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Selection of Plastics by Design of Experiments

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ABSTRACT

This work shows the optimization of two different types of plastic materials to measure a response variable, in order to select the best material that accomplishes the customer´s requirements in a company in the appliances sector. Factorial designs are an effective tool applied to compare two or more materials in order to choose the one that best accomplishes the requirement. The 2^4 factorial experimental design aims to study the effect of various factors on one or more response variables when it is necessary to know all factors. Factors considered in this case were: plasticity temperature, pigment, injection time and injection pressure. The objective of this work was to minimize weight as the response variable, this study was conducted between two plastics types: low-density polyethylene and nylon. The response variable was studied by an analysis of variance (ANOVA) and the equation of regression was obtained, to find the best array that optimizes both plastics separately with their different operating conditions and the customer can define which plastic is better taking decision based on the design of experiment as a powerful and effective tool that accomplishes the requirements. The results revealed that the most suitable plastic material is polyethylene because it fits with the specification that the client request.

Keywords: *ANOVA, Design of experiments, Polyethylene Low-Density, Nylon, Weight.*

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I. INTRODUCTION

Plastic injection is a physical process which melts the raw material called plastic by the heat effect, in an injection molding machine. After softening the material, this is injected into a mold with hollow cavities, with a predetermined pressure, speed, and temperature. After the plastic is injected into the mold it loses its heat to becoming, acquiring the shape of the mold.

Technology plastic injection molding has been widely used in a variety of high-tech products, generic auto parts, and household products. Against globalization waves, injection plastic companies should reduce the time for launching their products to the market in order to improve competition against their competitors, and therefore they can get rapidly a big objective market and set a price for plastic products. The back-propagation neural network (BP) was used in this research to make a model for estimating costs of plastic parts in the injection molding process in order to reduce the complexity in traditional cost estimation procedures [1].

Research injection molded plastic have been made concerning the pieces cross sections where the size is much smaller than its length. The plastic part in strip form is considered as a macroscopic ray little curved which is divided into a series of one-dimensional elements. In each elemental node, a finite elemental analysis is made in order to obtain the no uniform thermal stress caused by the difference in solidification time of the melted plastic in the mold. The stress relaxation and the creep were treated by using a special computing model. Finding that the elastic tension in the mold, was obtained at the time of the final flexion of the beam and warpage was predicted [2].

Another study reveals the design, the development and the implementation of an alternative plasticizing unit for micro injection molding. The geometry called reverse screw is designed and developed with tests for plasticizers trials [3].

Here is described each method and it is discussed a comparison between the experimental conditions and the conditions for a typical injection molding processing [4].

Injection molding is a technology widely used to process polymers that transforms plastic products into various shapes and types. Defects can occur in molded products during production due to an incorrect configuration. The online process optimization is a kind of systematic method that handles such problems by making correlations between the process variables and the quality of the final products. The proposed method is applied successfully to an injection molding machine. The experimental results show that can effectively determine optimal solutions to eliminate defects of molding pieces [5].
Experimental injection molding using polypropylene filled with fibers, together with the two gate locations. The successful reduction of deformation and injection pressure can help to reduce the amount of waste production and energy consumption ensuring free sustainable manufacturing defects [6].
Molding conditions or process parameters play a decisive role affecting the quality and productivity of plastic products [7].
Microcellular injection molding is the manufacturing method used for producing foamed plastic parts. The microcellular injection molding has many advantages, including materials, energy and cost savings as well as improved dimensional stability. Despite these advantages, this technique has been limited by its tendency to create parts with surface defects [8].
In this study was analyzed the effect of injection parameters in a welding line with polypropylene in moldings. The control parameters were temperature, compression pressure and injection pressure. A Taguchi L_9 orthogonal array was used for the experimental plan [9].
This study was made with fiberglass reinforced nylon 6, it was transformed after five processing cycles. L18 Taguchi experimental design and regression analysis were used to predict the tensile strength [10].

II. METHODOLOGY

The experimental strategy for making the best decision and accomplish the required specification by the customer in the weight of the plastic part with the injection process is as follows:
1. Select factors, variable and response levels.
2. Select the experiment design and perform the experiment.
3. Perform a statistical analysis of data using analysis of variance (ANOVA) for the response variable.
4. Obtain the first Order model indicated by Montgomery [11], which represents the process behavior between the values of the studied factors.

$$Y = + \beta o \ \Sigma ki \ \beta o Xi + \varepsilon = 0 \qquad (1)$$

5. Verification of the statistical assumptions in the adjusted regression models through the determination coefficients relative to ANOVA.
6. Optimization of the response variable [12].

Equipment and material
Equipment: Plastic injection molding machine. Brand HIATIAN. Stainless steel mold. Analytical balance reading accuracy 0.1 mg to 0.1 mg.
Materials: Low density polyethylene. Brand Alkathene. Pellets form. Density 0.915 to 0.935 g / cm3. 40-50% degree of crystallinity. Elongation at break 20%. Maximum operating temperature 50-90 ° C. BP-193® powder Ivory pigment.

Methods
Step 1: Basic preparation
The amounts of formulation components as the additive pigment for polyethylene (100g, 50g) and Nylon (190g, 130g), which incorporated the plastic achieve the ideal formulation for use and defined properties to be administered following a correct dosage, were weighed . After that a homogeneous mixing of 5 minutes from all the components of the formulation was held.
Mixing was in a cold way introducing the components into a bin that rotated about a single axis at low speed to achieve good mixing, because high speed separates the components of the mixture by size by the action of centrifugal force.

Step 2: Manufacturing the part
In the injection machine the injection times were programmed according to the formulation following the experiment design for the Low Density Polyethylene and Nylon. The injection times were (1.25, 0.75 minutes). The injection pressure for polyethylene (1250, 450 bar) and Nylon (1400, 900 bar). The Polyethylene plasticity temperatures (80 ° C, 70 ° C), and Nylon (170 ° C, 150 ° C).

Finally, the mixed components were place into the hopper with the mold previously mounted on the machine. Before starting to measure the plastic parts of each formulation 10 shots are made between each formulation and later take samples and weigh them.

Factorial design

It is common to make experiments with the intention of solving a conjecture. The experimental strategy to compare two plastic materials in order to select the one that best accomplishes the requirements requested by the customer are two design of factorial experiments $2^4 = 16$ [12], which aim to study the effect of various factors on a response variable.

In Table 1 and Table 2 factors, levels and response variables of the injection process requesting client are illustrated.

Table 1: Experimental factors, levels and measuring units for Polyethilene

Factors	Code	Levels		Measuring Units
		Low (-1)	High (1)	
Temperature Plasticity	A	70	80	°C[a]
Pigment	B	50	100	g[b]
Injection time	C	0.75	1.25	Min[c]
Injection pressure	D	450	1250	bar
[a] Celsius degrees,[b] grams y [c]minutes				

Table 2: Experimental factors, levels and measuring units for Nylon

Factors	Code	Levels		Measuring Units
		Bajo (-1)	Alto (1)	
Temperature Plasticity	A	150	170	°C[a]
Pigment	B	130	190	g[b]
Injection time	C	0.75	1.25	Min[c]
Injection pressure	D	900	1400	bar
[a] Celsius degrees,[b] grams y [c]minutes				

III. RESULTS AND DISCUSSIONS

The experiments were carried out and a statistical analysis for each type of plastic with a ANOVA [12] was performed to subsequently obtain the regression equation of each material and finally the optimization of each type of plastic was obtained to select the most suitable material.

The results and statistical analysis are shown in Table 3 and Table 6, which are supported by the package Statgraphics.

Table 3. Results of the experiment design 2^4 for Polyethylene

EXPERIMENTS	**Code Factors**				**RESPONSE VARIABLE WEIGHT**
	A	**B**	**C**	**D**	
1	-1	-1	-1	-1	515
2	1	-1	-1	-1	514
3	-1	1	-1	-1	512
4	1	1	-1	-1	511
5	-1	-1	1	-1	507
6	1	-1	1	-1	507
7	-1	1	1	-1	505
8	1	1	1	-1	504
9	-1	-1	-1	1	490
10	1	-1	-1	1	488
11	-1	1	-1	1	486
12	1	1	-1	1	483
13	-1	-1	1	1	473
14	1	-1	1	1	471
15	-1	1	1	1	469
16	1	1	1	1	468

Table 4 shows the best ANOVA for the response variable of the polyethylene WEIGHT.

Table 4: Analysis of Variance for polyethylene WEIGHT

Factors	*Sum of squares*	*Gl*	*Medium Square*	*Ratio-F*	*Value-P*
A	7.5625	1	7.5625	1.14	0.3211
C	564.063	1	564.063	85.03	0.0000
D	3813.06	1	3813.06	574.78	0.0000
AC	0.5625	1	0.5625	0.08	0.7793
AD	1.5625	1	1.5625	0.24	0.6423
BC	0.5625	1	0.5625	0.08	0.7793
BD	1.5625	1	1.5625	0.24	0.6423
CD	85.5625	1	85.5625	12.90	0.0088
Total Error	46.4375	7	6.63393		
Total (corr.)	4520.94	15			
adjusted R^2	97.7				

In this table are shown to main factors: C (injection time) and D (pressure injection) that influence the response variable polyethylene WEIGHT, plus CD (injection time and injection pressure) interaction is.
The 97% of adjusted R^2 explains the effects of variability observed, indicating that significant factors C and D are responsible for the response variable WEIGHT.
The regression model adjusted ANOVA related to equation (1) was obtained, as shown below:

$$WEIGHT = 493.938 - 5.9375*C - 15.4375*D - 2.3125*C*D \quad (2)$$

According to the model (2) values were estimated for the response variable weight polyethylene and this estimate was determined that the minimum value of weight for this material is 469.3 g. In Table 5, shown the arrangement of factors and levels that minimize this response variable, WEIGHT.

Table 5: Response optimal weight of polyethylene

Factors	*Low*	*High*	*Optimum*
A	-1.0	1.0	1.0
B	-1.0	1.0	1.0
C	-1.0	1.0	1.0
D	-1.0	1.0	1.0

Optimal minimum estimated value = 469.3 g.
As stated previously here shown the result of the experiments for Nylon plastic

Table 6: Results of experiment design for Nylon 2^4

EXPERIMENTS	**CODED FACTORS**				**VARIABLE RESPONSE WEIGHT**
	A	**B**	**C**	**D**	
1	-1	-1	-1	-1	578
2	1	-1	-1	-1	576
3	-1	1	-1	-1	560
4	1	1	-1	-1	560
5	-1	-1	1	-1	549
6	1	-1	1	-1	546
7	-1	1	1	-1	545
8	1	1	1	-1	543
9	-1	-1	-1	1	541
10	1	-1	-1	1	538
11	-1	1	-1	1	534
12	1	1	-1	1	530
13	-1	-1	1	1	525
14	1	-1	1	1	528
15	-1	1	1	1	529
16	1	1	1	1	526

Table 7 shows the best ANOVA variable Nylon WEIGHT response.

Table 7: Analysis of variance for Nylon WEIGHT

Sourse	*Sum of Squares*	*Gl*	*Square medium*	*Reason-F*	*Value-P*
A:A	12.25	1	12.25	3.34	0.1173
B:B	182.25	1	182.25	49.70	0.0004
C:C	992.25	1	992.25	270.61	0.0000
D:D	2652.25	1	2652.25	723.34	0.0000
AB	1.0	1	1.0	0.27	0.6202
AC	1.0	1	1.0	0.27	0.6202
BC	121.0	1	121.0	33.00	0.0012
BD	49.0	1	49.0	13.36	0.0106
CD	196.0	1	196.0	53.45	0.0003
Total error	22.0	6	3.66667		
Total (corr.)	4229.0	15			
R^2adjusted	98.6%				

In this table, shown three major principals factors B (Pigment), C (injection time) and D (pressure injection) that influence the response variable weight nylon, plus CD interaction (injection time and injection pressure).
The R^2 adjusted of 98%, explains the observed effects of variability, indicating that significant factors B, C and D are responsible for the response variable WEIGHT
Adjusted regression model related to ANOVA was obtained from equation (1), as shown below:

WEIGHT = 544.25 - 3.375*B - 7.875*C - 12.875*D + 2.75*B*C + 1.75*B*D + 3.5*C*D (3)

According to the model (3) values for the response variable were estimated Nylon WEIGHT and this estimate was determined that the minimum value of weight for this material is 521.7g. In Table 8, the arrangement of factors and levels that minimize this response variable shown WEIGHT.

Table 8: Optimal response Nylon WEIGHT

Factor	*Low*	*High*	*Optimum*
A	-1.0	1.0	-1.0
B	-1.0	1.0	-1.0
C	-1.0	1.0	1.0
D	-1.0	1.0	1.0

Optimal minimum estimated value = 521.7g.

IV. CONCLUSION

This paper presents two designs for factorial experiments 2^4 different types of plastics were applied as polyethylene and nylon were each with its own operating factors, to select the best plastic and formula for the piece requires the customer with minimum weight.
The solutions presented are applied mainly be useful in the process of plastic injection as an effective alternative not to make unnecessary expenses with materials and human resources, since all the records were sought in the literature, along with the designs of experiments applied time searching the best formulation was reduced
Moreover, as shown by the results reveal that the best plastic material to manufacture the part that requires the customer is low-density polyethylene with a minimum weight of 469 g. according to the optimization that was done with the design of experiment the best arrangement for polyethylene is A [1], B [1], C [1] and D [1]. To make it more understandable is that the temperature of plasticity at 80 ° C, 100g Pigment, Injection Time 1.25 minutes injection pressure 1250 bar so that the weight be 469 g.
This type of study is essential for good decision-making regarding the choice of new materials and more when you think about putting a new piece to manufacture in the company.

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