)} . (2)$$

Marking of combinations of factor's levels is shown in Figure 1. In the labels shown on the Figure 1, the first digit indicates the level of factor A, and the second digit the level of factor B.

The classical dispersion analysis, which gives two each degree of freedom for the effects of A and B, is possible here. If there is no repetition for each combination of levels, for the interaction mixed with error of experiment, remains 4 degrees of freedom.
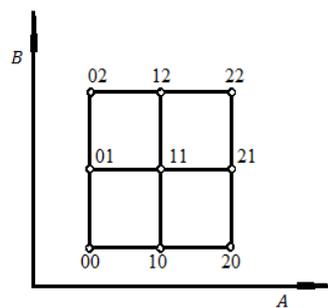

Figure 1 - A combination of factor's levels

For further analysis, the coefficients for the results at the individual combinations of factors' levels are selected as follows:

- for linear effects -1 for the lower, 0 for the normal and +1 for the upper and

- for a square +1 for the lower, -2 for the normal and +1 for the upper.

The coefficients' scheme, selected as previously described, is given in the experimental part of paper in Table 4.

3. EXPERIMENTAL RESEARCH

The process of determining the tensile properties of polymeric materials is defined in ISO 527-1:1996 [4, 5]. Tension testing of specimens was performed in the Laboratory for mechanical materials and deformation processing at Faculty of engineering, University of Kragujevac. Tests were performed on a universal testing machine *ZWICK/ROELL Z* 100.

The specimens are made from high-density polyethylene(Hostalen GC 7260). Injection of tensile test specimens was performed in company "21. October" in Kragujevac.

Hostalen GC 7260 is high-density polyethylene with general purpose. Different parts such as covers, toy parts,

bathroom's appliances and various types of packaging, are produced by injection [6].

During testing the specimens, three temperature levels: 0, -20 and -40°C and five different speeds of the tensioning: 10, 20, 50, 100 and 200 mm/min, were used. The tensile test specimens were cooled in a container with acetone, where it is added an appropriate amount of dry ice, in order to achieve the appropriate temperature (see Figure 2). The temperature is measured with a thermometer.

The obtained values of the elastic limit $R_{p0,2}$, tensile strength R_m, elongation corresponding to the tensile strength A_g and maximum elongation of A for various combinations of temperature and tensile speed values of specimens are given in Table 1.

Figure2 -Cooling of test specimens

Table1 -The results obtained by testing of all series

Temperature °C	Speed mm/min	Ordinal number of the series	$R_{p\,0.2}$ MPa	R_m N/mm^2	A_g %	A %
-40	200	1	25.63	39.11	3.66	13.93
	100	2	26.10	39.47	3.33	21.62
	50	3	25.72	37.88	3.83	40.73
	20	4	25.81	36.96	4.38	70.65
	10	5	25.96	36.48	2.08	-
-20	200	6	24.82	37.64	4.10	19.05
	100	7	24.98	37.84	4.35	34.76
	50	8	25.84	38.91	4.66	32.79
	20	9	25.81	37.27	4.25	25.28
	20	10	25.47	36.51	4.36	150.44
	10	11	25.92	35.78	1.94	47.76
0	200	12	23.77	35.25	4.90	27.81
	100	13	23.88	34.68	4.60	39.83
	50	14	24.09	34.31	5.27	73.12
	20	15	24.09	32.77	5.01	155.10
	10	16	24.34	32.11	2.04	164.77

4. RESULTS AND DISCUSSION

For the processing of previously obtained results, the Factor experiment 3^n is used. Number 3 represents the level number, and n is the number of factors. In this case $n = 2$, which means that there are two factors (temperature and speed). It was investigated the effect of the mentioned factors on the tensile strength which is expressed in MPa.

Speed factor is denoted by A, and the temperature factor by B. The lower level of speed and temperature is denoted by 0, the basic level with 1 and the upper level with 2.

For a temperature factor indicated by the number 0, the temperature is 0°C.

Number 1 indicates the temperature of -20°C and number 2 - the temperature of -40°C. In addition, number 0 marks a speed of 50 mm/min, number 1 - speed of 100 mm/min and number 2 - speed of 200 mm/min.

Based on the values from Table 2 for the basic level factors A and B, which is 37.84, an appropriate substitution has been introduced, in order to get zero value in that place in the table. Table 2 shows the test results that are coded by the replacement $x^* = x - 37.8$. Using this method of replacement, the further calculation is simplified.

Table2 -Results of testing

B	A			SB
	0	**1**	**2**	
0	-3.53	-3.16	-2.59	-9.28
1	1.07	0	-0.2	0.87
2	0.04	1.63	1.27	2.94
SA	-2.42	-1.53	-1.52	OS =-5.47

The sum for each factor level is:

$$S_j = \sum_{i=1}^{n_j} x_{ij}, \ (3)$$

so the overall sum will be:

$$OS = \sum_{j=1}^{k} S_j. \ \ (4)$$

Calculation of the overall sum of squares can be simplified by introducing additional parameters A and K, which are calculated using the formula:

$$A = \sum_{i=1}^{n_j} \sum_{j=1}^{k} x_{ij}^2, (5)$$
$$K = \frac{(OS)^2}{N}, \ (6)$$

while the overall sum of squares is equal to:

$$OSK = A - K. (7)$$

Some of the sums of squares are calculated based on the expression:

$$SKA = \sum_{i=1}^{a} \frac{SA^2}{nb} - \frac{OS^2}{nab}, (8)$$
$$SKB = \sum_{j=1}^{b} \frac{SB^2}{na} - \frac{OS^2}{nab}, \ (9)$$
$$SKAB = \sum_{i=1}^{a} \sum_{j=1}^{b} \frac{SAB^2}{n} - \sum_{i=1}^{a} \frac{SA^2}{nb} - \sum_{j=1}^{b} \frac{SB^2}{na} + \frac{OS^2}{nab}, (10)$$

where

SKA -the sum of squares of factor A,

SKB - the sum of squares of factor B,

$SKAB$ –the sum of squares of the mutual interaction between the factors A and B,

n - number of repetitions at each level of the factors,

a - number of levels of factor A and

b - number of levels of factor B.

Data processing results are given in tables 3 and 4.

Table3 - Display the result sums of squares and mean square

Selection of changes	The degree of freedom	The sum of squares	Intermediate squares	v_0	c	
					V=95%	V=99%
A	2	0.17806	0.0893	0.1343	6.94	18
B	2	28.4497	14.2248	21.397		
AB	4	2.6593	0.6648			
S	8	31.2864				

The resulting value of Fischer distribution, v_0, for the corresponding probabilities percentage of V = 95%, is compared with the value c which is calculated based on the degree of freedom of the considered factor in the table for the Fisher distribution [1]. The value of Fischer distribution, v_0 for AB is

not given in Table 3 because there are no interactions.

Based on the dispersion analysis, the value $v_0 = 0.1343$ is obtained for factor A, which is less than the comparative value 6.94. This means that the tensile speed has no influence to the tensile strength. The

value $v_0 = 21.397$ is obtained for speed factor B, which is greater than 6.94. Based on this, it can be concluded that only the temperature of a test specimens has influence on the tensile strength, which means that the further research could be carried out as one-factor experiment.

Table4- Scheme of coefficients

Factors	Combination of conditions									$\sum c_{mj}^2$
	00	01	02	10	11	12	20	21	22	
A_l	-1	-1	-1	0	0	0	1	1	1	6
A_{kv}	1	1	1	-2	-2	-2	1	1	1	18
B_l	-1	0	1	-1	0	1	-1	0	1	6
B_{kv}	1	-2	1	1	-2	1	1	-2	1	18
$A_l B_l$	1	0	-1	0	0	0	-1	0	1	4
$A_l B_{kv}$	-1	2	-1	0	0	0	1	-2	1	12
$A_{kv} B_l$	-1	0	1	2	0	-2	-1	0	1	12
$A_{kv} B_{kv}$	1	-2	1	-2	4	-2	1	-2	1	36
Results	-3.53	1.07	0.04	-3.16	0	1.63	-2.59	-0.2	1.27	-5.47

Labels in the first column of Table 4 for factors have the following meanings:

A_l - linear effect of factor A,

A_{kv} - quadratic effect of factor A,

B_l - linear effect of factor B,

B_{kv} - quadratic effect of factor B,

$A_l B_l$ - linear interaction of factors A and B,

$A_l B_{kv}$ - the interaction between the linear effect of factor A and the quadratic effect of factor B,

$A_{kv} B_l$ - the interaction between the quadratic effect of factor A and the linear effect of factor B and

$A_{kv} B_{kv}$ - the interaction between the quadratic effect of factor A and the quadratic effect of factor B.

During determining components of the interaction, it is possible to make a variety of combinations: $linA \times linB$, $linA \times sqvB$, $sqvA \times linB$, $sqvA \times sqvB$, and so on.

For determining the components of the linear and quadratic effects, all the values in Table 6 should be multiplied with the appropriate coefficients.

Intermediate squares of linear and quadratic effects of the factor A are calculated based on the equation:

$$SKA_l = \frac{A_l^2}{\sum c_{mj}^2}, \qquad (11)$$

$$SKA_{kv} = \frac{A_{kv}^2}{\sum c_{mj}^2}. \qquad (12)$$

Intermediate squares of linear and quadratic effect of factor B are calculated on the basis of the equation:

$$SKB_l = \frac{B_l^2}{\sum c_{mj}^2}, \qquad (13)$$

$$SKB_{kv} = \frac{B_{kv}^2}{\sum c_{mj}^2}. \qquad (14)$$

Intermediate squares combination of linear and the square values of factors A and B are calculated based on the equation:

$$SKA_l B_l = \frac{A_l B_l^2}{\sum c_{mj}^2}, \qquad (15)$$

$$SKA_l B_{kv} = \frac{A_l B_{kv}^2}{\sum c_{mj}^2}, \qquad (16)$$

$$SKA_{kv} B_l = \frac{A_{kv} B_l^2}{\sum c_{mj}^2}, \qquad (17)$$

$$SKA_{kv} B_{kv} = \frac{A_{kv} B_{kv}^2}{\sum c_{mj}^2}. \qquad (18)$$

The results of the dispersion analysis are given in Table 5. Based on the test results and statistical analysis of data by dispersion analysis, it can be concluded that only the temperature has the effect,

while tests' speed has very little influence on the experimental tests.

Table5 - The results of dispersion analysis

Selection of changes		The degree of freedom		The sum of squares	Intermediate squares	v_0	c
A		2		0.17806		0.1343	6.94
	A_l		1		0.135		
	A_{kv}		1		0.043		
B		2		28.4497		21.397	6.94
	B_l		1		24.88		
	B_{kv}		1		3.627		
AB		4		2.6593			
	$A_l B_l$		1		0.021		
	$A_l B_{kv}$		1		1.8486		
	$A_{kv} B_l$		1		0.3852		
	$A_{kv} B_{kv}$		1		0.3383		
Sum		8		31.2864			

5. CONCLUSION

Experimental research requires certain expenditures for consumed materials, making facility, purchase instruments, energy consumption and a large number of working hours. The objective of planning the experiment is to obtain as much reliable information at the minimum cost.

In the specific case, the statistical analysis of the results could be carried out with one-factor experiment, because, according to the partially completed experiment, it is found that temperature has a greater influence than the speed.

The main advantage of factorial experiment and its basic characteristic is that all levels of one factor combined with all levels of the other factors.Under the conditions of factorial experiments, choosingthefavourable type of plan can significantly increase the efficiency of the experiment. One more advantage,that should count, is the evaluation of interaction.

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