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Simulation and flow analysis with Moldflow to optimize specimen fabrication in tensile testing with ABS material

Simulación y análisis de flujo con Moldflow para optimizar la fabricación de probetas en el ensayo de tracción con material ABS

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Abstract

The objective of carrying out the Moldflow simulation and flow analysis to optimize the design of tensile test specimens made of ABS material, is to identify possible problems or defects in the design of parts or molds prior to their manufacture, allowing adjustments or improvements necessary to optimize the quality of the final product and reduce costs. The simulation is performed with the Moldflow program, which uses numerical algorithms to calculate and visualize the material flow, temperature distribution, mold filling, pressures and forces, among others. The simulation results are examined to identify potential problems, such as excessive deformations, underfilled areas, weld lines, porosity, abnormal stresses and forces, among others. Based on the results of the analysis, modifications are made to the part or mold design to correct the problems found and improve the quality and performance of the final product. The results obtained from the Moldflow simulation and analysis include detailed information about the behavior of the material during the injection process, allowing the identification of defects and areas for improvement in the design.

Design, Properties, Moldflow

Resumen

El objetivo de llevar a cabo la simulación y análisis de flujo de Moldflow para optimizar el diseño de probeta para el ensayo de tracción elaboradas con material ABS, es identificar posibles problemas o defectos en el diseño de piezas o moldes antes de su fabricación, permitiendo realizar ajustes o mejoras necesarias para optimizar la calidad del producto final y reducir costos. La simulación se ejecuta el programa Moldflow, que utiliza algoritmos numéricos para calcular y visualizar el flujo de material, distribución de temperaturas, llenado del molde, presiones y fuerzas, entre otros. Se examinan los resultados de la simulación para identificar posibles problemas, como deformaciones excesivas, áreas con falta de llenado, líneas de soldadura, porosidades, aparición de tensiones y fuerzas anormales, entre otros. Con base a los resultados del análisis, se realizan modificaciones en el diseño de la pieza o molde para corregir los problemas encontrados y mejorar la calidad y funcionamiento del producto final. Los resultados obtenidos de la simulación y análisis de flujo de Moldflow incluyen información detallada sobre el comportamiento del material durante el proceso de inyección, permitiendo identificar posibles defectos y áreas de mejora en el diseño.

Diseño, Propiedades, Moldflow

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Introduction

The research and work carried out with simulators in the areas of engineering are becoming more and more interesting to be analyzed, therefore it has been proposed to develop this work with the approach of validating the simulation with Moldflow in a case study and thus favoring an engineering analysis.

In the area of research, the predecessors of the company's predecessors have worked with an important impact on the use of simulators, specifically Moldflow, to validate the quality of the plastic injection process in products made of plastic material.

The works mentioned below are of great value for the realization of this research, with the purpose of generating new lines of research based on digital tools.

(Shin and Park, 2013), indicate that the use of Moldflow software analyzes and seeks to improve the conditions of the product and/or the mold in which the manufacturing process is carried out. In their study they analyzed the effect of temperature to identify defects in the incomplete filling of the mold by using and observing the behavior of phase separation in ABS resin, thus observing imperfections in the finished product.

(Ramorino et.al, 2020) in this article, present 3D finite element modeling for reactive injection molding (RICM) and produce rubber membranes using commercially available software. In particular, mold filling steps and material curing dynamics and results are validated by experimental tests to accurately determine process representation, rheological behavior during curing, thermal properties and kinetic behavior. The real rubber mixture was described using a mathematical model that allows validating what was done with the software, understanding that for this type of research it is required to make use of other engineering tools to obtain the best results.

(Wang et.al, 2021), for their research related to the optimization of plastic injection molding parameters, they use Moldflow to simulate the process of an automobile rear door, finding that the volumetric contraction is an indicator to evaluate this type of products, where they found that the contraction has a value of 14.3%, which allows them to perform simulations for further evaluations in the indicated process. This also shows the importance of using digital tools, such as Moldflow, to improve the conditions of a process and a product.

(Liparoti et.al, 2023) in his research states that one aspect that continues to be a challenge in molding when there are joints in the parts are what are known as weld lines. The weld lines are crucial to determine the mechanical performance of the part, it is mandatory to clarify the position and characteristics of the weld lines, especially at industrial scale during mold design, to limit the causes of failure. Many papers deal with weld lines and their dependence on processing parameters for conventional injection molding, thus offering trend lines to investigate and use simulators to improve processing conditions in molds and products to be manufactured.

(Wang & Lee, 2023) emphasize that the injection molding process is aimed at increasing productivity, which is affected by factors such as cooling time, temperature distribution of plastic parts, thermal stress, warpage, etc. The cooling phase of the forming process is a critical factor that significantly influences the quality and profitability of the final product in injection molding, so the use of mathematical models and simulators in process evaluation is necessary to improve processing conditions.

(González et.al, 2015) state that the purpose of their work is to validate the use of Moldflow as a design tool for the development of products made from plastic and wood-based composite materials. Considering existing methods and exploring comparisons to improve this manufacturing technology through 3D prototyping and the application of simulators in engineering materials.

(Media et.al, 2022) indicate that it is indisputable that the quality of the manufactured products is a major challenge in the design of plastic injection molds.

To achieve this, CAE simulation of the design parameters was studied to help predict the possibility of product failure. Attempts are made to use CAE to obtain results that approximate real values. However, the obstacle they face is that CAE users are relatively still very minimal due to the need for sufficient knowledge in its handling, as well as the trial and error process on the case studies, which is impacted by the use of simulators that allow getting into the variables and control parameters of the production processes.

(Yang, 2018) in this work, Moldflow software is used to optimize the insertion program for the assembly of two parts, which are joined under pressure and the pressure changes during the filling process. Using simulation analysis of existing molds, design defects are identified to guide repairs, contemplating the use of the simulator.

(Tian et.al, 2023) indicate that plastic containers have demonstrated advantages over ceramic and metal containers. This article examines the reliability and humidity of plastic sheathed devices. In which an experimental design was used to create 25 groups of simulation experiments, using Moldflow software for the analysis and simulation of the flow pattern. It can be concluded that moisture diffusion is related to the type of plastic packaging materials and the diffusion pathway.

(Erkan et.al, 2023) it´s agreed that mass production techniques include plastic injection molding, extrusion molding, blow molding and vacuum forming. The injection molding process involves pressing plastic material into the mold cavity to give it the shape of the part to be manufactured. Therefore, the simulation of the mold flow allows us to evaluate the optimal conditions for plastic processing and therefore the importance of its use.

(Yang et.al, 2022) the main objective of this work is to obtain the optimum process parameters for plastic automotive front frames. In this study, Moldflow software was used to model the injection molding of the plastic front frame bracket of a vehicle. Homogeneity experiments were designed and performed. Five parameters of the injection molding process, mold temperature, melt temperature, back pressure, injection time and back pressure time, were selected as experimental factors. Volume is used as a quality evaluation index.

(Wu et.al, 2021) this study uses Moldflow® software to simulate the injection molding of automotive instrument light guide supports and optimize the position of the injection point by achieving an optimal combination of molding parameters and volume shrinkage. Through simulation, maximum volume contraction and maximum torsion were found to be the most suitable. In the optimized design, the maximum torque is 6.75% and 1.99 mm, respectively.

In the works described above, the needs of using simulators for validation and optimization process in specific case studies have been identified, given the circumstances of these works, we have chosen to follow this line and use the Moldflow software to characterize specimens in the tensile test, made of plastic material with the purpose of being manufactured with the injection process, under the conditions offered by the results of applying the simulator.

The following section describes the methodology proposed for the development of this research as a case study applying the Moldflow simulator.

Methodology

The work was carried out from a series of stages that contribute to perform simulations and analyze the flow in the elaboration with the plastic transformation process, called injection, with the Moldflow software, in a specimen for the tensile test.

The following paragraphs describe each of the stages involved in the development of this work.

CAD modeling: the modeling is done in a software with educational license, where the plan and the model to be used in the following stages involved in this work methodology are obtained.

CAD files of the part to be analyzed are obtained, including dimensions and geometry. Figure 1 shows the 3D model.

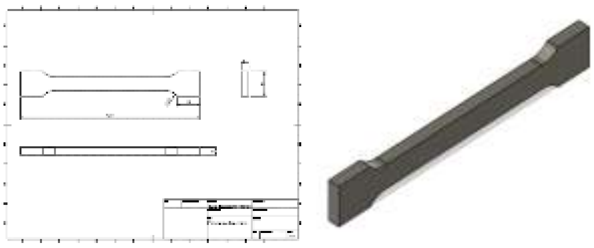


Figure 1 Plan and three-dimensional model
Source: Authors

Figure 1 shows the dimensions required for the fabrication of the specimen, based on ASTM D638 standards and the 3D model with the pre-established conditions for use in the flow simulation with Moldflow.

Physical properties of the material: a brief investigation of the physical properties of the material with which the simulation is carried out in the plastic injection process, since it is a predominant factor for the elaboration of the specimen and the conditions of the equipment to produce the specimen. Table 1 shows the properties of the material to be used, in this case Acrylonitrile Butadiene Styrene (ABS).

Material	Properties	Value/Unit
ABS	Tensile stress	30.46 [MPa]
	Deformation	4.52 [%]
	Hardness	69.2 Shore D
	Flexural modulus	1.08 [GPa]

Table 1 Physical properties of ABS
Source: https://www.matweb.com/index.aspx

The properties are of the generic ABS material, and in the future we plan to carry out simulations and analyses with materials from different suppliers to identify the homogenization of the behavior of each of these materials and maintain standardization in the results of the evaluations.

Definition of simulation parameters: the conditions of flow, temperature and injection time are established, as well as the material properties.

The information is described in Table 2.

Parameter	Description
Material	Suitable materials should be selected for the simulation, taking into account their thermal, flow and mechanical properties.
Material properties	Material properties such as viscosity and thermal conductivity must be specified correctly. These properties can vary with temperature and pressure.
Injection	Injection conditions, such as injection speed and pressure, lead time, and packaging pressure, must be defined.
Geometry	The geometry of the mold and part must be accurately modeled, including details such as inlets, cavities, and cooling channels.
Post-processing analysis	You can specify the results you want to analyze and display, such as final temperature, injection pressure, flow length, and shrinkage distribution.

Table 2 Parameters for simulations
Source: Authors

The identified in Table 2 are some of the parameters of importance or interest for the development of the simulations and to link the improvement trends that can be presented after performing the corresponding analysis with Moldflow.

Simulation performance: the Moldflow simulation program is run, which uses numerical algorithms to calculate and visualize material flow, temperature distribution, mold filling, pressures and forces, among others.

The simulation has parameters to consider which are shown in Figure 2.

Figure 2 Simulation parameters
Source: Authors

The parameters involved in the simulation and that can be modified for the optimization of the improvement in the specimen, as shown in Figure 2, are:

- Geometry: identified as body 1
- Material: selected ABS generic.
- Injection points: For this case study, only one injection point is considered due to the type of geometry available.
- Aesthetic faces: not taken into account because the geometry is regular.
- Injection time: automatically configured with the software variables.
- Melt temperature: 230 °C for this material.
- Geometry surface temperature: 60°C, which can be modified according to the climatic conditions for the manufacturing of the specimen.

The described is taken as a standard for each of the simulations to be worked, in the test specimen of the tensile test specimen, 10 injection points have been evaluated with the other parameters constant, with which it is sought to identify the best option for the elaboration of the product in the injection process for plastics.

Figure 3 shows some of the images corresponding to the Moldflow evaluations, where the different injection points considered for the case study can be located.

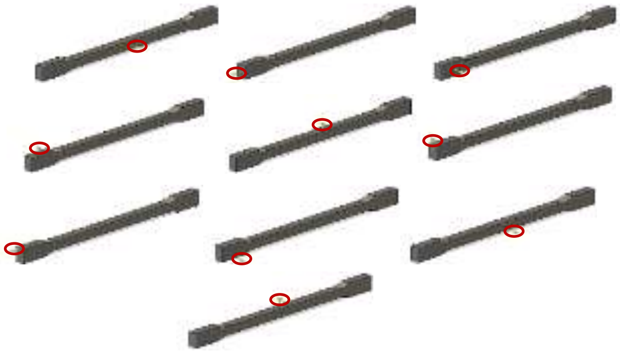


Figure 3 Injection points assessed
Source: Authors

In Figure 3 the injection points have been identified with a red circle, with the purpose of observing the section where each of the simulations is performed.

Data collection: involves the process of gathering information about the behavior of the material and the mold during plastic injection molding. This information is used to analyze and optimize the injection molding process.

During simulation, Moldflow performs advanced calculations to predict how the material will behave when injected into the mold. These calculations take into account factors such as heat transfer, injection pressure, material solidification and plastic flow in the mold.

Some of the mathematical models involved in the Moldflow simulations are:

Cross-WLF model, describes the viscosity of pseudoplastic materials.

$$\eta = \frac{\eta_0}{1+\left(\frac{\eta_0 \cdot \gamma}{\tau^*}\right)^{1-n}} \tag{1}$$

η_0 : Material viscosity at zero shear conditions.
τ^* : Shear stress at which pseudoplastic behavior occurs.
γ : Shearing speed.
1-n: slope of the pseudo-plastic behavior.

Williams-Landel-Ferry model calculates viscosity under zero shear conditions.

$$\eta_0 = D_1 \cdot e^{A_1\left(\frac{(T-\hat{T})}{A_2+(T-\hat{T})}\right)} \tag{2}$$

$$A_2 = \widehat{A_2} + D_3 \cdot p$$

$$\hat{T} = D_2 + D_3 \cdot p$$

D_1: Constant indicating viscosity, transition temperature and zero shear pressure.
D_2 : Constant indicating T of material transition.
D_3 : Constant relating variation of T to pressure.
$\hat{T}$: Material transition.
A_1 and A_2: model constants.

Modified Tait's model describes the pvT behavior in the solid and liquid states.

$$v(p,T) = v_0(T) \cdot \left(1 - 0{,}0894 \cdot \ln\left(1 + \frac{p}{B(T)}\right)\right) + v_f(p,T) \tag{3}$$

The above equations are alternatives for evaluation with Moldflow simulators, which are related to the conditions established for solid and liquid state materials.

On the other hand, the data obtained are presented in the form of tables and 3D visualizations that allow to analyze and understand the behavior of the injection molding process.

Table 3 shows the representative data of the process: specimen (PB), filling time (TLL), injection pressure (PIY) and solidification time (TSL).

PB	TLL [s]	PIY [MPa]	TSL [s]
1	0.51	6.5	36.54
2	1.03	11.2	36.11
3	0.92	10.5	36.36
4	1.03	10.8	36.45
5	0.51	8.2	35.83
6	1.13	12.7	36.33
7	1.13	13.5	36.48
8	1.03	11.4	36.47
9	0.51	8.7	36.55
10	0.51	9.4	36.47

Table 3 Injection process data with Moldflow
Source: Authors

Table 3 shows that the injection points corresponding to specimens 1, 5, 9 and 10 are the optimal ones according to the simulation, since they offer the shortest mold filling time, 0.51 s, while a fifth option is specimen 3 with 0.92 s. The rest of the specimens will have to be reviewed specifically to identify the effect that the specimen undergoes in the simulation in order to optimize it later in another study with these characteristics.

Figure 4 shows the filling in two of the specimens 9 and 7.

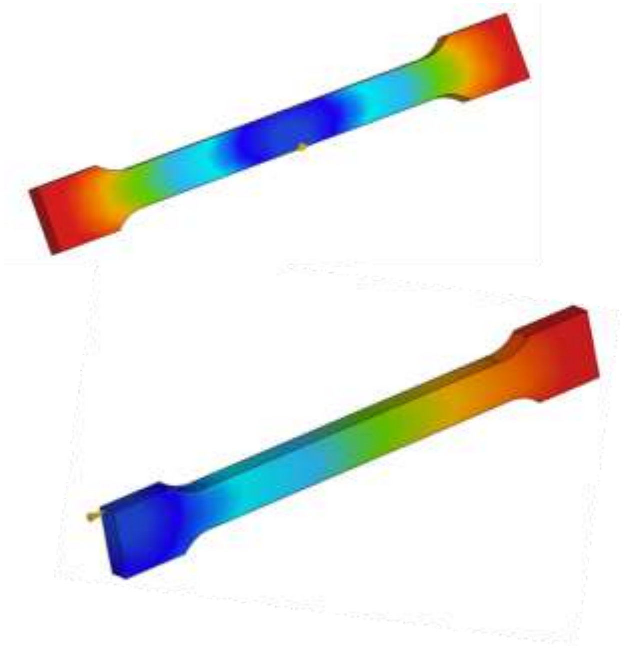


Figure 4 Simulation of specimens with Moldflow
Source: Authors

Figure 4 shows the colored zones where each section has a meaning. The blue color represents the minimum filling time, the orange color the intermediate time and the red color the maximum filling time for each of the simulated specimens. The temperatures involved in the simulation related to the plastic injection process with the specimen to be manufactured are also identified: flow front temperature (TFF), mean temperature (TMD) and time to ejection temperature (TTE), these data are shown in Table 4.

PB	TFF [°C]	TMD [°C]	TTE [s]
1	[230.1, 230.9]	[226.3, 231.5]	[32.31, 48.99]
2	[228.3, 230.7]	[221.6, 232.2]	[30.33, 49.36]
3	[229.0, 230.7]	[221.3, 232.0]	[32.61. 49.09]
4	[228.3, 230.6]	[220.7, 232.0]	[30.87, 49.10]
5	[230.1, 230.8]	[224.8, 231.6]	[29.19, 48.95]
6	[228.3, 230.7]	[219.0, 232.4]	[9.78, 49.50]
7	[228.0, 231.0]	[217.7, 232.5]	[13.54, 49.63]
8	[228.4, 231.0]	[220.0, 232.2]	[12.76, 49.24]
9	[230.1, 231.0]	[225.6, 231.8]	[160.4, 49.13]
10	[230.1, 231.3]	[225.6, 231.8]	[12.60, 49.14]

Table 4 Temperature data in the simulation
Source: Authors

Table 4 shows that the TFF remains at values close to those of TMD, where the means for each case are 229.87 [°C] and 223.86 [°C], respectively. Figure 5 refers to the temperatures described.

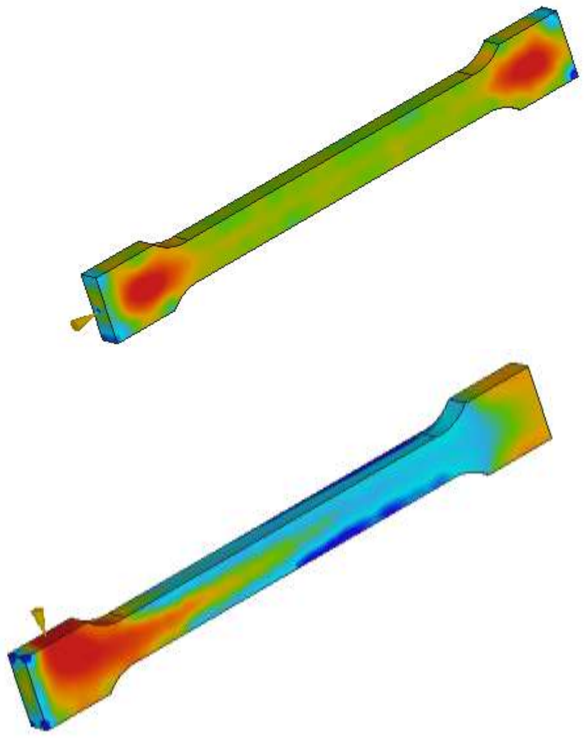


Figure 5 Simulation of specimens with temperature in Moldflow
Source: Authors

On the other hand, there are a series of references related to volumetric contraction (VC), solidified plastic at filling (PSLL) and solidified plastic at ejection (PSLE), whose values are shown in Table 5.

PB	CV [%]	PSLL [%]	PSLE [%]
1	[2.79, 6.38]	[0, 3.46]	[74.82, 100]
2	[2.40, 6.15]	[0, 6.13]	[74.35, 100]
3	[2.66, 6.26]	[0, 5.74]	[74.92, 100]
4	[2.14, 6.29]	[0, 6.18]	[82.22, 100]
5	[2.54, 6.45]	[0, 3.36]	[72.62, 100]
6	[1.78, 6.40]	[0, 5.90]	[71.99, 100]
7	[1.78, 6.40]	[0, 6.43]	[84.55, 100]
8	[2.04, 6.34]	[0, 5.60]	[85.49, 100]
9	[2.21, 6.52]	[0, 3.39]	[73.61, 100]
10	[2.11, 6.55]	[0, 3.38]	[72.67, 100]

Table 5 Volumetric contraction data
Source: Authors

Table 5 is intended to show the shrinkage ranges and the way in which the specimen solidifies during the plastic injection process for the study specimen. In this case, the first five specimens have a lower contraction percentage, which is equivalent to a good cooling process of the part in the mold, which will have a statistical support that is reflected in the results of this work.

On the other hand, Figure 6 shows the visualization of the shrinkage of the tensile specimens, where the red color represents the highest percentage of contraction.

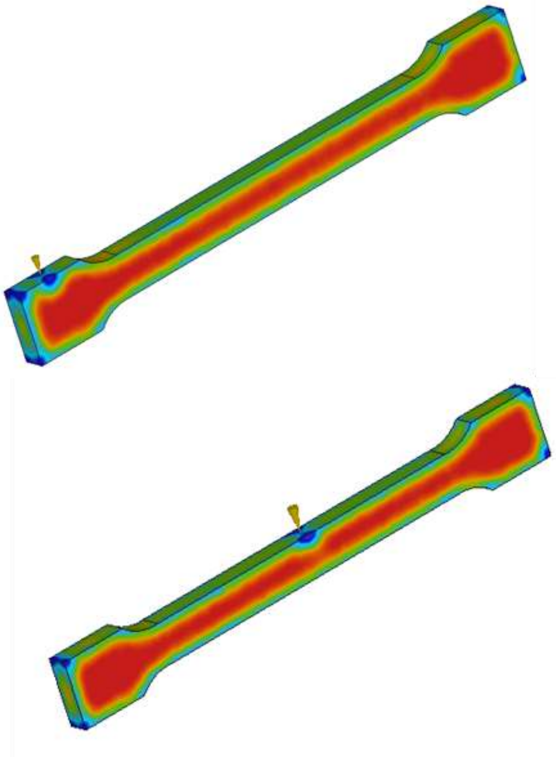


Figure 6 Contraction with the Moldflow simulator
Source: Authors

In each of the simulations performed, the parameters of weld lines (LS), air bubbles (BA), shrinkage (RC) and maximum deflection (DF) must also be taken into account.

PB	LS	BA	RC	DF [mm]
1	None		None	0.50
2	None		None	0.50
3	None		None	0.50
4	None		None	0.50
5	None		None	0.51
6	None		None	0.51
7	None		None	0.52
8	None		None	0.50
9	None		None	0.52
10	None		None	0.53

Table 6 Representative data in Moldflow
Source: Authors

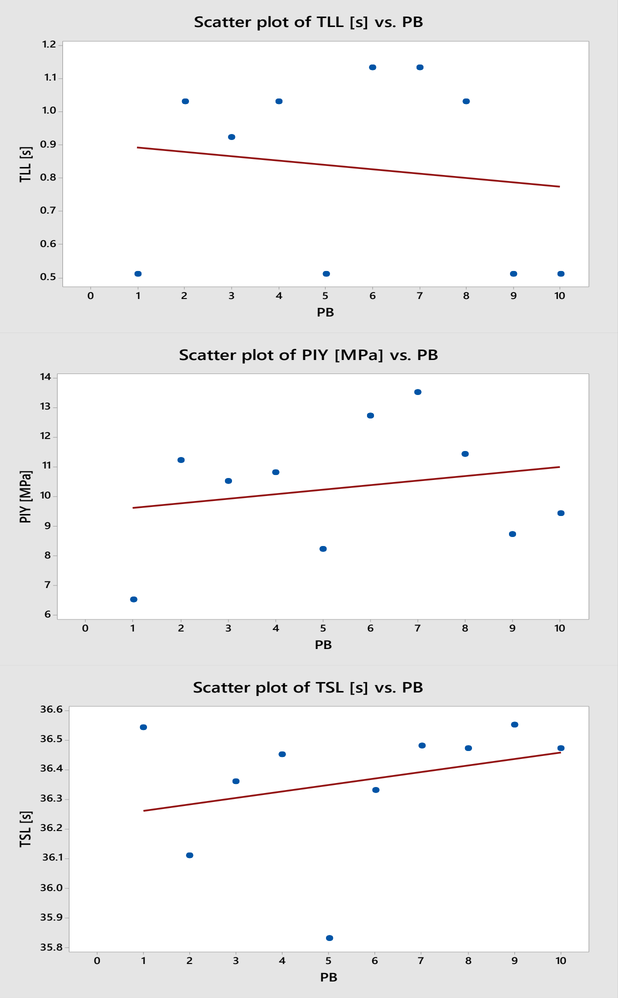
Table 6 shows the location of air bubbles that have been identified during the simulation of the plastic injection process for the tensile specimen, which influences the deformation of the specimens at the time of testing as part of the experiments for the identification of the physical properties of the materials. In this case the specimens with a higher amount of BA are 5 and 10, which depends specifically on the position of the injection point, showing an area of opportunity to modify the location of the points.

The following section, results, identifies possible working trends for this type of specimens with the use of simulation software.

Results

As part of this section, the graphs of the information obtained in the simulations with Moldflow for the case study, tensile specimens in plastic material called ABS, are described.

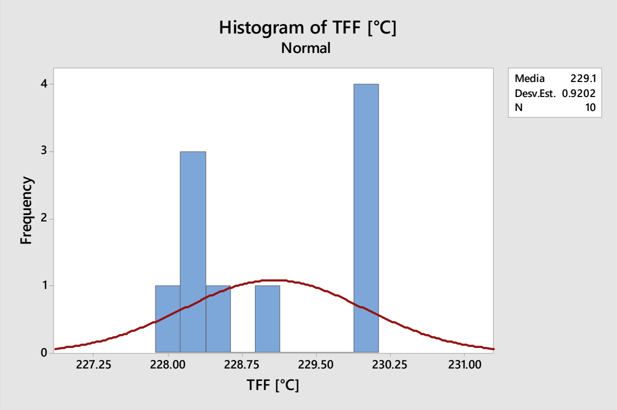
First, Graph 1 shows the dispersion of values related to TLL, PIY and TSL.



Graphic 1 Dispersion of simulator data
Source: Authors

This Graph 1 shows the data corresponding to the control parameters in the injection process, highlighting that new simulations must be conducted to achieve homogeneity in each of the specimens and to modify the design of the specimen in order to eliminate the action angles.

In Figure 2, a frequency histogram with respect to TFF is described in general terms.

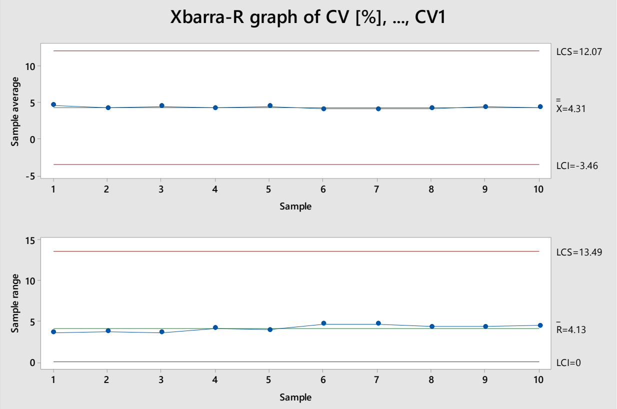


Graphic 2 TFF frequency with simulator
Source: Authors

With these data identified in the frequency of the TFF, it is notorious that the processing conditions must be improved to control the corresponding temperature in the manufacture of the specimen, achieving that most of the data are located within the bell in the statistician. This indicates that the sample of simulations should be enlarged.

The standard deviation is indicating the existing dispersion in the data extracted from the simulations, so the measurements should be improved, choosing to place the injection points in different positions.

In Figure 3, it will be determined whether there is statistical control for the Moldflow simulations on the tensile specimens.



Graphic 3 Statistical process control with simulator data
Source: Authors

Regarding Graph 3, it is determined that by observing that none of the test specimens are outside the lower limits as upper limits, the statistical control is adequate for the process in the simulation with the Moldflow software.

In this work as in those presented by other researchers (Schrank et.al, 2022), the use of finite element software such as Moldflow presents satisfactory results with respect to the operating conditions of the plastic injection molding process which translates as motivation to continue with research related to the optimization of control parameters in simulators.

(Huang et.al, 2020) the aim of this research is to successfully produce thin-walled parts by thin-walled injection molding. This study determines the optimum process parameters for thin-walled parts using minimum product distortion. Regardless of the experiments or numerical simulations, this work is shown in Table 6, with the maximum deflections that coincide with those expressed by the aforementioned researchers.

It was also observed that the specimens with the highest rate of air bubbles are those that have the injection point at the edges of the geometry of the tensile specimen, so that these points are not strategic for the manufacture of the specimen.

What has been described so far in this research work consists of improving the operating conditions of the injection process and performing simulations with Moldflow, always providing trends from an engineering and statistical perspective.

The graphs presented in this section allow us to visualize important aspects to be improved and to generate new evaluation alternatives in case studies for use with the simulator used in this work. In the following section we have the general points of view that contribute to the methodology, results and trends in favor of this type of research, which have application in engineering.

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Conclusions

The results obtained from the Moldflow simulations for the case study of ABS plastic tensile specimens have provided valuable information on the behavior of this material. The graphs generated have made it possible to visualize the trends and patterns of the parameters that control the injection process through the simulator.

Carrying out this type of analysis and simulation is essential to make informed decisions in the design and manufacture of parts or molds in mechanical engineering. Potential problems can be identified, necessary design modifications can be made, the performance of the part or mold under actual production conditions can be predicted and the manufacturing process can be optimized.

In addition, Moldflow simulation and flow analysis enables cost reduction, quality improvement and efficiency in the design and manufacture of engineered products.

By using statistics in the Moldflow simulation, it is possible to perform a detailed and exhaustive analysis of the data obtained, which makes it possible to identify potential problems and manufacturing defects, as well as to optimize the part design to improve its performance and durability.

Statistics also provide information on the variability of the results, which helps to assess the robustness and stability of the molding process. This is especially useful for ensuring the quality and consistency of parts produced on a large scale. In this case study it was determined, with the statistical aspects, that the sample is small and a larger number of simulations should be considered to enrich the statistics.

From the simulator's execution point of view, it offers substantial advantages at the moment of performing it with the specimens, because it allows to observe those limitations in the design of the part that should be improved, in that sense, avoid 90° angles in the corners, try to make designs with small radii and that do not produce air bubbles. In this case study there were no welding lines because the decision was made to make a single piece in the mold and the geometry is homogeneous, thus avoiding the existence of shrinkage.

From the production point of view, the injection pressure that best fits, together with the other variables, was for specimen 1 with a value of 6.5 [MPa], taking into account that the mean was 0.84 [MPa], standard deviation of 0.27. In the case of the solidification time was 36.54 [s], with a mean value of 36.50 [s] and a standard deviation of 0.024 [s]. With these results it is observed that the filling time, with the data worked, has a good behavior from the statistical point of view, indicating that it is necessary to work with simulations for the injection pressure and to improve the conditioning standard deviation.

With respect to volumetric shrinkage, as a factor of interest in parts made by plastic injection molding, this study obtained a mean of 2.15 and a standard deviation of 0.25, again the data are scattered, so future work should be done to improve the CV variable.

The choice and adjustment of the parameters depends on the specific characteristics of the mold and the part, as well as on the simulation objectives. It is important to perform tests and adjustments to obtain more accurate and reliable results.

After performing the simulations it is identified that one of the trends of this study is to perform iterations with different materials to visualize the effects of the parameters, in conjunction with the variables involved in the injection process and in the simulator, comparing data and achieving homogeneity in the study with statistics for a better understanding of engineering and its areas of application.

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