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APPLICATION OF TAGUCHI METHODS IN TESTING TENSILE STRENGTH OF POLYETHYLENE

Abstract: *The application of Taguchi methods, that represent a form of statistical analysis of the sensitivity, is subject of this paper. They are used to reduce the number of experimental samples during the experiment. The research was conducted in order to determine which factors and how much they affected the breakage of the specimens made ofHostalen GC 7260, high-density polyethylene. The tensile strength of polyethylene specimens was investigated. The obtained results for three samples per experiment were statistically analyzedby the use of Taguchi methods, more accurately by the use of orthogonal arrays and the S/N ratio.*
Keywords: *Taguchi methods, robust design,quality loss function, S/N ratio, orthogonal arrays, polyethylene, tension test.*

1. INTRODUCTION

In the modern economy, quality is viewed from the aspect of management, so that the quality management should enable the improvement of the quality of the entire company business [1].The key to success is to achieve good price-quality ratio, based on the continuous improvement of business productivity.

Quality management represents also a form of the total management function, which should determine and implement the quality policyin general. The model of total quality management (TQM) represents the highest achievement in the field of quality [2].

Taguchi methods are techniques for improving the quality. The main purpose of these methods is to relieve the function of quality control and to form a robust (stable) system.

Polyethylene is a polymer material which is widely used in industrial manufacturingtoday [3].*Hostalen GC 7260* is a high-density polyethylene which is used for general-purpose items, among other things,for household appliances' parts [4].

2. TAGUCHI METHODS

Taguchi methods are statistical methods developed by Genichi Taguchi to improve the quality of products [5].

Taguchi methods include reducing of variation in the process through robust design of experiments. The overall objective of this method is reaching the high-quality products at a low manufacturing price [6].

The robust design is a new concept (Figure 1) which is related to the manufacture of productsand high-quality service with no defects [7]. This design has a high tolerance to factors, which can't be controlled.

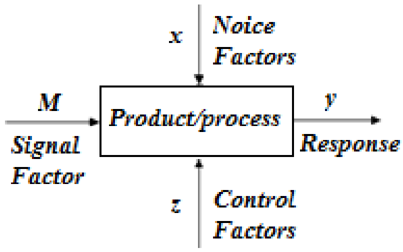

Figure 1 -The concept of robust design

In the optimization problems,Taguchi method takes place in four steps [7]:

1. definition of all relevant factors specific for the optimization problem and their values;

2.selection of suitable orthogonal fields for control factors and noises, among standard factors or their modifications;

3.conducting experiments and analysis of results and

4.conducting of the verifiable experiments, which should confirm improvement that occurs by optimum combination of factors.

Signal Factor is a variable whose value is an objective of the process. *Control Factors* are variables whose valuescan be directly affectedby the process designers. In fact, the main objective of conducting the experiment is to set the values of these variables at optimal levels. *Noise Factors* are variables whose values can't be affecteddirectly, because they are difficult or impossible to control. *Response* is a real response of the process. This response is shown by atermthe quality characteristic (QC). Briefly, QC is a measure of the functionality of the process to improve the product performances,i.e. its quality [8].

Depending on the specifications of the product's characteristics, there are three characteristic forms of Taguchi loss functions,which are shown in Figure 2 [8].

The first form of the function, Figure 2a), refers to the case whenthe lower, and the upper tolerance limit(T_d, T_g) is set for parameter, as well asa nominal measure of the parameter (m). Then, the loss function is defined as ([9], [10]):

$L(y) = k(y-m)^2$, (1)

and the total loss observed on the sample size of n:

$L = k\sum_{i=1}^{n}(y_i - m)^2$, (2)

where

$L(y)$ – loss function,

L – total loss observed on a sample size of n,

k – the coefficient of loss,

y – observed parameter,

m – the nominal value of the parameter and

n – sample size.

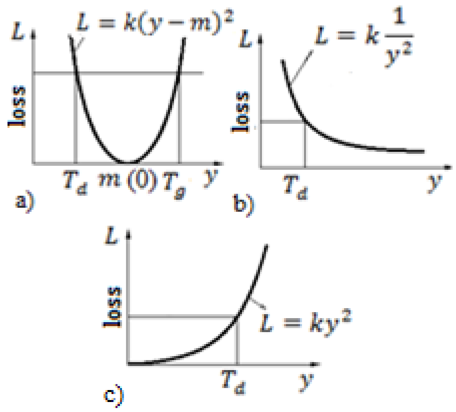

Figure 2 - Typical forms of Taguchi loss function: a) type N, b) type B, c) Type S

The second form of the function, Figure 2b), refers to the case whenthe lower tolerance limit (T_d) is set for the parameter. Then the loss function is defined as:

$L(y) = k\frac{1}{y^2}$, (3)

and the total loss observed on the sample size of n:

$L = k\sum_{i=1}^{n}\frac{1}{y_i^2}$. (4)

The third form of the function, Figure 2c), refers to the case whenthe upper tolerance limit (T_g) is set for the parameter. Then the loss function is defined as:

$L(y) = ky^2$, (5)

and the total loss observed on the sample size of n:

$L = k\sum_{i=1}^{n}y_i^2$. (6)

The parameters selectionaccording to Taguchi methods is achieved by planning the experiments, and Taguchi proposes the parallel use of normal indicators together with the new quality indicator, so called the signal/noise - *S/N*, which has a very important role in the methodology [11].

S/N ratios proposed by Taguchi in 1987,for different types of loss functions have a form [12], [13]:

- For the type *N*, the first form of Taguchi loss function (Figure 2a):
  $S/N = 10\log\left(\frac{\bar{y}^2}{S^2}\right)$, (7)

where

- the mean value of response process:
  $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$,(8)
- standard deviation:
  $S = \sqrt{\sum_{i=1}^{n}\frac{(y_i-\bar{y})^2}{n-1}}$, (9)

where

y_i – observed parameter and
n–number of experiments.

- For type *B*, second form of Taguchi loss function (Figure 2b):
  $S/N = 10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_i}^2}\right)$. (10)
- For type *S*, a third form of Taguchi loss function (Figure 2c):
  $S/N = 10\log\left(\frac{1}{n}\sum_{i=1}^{n}{y_i}^2\right)$.(11)

These *S/N*indicatorsare derived from the quadratic loss function and are expressed in decibel scale (dB).

Taguchi has developed a method for designing experiments to investigate how different parameters affect the mean value and variances of the process performance characteristics that define how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrayfor parameters organization affecting the process and the levels at which they should be varied. The use of the orthogonal arrayenables the collection of the necessary data to determine which factors affect mostly on product qualitywith a minimum amount of experimentation, thus saving time and resources.Analysis of variablebased on the collected data from the Taguchi's experiment design can be used for selection ofa new parameter values to optimize the performance characteristic [6].

3. EXPERIMENTAL RESEARCH

3.1 Materials and methods

The testing material, *PE - Hostalen GC* 7260 is used for freezer's baskets intended for households. This material exhibits good flow during the casting andhigh stiffness and is used for injection molding and other conversion processes [4]. The reason for testing is a practical problem of shrinkage of hostalen baskets inside the freezer and its breakage at low temperatures.

Specimens made by injection of *Hostalen GC* 7260 at the temperature of 210°C and the pressure of 100 barare used during the tests. Cooling time in the mold is 35 s. Injection is carried out at the factory "21 October"in Kragujevac. Specimens have the standard form (ISO 527-2:1996), type A [14]. They were tested on the universal materials testing machine Zwick/Roell Z 100.Research was conducted at the Laboratory for mechanical materials and processing by deforming, at Faculty of Engineering, University of Kragujevac.

Before thestraining of specimens is carried out at different speeds and at different temperatures, specimenswere subjected to the different conditions (treating in water and exposing to *UV* radiation). Treated with water is conducted by immersion the specimens in a utensil with water, the appropriate period of time. Specimens were exposed to *UV* radiation more precisely to sunlight. According to Taguchi methods, factors affecting the tension of specimens are tightening speed, temperature, time of watertreatment and *UV* radiation.

Speeds for deformation of specimens that were used during testing (50, 100, and 200 mm/min), were selected based on the ISO standard 527-1:1996 for determining tensile properties of plastic masses [15].

Tests were performed at temperatures 0, -20 and -40˚C. Specimens were cooled with dry ice and acetone, and the temperature was measured by the thermometer.

Some specimens were not treated with water (0 h), and others were treated 1 day (24 h) and 7 days (168 h). All specimens were exposed to the sunlight during the same period of time (168h).For each combination of the analyzed factors, three repeated measurementswere performed.

3.2 Determination of the orthogonal array

In order to perform Taguchi's method,it is necessary to determine the orthogonal array,based on factors and factor's levels.

The conditions for each parameter and level are listed:

- ***A*: Tensile speed** (A_1=50 mm/min, A_2=100 mm/min, A_3=200 mm/min);
- ***B*: Temperature** (B_1=0ºC, B_2=-20ºC, B_3 = -40ºC);
- ***C*: Treatment by water** (C_1=0h, C_2=24h, C_3=168h) and
- ***D*:*UV* radiation** (D_1=D_2=D_3= 168 h).

In this case, the L_9orthogonal array is used for four variables with three levels each.The filled in orthogonal array should look like as shown in Table 1.

Table 1 -Arrays with the values of variables at different levels

Experiment number	A	B	C	*D*
1	50	0	0	168
2	50	-20	24	168
3	50	-40	168	168
4	100	0	24	168
5	100	-20	168	168
6	100	-40	0	168
7	200	0	168	168
8	200	-20	0	168
9	200	-40	24	168

4. RESULTS AND DISCUSSION

The tensile strength, which is obtained by the examination of three samples per a test, is given in Table 2. *S/N* ratios for all of performed experimentsare calculated using the equations (7), (8) and (9). The obtained results for the *S/N* ratio are presented in Table 3.

Table2 -Showing the results of tensile strength in MPa

Experiment number	A	B	C	*D*	Sample1	Sample 2	Sample 3	The mean value
1	50	0	0	168	34,31	34,18	34,57	34,35
2	50	-20	24	168	38,91	38,88	38,90	38,89
3	50	-40	168	168	37,88	37,80	37,92	37,86
4	100	0	24	168	34,68	34,73	34,52	34,65
5	100	-20	168	168	37,84	37,82	37,81	37,82
6	100	-40	0	168	39,47	39,52	39,46	39,48
7	200	0	168	168	35,25	35,02	35,20	35,16
8	200	-20	0	168	37,64	37,73	37,51	37,63
9	200	-40	24	168	39,11	39,08	39, 02	39,07

Table 3 -Results for the S/N ratio

Experiment number	*A*	*B*	*C*	*D*	Sample 1	Sample 2	Sample 3	*S/N*
1	1	1	1	1	34,31	34,18	34,57	44,758
2	1	2	2	2	38,91	38,88	38,90	67,025
3	1	3	3	3	37,88	37,80	37,92	55,766
4	2	1	2	3	34,68	34,73	34,52	49,966
5	2	2	3	1	37,84	37,82	37,81	67,575
6	2	3	1	2	39,47	39,52	39,46	61,716
7	3	1	3	2	35,25	35,02	35,20	49,263
8	3	2	1	3	37,64	37,73	37,51	50,629
9	3	3	2	1	39,11	39,08	39, 02	58,615

Average values of *S/N* ratio for all factors are given in Table 4.

Table4 -Average values of S/N ratio for all factors

Level	*A*	*B*	*C*	*D*
1	55,85	47,99	52,37	
2	59,75	61,74	58,54	
3	52,84	58,70	57,53	

In this case, the factor *D* is not considered nor the average *S/N* ratio of the aforementioned factor is calculated, because all the specimens were exposed to the same *UV* radiation.

Graphic of factors' response *A*, *B* and *C*to the tensile strength for the calculated *S/N* ratio, at the best nominal value, is shown in Figure 3.

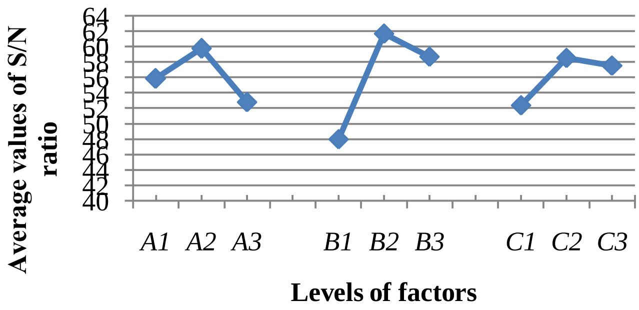

Figure 3 -Graphic factors response A, B and C to the tensile strength

Based on the average value of *S/N* ratio for all the factors, calculation of the effect of these factorsbased on the determination of the range is done (Table 4):

$$\Delta = Max - Min, \quad (12)$$

where

Δ - the range of effect,

Max –the maximum value of the average *S/N* ratio for a factor and

Min–the minimum average value of *S/N* ratio for a factor.

Table5 -Range of the factors and ranking of factors

Level	*A*	*B*	*C*	*D*
1	55,85	47,99	52,37	
2	59,75	61,74	58,54	
3	52,84	58,70	57,53	
Δ	6,91	13,75	6,17	
Rank	**2**	**1**	**3**	**4**

Based on theTable 5,it can be seen that the greatest influence on the tensile strength of specimens has the temperature, and the smallest influencehas the treatment of the water.

The effect of *UV* radiation is neglected, since all the specimens that have been tested are equally exposed to radiation.

5. CONCLUSION

Taguchi methods represent integrated set of methods,which enable, even in the process of development,tobe provided the high level of product quality, with minimal waste of values of product characteristics having in mind the projected nominal values.

Taguchi methods enable the analysis of different influential parameters without a great number of experiments and identify key parameters that have the greatest effect on the observed process. The lack of the Taguchi methods is a problem of calculation withmutual interaction of parameters when a great number of parameters affect the process under the examination.

The experiment, whose results are given in the work, was conducted to determine which of the influence factors has the greatest impact on the tensile strength specimens made of polyethylene. As the influential factors on the tensile strength specimens made of polyethylene,were considered speed, tensile testing, temperature, the effect of water and *UV* radiation.

By using Taguchi methods, namely the analysis of the obtained experimental results by using the orthogonal array and *S/N* ratio, it can be concluded thatthe greatest influenceon the tensile strength of tested specimens made of polyethylene has the temperature. Tensile speed and the effect of water have small influence, while the influence *UV* radiation could be neglected.

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