RESEARCH ARTICLE OPEN ACCESS

Optimization of an injection moulding process by using recycled plastic as a raw material.

Domínguez D.J.∗ Guadarrama B.L.† Lozano D.A.‡§
Corresponding Author: Domínguezd.J

ABSTRACT: The aim of this work is to present a program of multi-response optimization procedure based on two quality characteristics of recycled plastic as raw material and the manufacturing cost of production by injection moulding. Through a design of experiments, we obtain different blends, taking into account of compacted and pellets formats and fiber-rein forced recycled plastic composites, in order to determine the optimum for the fluency, contraction and manufacturing cost. For this study the process factor was given and no noise was considered. The direct profits and impact of this study increase production capacity of the company and the reduction of manufacturing defect.

Keywords: Optimization, Design of Experiments, Injection moulding, Recycled plastic

---

Date Of Submission: 22-06-2019 Date Of Acceptance: 08-07-2019

I. INTRODUCTION

The plastic transformation is an important transformation industry, because is a dynamic tech-nology sector with dramatic growth. This is due in part to the emerging of new raw material with better physical properties, on the other hand to the increased sophistication, efficiency and specialization of plastic process equipment. For these reasons any company of this sector that would reach and keep a competitive position in the market must have mechanisms to allow the technological improvement assimilation [3].

Injection moulding is a fast process and is used to produce large numbers of identical items from high precision engineering components to disposable consumer goods. However, plastic item are one of the most widely available and overused item, because is versatile, lightweight, flexible, moisture resistant, strong, and relatively inexpensive but durable and very slow to degrade, all these have negative effects on the environment that has become a major concern. The recycling is a way to reduce plastic pollution. It is well known that the industrial processes that use recycled resins has more disadvantage than the ones that use virgin material mainly because the variability due to the different type of resins and the quality of the previews recycled possess.

It is an important issue to design an appropriate process of injection moulding by recycled plastic in order to be productive and to assure quality standards, this is an extremely difficult task. Mixture design has been playing an important role in the improvement and innovation in different types of manufacturing process as described by [8]

∗Centro de Investigación en Matemáticas, jorge@cimat.mx

† Corresponding author, CONACYT/Centro de Investigación en Matemáticas, Aguascalientes, AGS 20200, MEXICO, lili.guadarrama@cimat.mx

‡ Industrias Boris, S.A. de C.V.,produccion@plasticaboris.com.mx

§ This research was supported by CONACyT and IndustriasBoris

In the interest of improve appearance and functional characteristic and to design robust processes of items produced by recycled resins, we study the different resins type and combination of them to archive this goal. Through an optimal blending via statistical design of experiments applied to the injection moulding it is obtained an optimal blend that increase the profits and production of item made with recycled plastic. For the methodology employed in this work see [10] and [5].

II. METHODS AND MATERIALS

In the recycled plastic industry, it is crucial the basic mixture formulation in the injection moulding process in order to reach the optimal conditions to exploit the recycled as raw material.

In this study, we are interested in the plastic bucket manufacturing through an injection moulding process. These buckets have multiple industrial purposes, then it is equipped with a metallic and le 6 and a hermetic cover. Since these items are highly commercial, it is necessary, take into account the following considerations:

1. Competitive price, functionality and high quality.
2. In order to economize the manufacturing cost, the plastic bucket has a thickness that minimized the weight and therefore the use of raw material but high performance. To achieve the thickness required, the polymer has to attain all the mold corners during the injection process; this implies that the polymer must have an appropriate fluency.
3. In the interest of ensuring the hermetic property of the cover's bucket it is necessary that both possess critical dimensions in order to have the functionality and confiability of this property.

In the manufacturing process of the bucket 19 liters with recycled plastic as a raw material there are three types of components in the mixture that will pass by the hopper receptacle through the screw for injecting this material into a mold; these components are described below,

Compacted. This type of recycled plastic used as raw material is originated by a compression previous process of plastic that are in a sheet, film, foil or other flat shape; this type of plastic presentation is used in the fabrication of diaper, protection films, lining, cover, etc. Because of the lightweight plastic shape it is not possible to fall through hopper receptacle so it is necessary to form granules in order to feed the screw.

Fibre-reinforced recycled plastic composites. Products made from composite FRP materials offer attractive benefits, the mechanical strength and elasticity of the plastics are enhanced through incorporation of fiber materials, in particular carbon based fiber reinforced plastics offer low weight, good mechanical properties, high tensile strength, chemical resistance, stiffness, and temperature tolerance along with low thermal expansion.

Pallets. This material is generated by the extrusion of several plastics in order to homogenize in uniform-sized and shape granules to facilitate the material slide down into the feed throat so all the pellets to be uniformly melted at the proper temperature in the injection moulding process. In this research the material in pellet format is from virgin raw material, the benefits are that the final recycled plastic has a low level of degradation and a good appearance, functionality and stability performance.

This injection moulding process has control parameters that are vital for the production items. These parameters are injection pressure, velocity injection, material temperature. All these were fixed during the experiments.

The process is evaluated trough the following output variables,

- Y_1: Viscosity
- Y_2: % of contraction
- Y_3:Cost

These output variables will allow to determine a model that finds the optimal blend for the process.

i. Mixture experiments

By the nature of the problem, there exist constraints in the proportions of the materials that we model in the following way. Suppose we have a mixture experiment with q components, where X_i is the proportion of the i−th component. It is common to consider two values for the mixture constraints, one less than L_i and the other upper than U_i, ie $L_i \leq X_i \leq U_i$. In that way we have,

$$\sum_{i=1}^{q} X_i = X_1 + X_2 + \ldots + X_q = 1 \quad (1)$$

$$L_i \leq X_i \leq U_i, \quad i = 1, 2, \ldots, q, \quad (2)$$

Where $L_i \geq 0$ and $U_i \leq 1$.

These constraints has an impact in the design of experiments for the mixture in a sub-region of the simplex. This last one corresponds to the geometric structure of the generated space by the variables. The constraint 1 concerns that each mixture component proportion x_i non independent, which means that mixture experiment are different from the usual experiments of classical theory ($X_i \geq 0$) that defines the mixture. See [7], [6],[1]

ii. Desirability function

In this study there are several outputs that characterized the process performance. The priority is to find a mutual optimum for the three outputs with the final purpose of improving the plastic manufacturing productivity. The procedure consists of built an objective function in order to optimize the three variables under the following scheme:

Optimize $Y_j(X_q)$
Subject to $L_i \leq X_i \leq U_i$

The objective function in this case was based on the desirability function proposed by [4]. The procedure consists of transforming the regression model $\hat{Y}_j$, j = 1, 2, ..., r named the desirability d_j for each one of the r-variables; however [2] adjust this idea for three different situations see figure 1, as described below,

The objective is the best of 7

$$d_j(\hat{Y}_j(x)) = \begin{cases} 0 & if \quad \hat{Y}_j(x) \le Y_j^{min} \text{ o } \hat{Y}_j(x) \ge Y_j^{max} \\ 1 - \left(\frac{M_j - \hat{Y}_j(x_i)}{M_j - Y_j^{min}}\right)^s & if \quad Y_j^{min} < \hat{Y}_j(x) \le M_j \\ 1 - \left(\frac{\hat{Y}_j(x_i) - M_j}{Y_j^{max} - M_j}\right)^t & if \quad M_j \le \hat{Y}_j(x) < Y_j^{max}. \end{cases}$$

(3)

Where

$$\left(Y_j^{\min} = \min_{x \in R}[\hat{Y}_j(x)],\ Y_j^{\max} = \max_{x \in R}[\hat{Y}_j(x)]\right)$$

The smallest is the best,

$$d_j(\hat{Y}_j(x)) = \begin{cases} 1 & \text{si} \quad \hat{Y}_j(x) < Y_j^{\min}, \\ 1 - \left(\frac{\hat{Y}_j(x) - Y_j^{\min}}{Y_j^{\max} - Y_j^{\min}}\right)^s & \text{if} \quad Y_j^{\min} \le \hat{Y}_j(x) \le Y_j^{\max}, \\ 0 & \text{if} \quad \hat{Y}_j(x) > Y_j^{\max}. \end{cases}$$

(4)

The biggest is the best,

$$d_j(\hat{Y}_j(x)) = \begin{cases} 0 & \text{if} \quad \hat{Y}_j(x) < Y_j^{\min}, \\ 1 - \left(\frac{Y_j^{\max} - \hat{Y}_j(x)}{Y_j^{\max} - Y_j^{\min}}\right)^t & \text{if} \quad Y_j^{\min} \le \hat{Y}_j(x) \le Y_j^{\max}, \\ 1 & \text{if} \quad \hat{Y}_j(x) > Y_j^{\max}. \end{cases}$$

(5)

The global desirability is obtained by the geometric mean,

$$D = (d_1 d_2 ... d_r)^{1/r} \qquad (6)$$

The objective is to find the value of the variable X_o that maximize the value of D. The weighted geometric mean has the general expression,

$$D = (d_1^{w_1} d_2^{w_2} ... d_r^{w_r})^{1/r} \qquad (7)$$

Where w_j denote the relative weight of the r responses. Then the optimum is obtained by maximizing the desirability function that includes the r-variables, that means,

Maximize D
Subject to $X \in R$
Where

$$D = (d_1^{w_1} d_2^{w_2} ... d_r^{w_r})^{1/r}$$

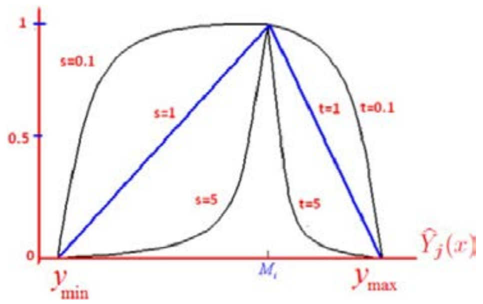

Figure 1: Description of Desirable Function

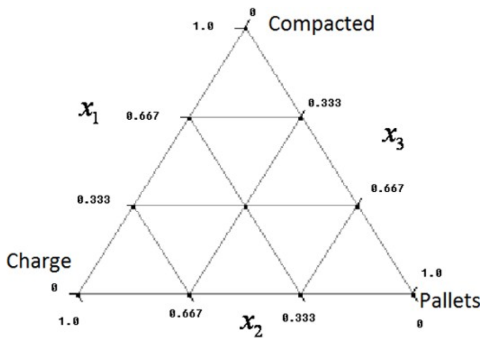

Figure 2: Mixture design scheme for the injection moulding process

III. RESULTS AND DISCUSSION
IV.

The graphic representation of the mixture experiment is shown in figure 2

The experimental results are shown in table 1

Test	Compactado	Charge	Pallet	Fluency	% Conc	$Cost
1	0	0	1	8.5	1	9.6
2	1	0	0	9.73	1.14	11.2
3	0	0	1	7.83	0.92	9.6
4	0.333	0.333	0.333	8.05	0.94	9.2
5	0.167	0.667	0.167	8.74	1.02	8
6	0	0.5	0.5	8.62	1.01	8.2
7	0	1	0	8.74	1.02	6.8
8	1	0	0	10.23	1.2	11.2
9	0.5	0	0.5	9.4	1.1	10.4
10	0.167	0.167	0.667	7.75	0.91	9.4
11	0	1	0	8.78	1.03	6.8
12	0.667	0.167	0.167	8.92	1.05	10.2
13	0.5	0.5	0	9.67	1.13	9

Table 1: Experiment results

From the experimental results three models were generated,

- Viscosity:
  $\hat{Y}_1 = 9.96x_1 + 8.81x_2 + 8.12x_3$
  $+ 1.4x_1x_2 + 0.9x_1x_3 + 0.6x_2x_3$
  $- 31.2x_1x_2x_3$

- Contraction:
  $\hat{Y}_2 = 1.73x_1 + 1.031x_2 + 0.96x_3$
  $- 0.10x_1x_2 - 0.15x_1x_{23} - 0.18x_2x_{23}$

- Cost:
  $\hat{Y}_3 = 11.2x_1 + 6.8x_2 + 9.6x_3$

The following desirability function is used for the optimization of the above multiple response process.

$$D = (d_1 d_2 d_3)^{1/3} \quad (8)$$

Where,

$$d_i = \begin{cases} 1 - \frac{\hat{y}_i - lei}{les - lei} & \hat{y}_i \geq lei \\ 0 & \hat{y}_i < lei \end{cases}$$

The constraint ranges for each response variable is indicated in the table 2

Response	Minimum (*lei*)	Maximum (*les*)	Optimum
Fluency	8	9.5	9.152
Contraction	0.9	1.1	0.996
Cost	7.5	8.9	9.149

Table 2: The minimum, maximum and the optimum of the response variables

The desirability function 8 is applied and the optimum result is shown in the last column of table 2. The graphic description of this optimization process is shown in figure 3

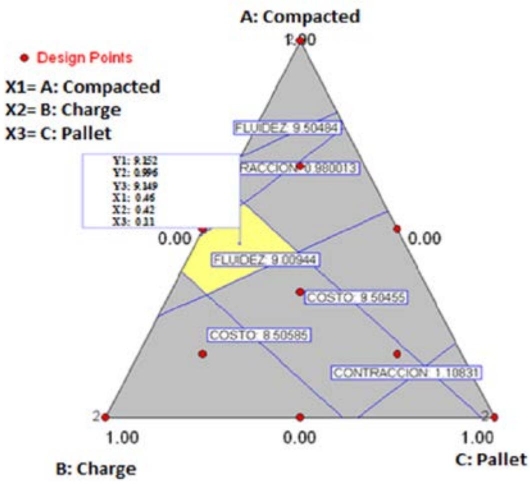

Figure 3: Optimization process results

V. CONCLUSION

In the present research work on mixture design with constraints and optimizing using the desirability function, an economic impact was achieved that was highly profitable for the company. Furthermore, a significant improvement to the process. The optimum proportion of the mixture is: 0.46, 0.42 and 0.11, with this blend the production capacity of the plant was improved in 5%, the manufacturing defect was reduced to 1.1%. This project was born because the initiative of the engineer of the process and it was crucial for the application of this methodology to implicate the manager of the company.

A relevant part of this type of research is that it allows the relationship between process engineering and technological development, because experimental planning is an aid to an engineer to understand more clearly the performance of plastics. As a product of the experimental results allows them to build mathematical models, thus to know the injection processes. This type of applied research allows us to develop other mathematical methodologies for the study of plastics such as modeling and optimization procedures that generate alternative solutions to improve processes and products. Jointly, research in the field of blending design advances by proposing innovative methods for solving problems in process engineering in industry.

REFERENCES

[1]. John A. Cornell. A Primer on Experiments with Mixtures. John Wiley & Sons, USA, 2011.

[2]. Derringer G, Suich R. Simultaneous optimization of several response variables. J Quality Technology 1980, 12: 214−219.

[3]. García A. J. L.,Lean Manufacturing in

Developing World-Methodology, Case Sudies and Trends from Latin American. Springer, 2014.

[4]. Harrington, E. C., Jr. The Desirability Function. Industrial Quality Control, (1965), 21,494-498.

[5]. Ibrahim N. H., Che Man Y. B. Tan Ch. P. and Idris N. A., Design experiment of Flow Behavior of O/W Emulsions as Affect by Polysaccharide Interactions. World Academy of Science, Engineering and Technology, International Science Index 43, International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering, (2010), 4(7), 464 - 470..

[6]. Khuri, A. I. and Mukhopadhyay, S. Response Surface Methodology. Wiley Interdisciplinary Reviews, Computational Statistics, Volume 2, Number 2. E. J. Wegman, Y. H. Said, and D. W. Scott, Editors. Wiley, Hoboken, New Jersey, 2010 pp.128-149.

[7]. Myers R. H., Montgomery D. C., Anderson-Cook C. M. Response Surface Methodology: Process and Product Optimization Using Designed Experiments. John Wiley & Sons, USA, 2011.

[8]. Piepel G.F. 50 years of Mixture Experiment Research 1995-2004, Chapter 12, Response Surface Methodology and Related Topics, Khuri A. I (Editor). World Scientific, Singapore, 2006.

[9]. Taavitsainena V. M., Anssi Lehtovaarab A. and Lathteenmakib M. Response surfaces, desirabilities and rational functions in optimizing sugar production. J. chemometrics (2010), 24(7-8),505-513.

[10]. Tsai Ch. W., Tong L.T. and Wang Ch.H..Using DEA to optimize a mixture design with multiple responses incorporating cost considerations. Journal of Scientific & industrial Research (2008), 67(7), 479-485.

7