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Simulation of the filling stage for the pc+abs blend during the injection molding process

Simulación de la etapa de llenado de la mezcla PC+ABS durante el proceso de moldeo por inyección

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Abstract— The computational fluid dynamics simulation presented shows the behavior of the PC+ABS blends during the injection phase through a transient analysis of the injection molding process. The Fluent® computational fluid dynamic analysis module of Ansys Workbench® makes it possible to know the behavior of the injected material according to its properties and the design of the geometry of the injected product, represented by the mold cavities (fluid domain). The implementation of simulation allows engineers and processors to efficiently analyze the filling phase from early design stages due to obtaining the results of maximum filling pressure, visualization of the polymer flow front, pressure increase at the inlet, and the temperature of the flow front at the end of the injection phase. In conclusion, the computational simulation generates a prior understanding of the filling phase while minimizing the failures found until the advanced stages of production (injection mold and injected product manufactured). In addition, it guarantees the reduction of time and costs of the injection molding process through a completely computer-assisted environment.

Keywords— Injection molding; Filling phase; Mold design; PC+ABS blends; Process parameters; Cross-viscosity model.

Resumen— La simulación computacional de la dinámica del fluido presentada muestra el comportamiento de la mezcla PC+ABS durante la fase de inyección mediante un análisis transitorio del proceso de moldeo por inyección. El módulo de análisis fluidodinámico computacional Fluent® de Ansys Workbench® posibilita conocer el comportamiento del material inyectado de acuerdo a sus propiedades y al diseño de la geometría del producto inyectado, representado por las cavidades del molde (domino fluido). La implementación de la simulación permite a los ingenieros y procesadores analizar de manera eficiente la fase de llenado desde etapas tempranas de diseño debido a la obtención de los resultados de presión máxima de llenado, visualización del frente de flujo del polímero, el incremento de la presión a la entrada, y la temperatura del frente de flujo al final de la fase de inyección. En conclusión, la simulación computacional genera una comprensión previa de la fase de llenado al tiempo que minimiza las fallas encontradas hasta etapas avanzadas de la producción (molde de inyección y producto inyectado fabricados). Además, garantiza la reducción de tiempos y costos del proceso de moldeo por inyección mediante un entorno completamente asistido por ordenador.

Palabras clave— Moldeo por inyección; Fase de llenado, diseño de molde, Mezcla de PC+ABS, Parámetros de proceso, Modelo de viscosidad de Cross.

I. INTRODUCTION

The polymer injection molding process has been used for years to manufacture geometrically complex parts (Araújo et al., 2023; Czepiel et al., 2023; Kalwik et al., 2022; Kashyap & Datta, 2015; Khosravani & Nasiri, 2020; Wang et al., 2020) from multiple materials (thermoplastics, thermo-sets, elastomers, foams, and composite materials) (Chung et al., 2021; H. Fu et al., 2020; Godec et al., 2021; Jachowicz et al., 2021). Even with the existence and development of other manufacturing techniques (blow molding, thermoforming, 3D printing), injection molding occupies a third of all products made with polymeric materials in different fields of the industry (Abdullah et al., 2023; Khosravani & Nasiri, 2020), covering the manufacture of toys, devices used in the optical area, packaging products, medical equipment, drug administration, parts used in the automotive and aerospace industry (Czepiel et al., 2023; De Miranda & Nogueira, 2019; H. Fu et al., 2020; Galuppo et al., 2021; Kalwik et al., 2022; Myers et al., 2023; Páramo et al., 2019). The level of use of the injection molding process is mainly due to the high production rate, high dimensional precision of the manufactured parts, repeatability, machinability, low cost, quality of the final product, good mechanical properties, and biocompatibility, among others. In addition to that, among the expectations of the injection molding process are the development of new variants to those already existing today (gas-assisted molding, water-assisted molding, micro-injection molding, injection foam molding, low-pressure molding, injection compression molding) and a growing global product market estimated in $266 billion by 2030 (Myers et al., 2023; Veltmaat et al., 2022).

When manufacturing a part by injection molding, many factors significantly influence its quality (physical and structural condition) and properties (thermal, functional, and mechanical) (Chung et al., 2021; Czepiel et al., 2023; Godec et al., 2021; Hentati et al., 2019; Jachowicz et al., 2021; Kalwik et al., 2022; Khosravani & Nasiri, 2020; Myers et al., 2023; Wang et al., 2020; Yu et al., 2020). The molded part is the result of the processed polymeric material (physicochemical and rheological properties), the design characteristics of the injection mold (wall thickness, surface inclination, radius of rounding of the edges, shape, dimensions of the cross sections, precision desired geometry and material of the injection mold) and the specific parameters of the process (injection temperature, mold temperature, injection and packing pressure, injection speed, cycle time, clamping force) (Araújo et al., 2023; De Miranda & Nogueira, 2019; Kashyap & Datta, 2015; Shen et al., 2008). Understanding and identifying the key factors that impact the final product and cycle time of the injection molding process has been a part of academic and industrial research for a long time (Abdullah et al., 2023; Hentati et al., 2019; Kashyap & Datta, 2015; Veltmaat et al., 2022). Each product manufactured by injection molding is a particular process, and it is necessary to find acceptable limits of the factors to ensure successfully molded parts with reproducibility, efficiency, and profitability, involving considerable time and money. Inadequate limits of the factors generate process failures (short shots, insufficient clamping force, excess injected material) and defects in the final product (flow marks, flashing, deformations, shrinkage, welding marks, burns, residual stresses) (Jachowicz et al., 2021; Kalwik et al., 2022; Myers et al., 2023). Additionally, they also tend to affect the amount of postprocessing that a molded part may require due to removal of excess material, application of layers of paint, or difficulty in assembly due to inadequate configuration of the injection molding process (Czepiel et al., 2023; H. Fu et al., 2020).

Multiple approaches have contributed to the understanding and improvement of the injection molding process to achieve the desired quality and precision in the manufactured products while reducing production times and costs. Initially, the injection molding process and mold design were mainly based on years of experience, causing a slow process flow with constant correction of faults and defects through trial and error, which made the process inefficient and unprofitable (Yu et al., 2020). Additionally, determining the factors that affected the injection molding process through trial and error did not allow for consideration of the effects caused by the interaction of multiple factors, and erroneous conclusions were obtained. The need to adequately adjust key affecting factors while considerably improving process flow generated the development of more successfully applied methods. Experimental design strategies (Taguchi method, response surface methodology, one-factor design at a time, and multi-factor ANOVA) and some other methods such as artificial neural networks (ANN), fuzzy logic (FL), genetic algorithms (GA), principal component analysis and case-based reasoning (CBR) allow obtaining appropriate process parameters based on the collection of real-time data from the properly instrumented process. At that time, it was possible to establish the parameters that affect the injection molding process efficiently to eliminate potential defects, achieve desired qualities in the molded parts, and make the process repeatable and profitable (Araújo et al., 2023; Chung et al., 2021; Hentati et al., 2019; Khosravani & Nasiri, 2020; Wang et al., 2020).

However, the time required in the experimental stage in a process where each manufactured product requires considerable particular attention made it necessary to develop technologies capable of numerically modeling the injection molding process. In many fields, processes are modeled and simulated by reducing the experimental stage through computational approximations of reality, which reduces production times and makes this technology indispensable to minimize the risk of errors by helping to choose actions from the production stage

(Araújo et al., 2023; Galuppo et al., 2021; Godec et al., 2021; Jachowicz et al., 2021; Myers et al., 2023). CAD/CAM/CAE software has made it possible to accurately simulate the phases of the injection molding process, considering the complex physical processes involved, the properties of the materials, and the specific parameters of the process (Czepiel et al., 2023; De Miranda & Nogueira, 2019; Deng et al., 2021; J. Fu & Ma, 2019). Multiple challenges are faced when modeling and simulating the injection molding process since it involves the conservation of mass, momentum, and energy with two phases (polymer-air) in motion, in addition to characteristics of the polymer, such as its non-Newtonian behavior (Deng et al., 2021; Veltmaat et al., 2022). Despite the challenges, numerous case studies verify the agreement of the injection molding process experimentally concerning the results achieved through different simulations carried out in commercial software such as Moldflow® (J. Fu & Ma, 2019; Huszar et al., 2015; Lucyshyn et al., 2021; Oliaei et al., 2016; Shen et al., 2008), Moldex3D® (Araújo et al., 2023; Chung et al., 2021; Godec et al., 2021; Myers et al., 2023), SolidWorks® Plastic (De Miranda & Nogueira, 2019; Hentati et al., 2019), Ansys® Workbench (Abdullah et al., 2023; Baum et al., 2022; J. Fu & Ma, 2019; Páramo et al., 2019; Rusdi et al., 2016), Cadmould® 3D-F (Jachowicz et al., 2021), and OpenFOAM® (Galuppo et al., 2021).

In this study, a fluid dynamics simulation carried out using Ansys® Workbench software covers the injection phase considering the study of the fluid (molten polymer) as it fills the mold cavities (fluid domain) through a transient analysis of the injection molding process. The main objective is to present the current scope of simulation of the injection molding process as a tool that allows obtaining the appropriate processability parameters and thus avoiding possible failures in the injected part. The proposed simulation achieves the scope of simulations that focus on fluid dynamics. For this reason, the simulation of the case is also carried out through the Moldflow® software, guaranteeing the correspondence of the results obtained in both software but finally demonstrating that the simulation through the Ansys® Workbench software allows intervention and control by the user in the simulation configuration. As an initial conclusion, the proposed simulation covers the main characteristics established by the user to obtain process parameters while guaranteeing the adequate design of the injection mold cavities, expanding the understanding, repeatability, quality, and profitability of the process and product from the early stages of design.

II. MATERIALS AND METHODS

The injection molding process involves the interaction between a melted polymer and the internal walls of a mold. The process consists of filling the cavities of a mold with a melted polymer under adequate pressure. The goal is to obtain a replica of the designed shape inside the mold by solidifying the melted polymer. This section presents the analysis of the filling phase within the injection molding process using the Ansys® workbench software.

The simulation of the injection phase requires considering the design characteristics that allow modeling the geometry corresponding to the fluid domain, that is, the machined cavities in the injection mold. Likewise, configuring the simulation of the injection phase requires selecting the study material considering its properties, processability characteristics, and behavior.

A. Geometry design

Reviewing the ASTM D638-02a (ASTM D638-02a, 2002) and ASTM D3641-02 (ASTM D3641-02, 2002) standards to design the injection mold provided some dimensional specifications to manufacture specimens for testing the tensile properties of plastics. Design considerations not established in the previously mentioned standards were adjusted under design and manufacturing criteria considering the injection molding process and the selected plastic material.

Modeling of the geometries shown in Figure 1 made through SolidWorks® computer-aided design software, including the following features: 1/2° draft angles, selection of multiple identical mold cavities, uniform distribution of mold area specimen surface over total mold surface, Z-type arrangement for runners, modified trapezoidal runner type with 10° inclination angle, uniform distribution of runners to ensure equal pressure drops, gate width equal to gate width cavity, gate depth of at least two-thirds of the cavity depth, gate length less than 3 mm, arrangement of parallel-type cooling channels to achieve approximately uniform cooling.

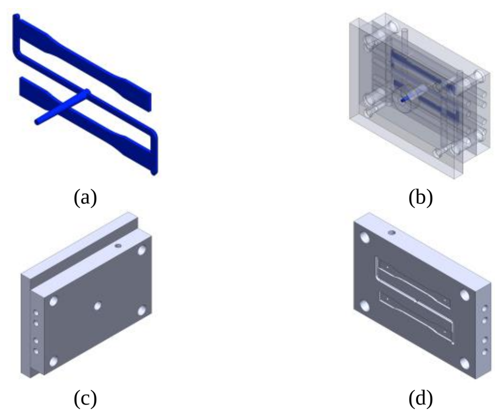


Fig. 1. CAD models needed to simulate the injection molding process: (a) Fluid domain; (b) Assembled mold; (c) Fixed mold plate; (d) Mobile mold plate.
Source: Project Author.

B. Polymer injection phase

The selected material is an amorphous thermoplastic blend made of polycarbonate (PC) and acrylonitrile-butadiene-styrene (ABS), which adds the high processability of ABS with the excellent thermal, mechanical, and impact resistance properties of PC, with considerable attention in engineering applications, mainly in the automotive industry (Hentati et al., 2019; Jurado Páramo et al., 2021).

The manufacturer of the PC+ABS material provided the recommended processability parameters. Additionally, the information available within the Moldflow® Adviser and Moldex3D® software libraries, widely used in the simulation and analysis of the injection molding process, was also reviewed. The melt temperature, mold temperature, and melt density reported in Table 1. are the material data required for the simulation and analysis of the filling phase within the injection molding process.

Table 1. PC+ABS processability parameters.

Processability parameter	**Material manufacturer**	**Moldflow® Adviser**	**Moldex3D®**
Mold temperature	60-90 °C	60-90 °C 75 °C (Recommended)	60-90 °C 75 °C (Recommended)
Melt temperature	260-290 °C	260-290 °C 275 °C (Recommended)	260-290 °C 275 °C (Recommended)
Melt density	1.02 g/cm^3	1.0239 g/cm^3	1.02 g/cm^3

Source: Author

The geometry used to simulate the injection phase through the Fluid Flow (Fluent®) module shown in Figure 2 represents only the fluid domain constituted by the mold cavities, gates, runners, and sprue.

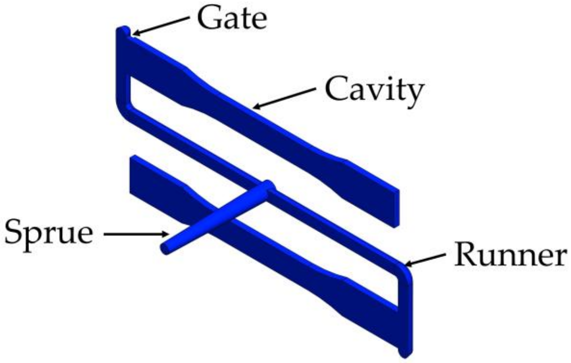


Fig. 2. Fluid domain parts.
Source: Project Author.

An analysis of mesh independence produces the discretization of the volume shown in Figure 3. The mesh made through local mesh controls has mostly hexahedral-type elements and an orthogonal quality above 0.6.

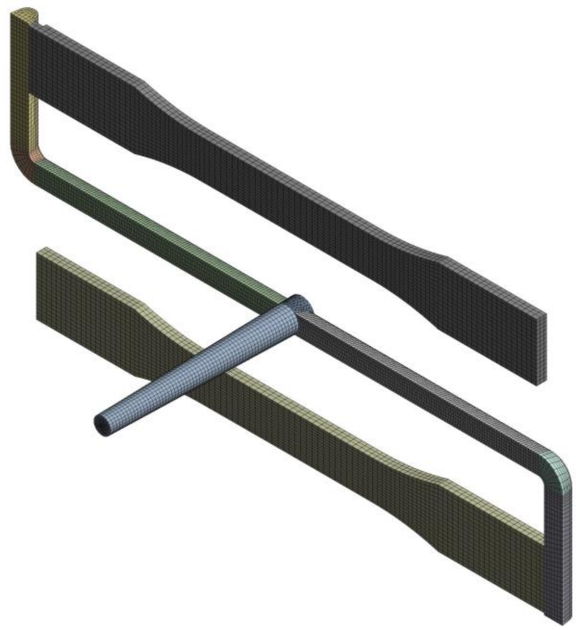


Fig. 3. Fluid domain meshing.
Source: Project Author.

The boundary conditions applied to simulate the injection phase in Figure 4 include smooth walls without slip that limits the fluid domain allowing analysis of the effect of viscosity, inlet velocity of the melted polymer into the sprue, and zones with free external pressure that represents the exit of the displaced air in the locations furthest from the sprue (Abdullah et al., 2023; Páramo et al., 2019; Veltmaat et al., 2022).

Fig. 4. Boundary conditions for the injection phase: (a) Walls; (b) Inlet; (c) Outlets.
Source: Project Author.

The value of the inlet velocity of the polymer (3.6 m/s) calculated through equation (1) considered the volume of the fluid domain (0.00002595 m^3) and the area at the beginning of the sprue (0.00002425 m^2) determined through SolidWorks® computer-aided design software. In the absence of experimental data, the best alternative to complete the data in equation 1 was to assume a cycle time (0.3 s) to obtain calculations quickly in the simulation environment, bearing in mind that the implemented simulation is a transient state analysis and requires higher computational power compared to a steady state analysis.

$$Vel_{in} = \frac{Vol_{geometry}}{t_{cycle} * A_{in}} \quad (1)$$

In the behavior of the PC+ABS polymer, the viscosity is variable and depends on the temperature and the shear rate. The best way to represent the behavior of the melted polymer is through the Cross-viscosity model for non-Newtonian fluids (Abdullah et al., 2023; Jurado Páramo et al., 2021; Páramo et al., 2019; Veltmaat et al., 2022), equation (2).

$$\eta(\gamma) = \frac{\eta_0}{1 + (\lambda * \gamma)^{(1-n)}} \quad (2)$$

Where: $\eta(\gamma)$, the viscosity [Pa·s]; η_0, the upper limit viscosity [Pa·s]; γ, the shear rate [s^{-1}]; λ, the time constant [s], and n, the power law index.

The material libraries of the Moldflow® Adviser and Moldex3D® software contain the coefficients necessary to solve the Cross-viscosity model considering the material and the temperature of the melted polymer. In the case of the PC+ABS polymer blend, the values calculated at 275 °C for each software are in Table 2. Subsequently, Figure 5 presents the log-log graph of the viscosity as a function of the shear rate using the Cross-viscosity model for each software.

Table 2. Cross-viscosity model coefficients for PC+ABS polymer blend for 275 °C.

Cross-viscosity model	Moldflow® Adviser	Moldex3D®
Upper limit viscosity	355.598 Pa·s	357.984 Pa·s
Time constant	0.002 s	0.002494 s
Power law index	0.2735	0.2739

Source: Author

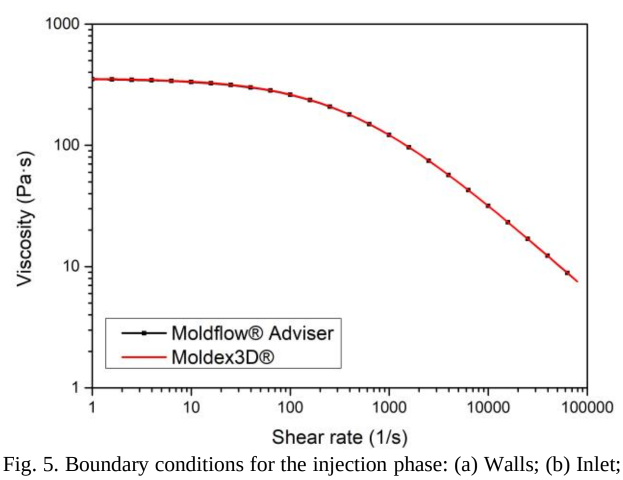


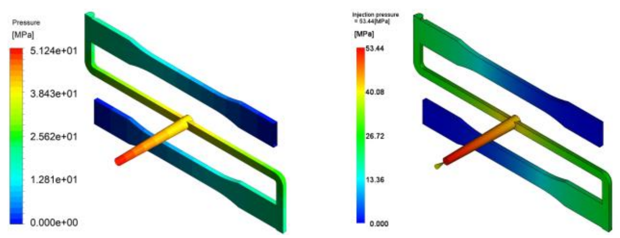
Fig. 5. Boundary conditions for the injection phase: (a) Walls; (b) Inlet; (c) Outlets.
Source: Project Author.

III. RESULTS OF THE POLYMER INJECTION PHASE

The Fluid Flow (Fluent®) module using the Ansys® Workbench software allowed obtaining the results of the pressure required to fill the mold cavities, the visualization of the polymer flow front, pressure increase at the inlet, and the temperature at the flow front by transient simulation of the injection phase. A simulation under the same conditions implemented in the Fluid Flow (Fluent®) module carried out in the application software specialized in the injection molding process Moldflow® Adviser allowed a comparative analysis of the results of the injection phase.

A. Maximum filling pressure

Considering the simulation conditions mentioned in the previous section, the result for the injection pressure required to fill the mold cavities by Fluid Flow (Fluent®) module using Ansys® Workbench software is 51.24 MPa, as shown in Figure 6 (a). Similarly, the result of the injection pressure required to fill the mold cavities using the Moldflow® Adviser software is 53.44 MPa, as shown in Figure 6 (b).



(a) (b)

Fig. 6. Result of the injection pressure required to fill the mold cavities: (a) Ansys® Workbench/Fluent module; (b) Moldflow® Adviser.
Source: Project Author.

The percentage difference of 4.12% calculated for the injection pressure results according to equation (3) validated the simulation result obtained by the Fluid Flow (Fluent®) module using Ansys® Workbench software, considering the result of Moldflow® Adviser software as a theoretical value or expected value due to the specialized application in the injection molding process (J. Fu & Ma, 2019; Huszar et al., 2015; Lucyshyn et al., 2021; Oliaei et al., 2016; Shen et al., 2008).

$$\%\ difference = \left|\frac{\text{Ansys® Workbench result} - \text{Moldflow® Adviser result}}{\text{Moldflow® Adviser result}}\right| * 100 \quad (3)$$

B. Polymer flow front

The result of the polymer flow front visualization obtained through the Fluid Flow (Fluent®) module with Ansys® Workbench software compared with the result obtained through the Moldflow® Adviser software shows that the filling of the different mold zones occurs at similar times, as shown in Figure

7.

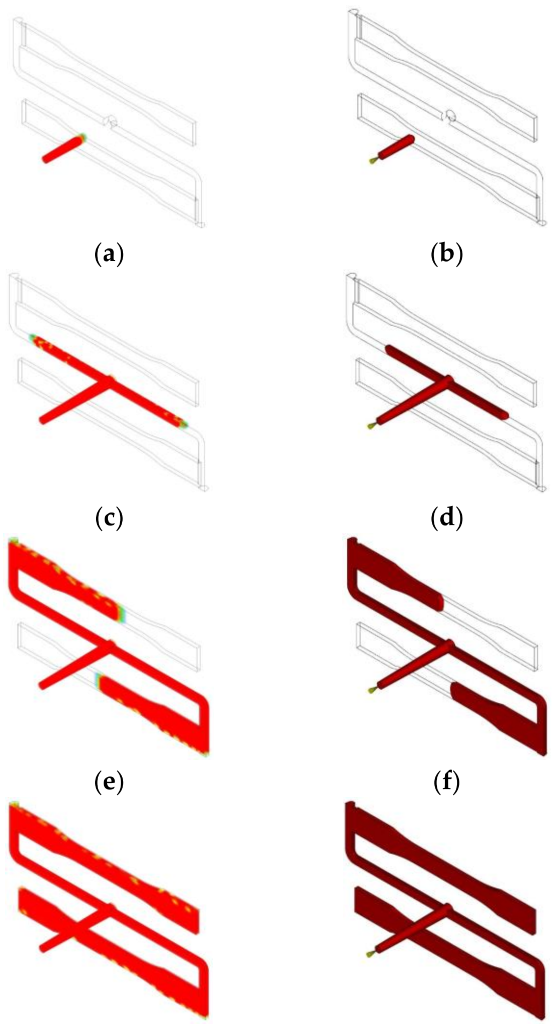


Fig. 7. Polymer flow front visualization results over time: (a) Mold filling in time = 0.0130 s using Ansys® Workbench/Fluent module; (b) Mold filling in time = 0.0129 s using Moldflow® Adviser; (c) Mold filling in time = 0.0650 s using Ansys® Workbench/Fluent module; (d) Mold filling in time = 0.0645 s using Moldflow® Adviser; (e) Mold filling in time = 0.2070 s using Ansys® Workbench/Fluent module; (f) Mold filling in time = 0.2065 s using Moldflow® Adviser; (g) Mold filling in time = 0.3000 s using Ansys® Workbench/Fluent module; (h) Mold filling in time = 0.3097 s using Moldflow® Adviser.
Source: Project Author.

The simulation presented in this study allows for obtaining the trajectory of the melted polymer in time with the main objective of guaranteeing the correct filling of the injected parts. The result offers the visualization of the polymer flow front achieved by performing the simulation of the injection phase in a transient state analysis.

C. Pressure increase at the inlet

The result presents the inlet pressure profile over time for the analyzed geometry. The injection pressure at the injection location increases as the molten polymer advances, filling the mold cavities according to the characteristic pressure profile (Yu et al., 2020). The pressure at the end of the time coincides with the maximum filling pressure, see Figure 8.

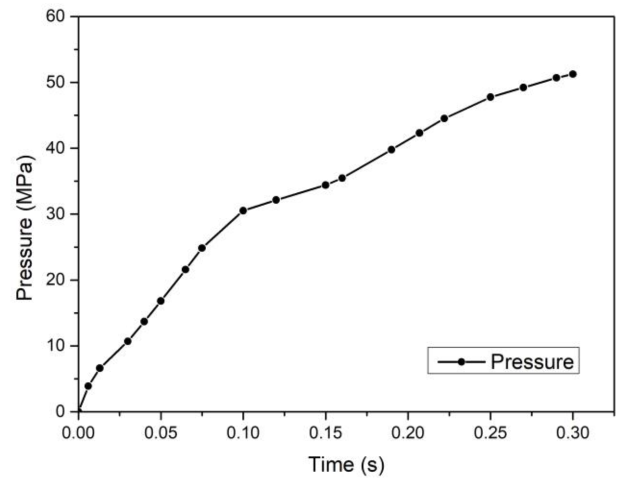


Fig. 8. Inlet pressure profile over time.
Source: Project Author.

C. Temperature at flow front

The flow front temperature results show the temperature distribution of the melted polymer at the end of the injection phase. The result obtained for the maximum temperature in the flow front using the Fluid Flow (Fluent®) module with the Ansys® Workbench software is 277.4 °C, as shown in Figure 9.

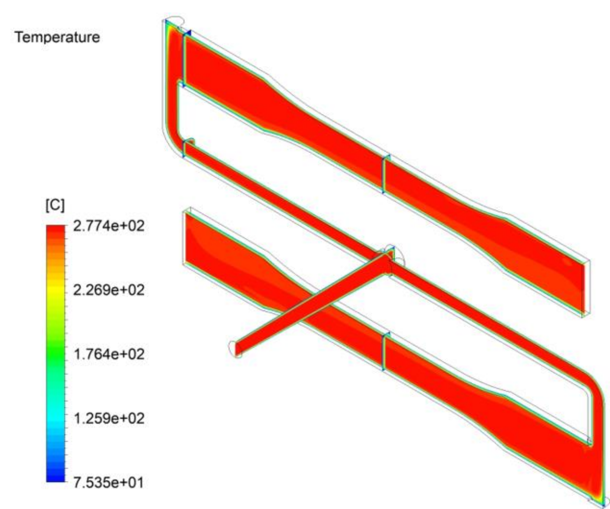


Fig. 9. Flow front temperature results using Ansys® Workbench/Fluent module.
Source: Project Author.

Similarly, the maximum temperature at the flow front using the Moldflow® Adviser software is 282.4 °C, as shown in Figure 10.

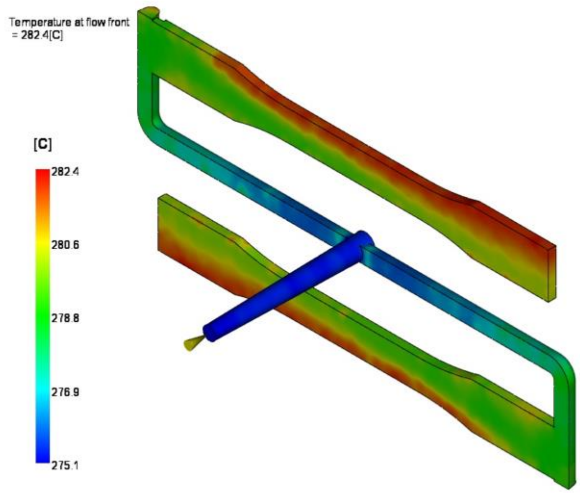


Fig. 10. Flow front temperature results using Moldflow® Adviser.
Source: Project Author.

The flow front temperature increases by 2.4 °C during the injection molding process based on the result of the Fluid Flow (Fluent®) module with Ansys® Workbench software. In the case of the Moldflow® Adviser software, the temperature of the flow front increases by 7.4 °C.

IV. DISCUSSION

The simulation considers the 3D case using the finite volume (VOF) method that allows the visualization of the volume fraction of two or more fluids (phases) throughout the domain (Abdullah et al., 2023; Galuppo et al., 2021). The computational fluid dynamic simulation (CFD) used as processability parameters values recommended by the raw material supplier corroborated concerning data available within software libraries such as Moldflow® and Moldex3D®, which confirms the availability of relevant information for multiple polymers used in the injection molding process. The meshing process of the fluid domain for computational fluid dynamics simulation (CFD) requires considerable time for its development, generally carried out through a mesh sensitivity analysis that allows evaluating the meshing qualities concerning the numerical solution of the problem for adequate computational resolution time. The simulations of the injection molding process free of mesh (Veltmaat et al., 2022) are future work with possible improvements of the proposed implementation since they show a reduction in the time dedicated to generating the simulation concerning the proposed methodology.

The injection pressure reported in this study shows an adequate error percentage concerning the injection pressure calculated employing the Moldflow® Adviser software validated through different cases in an industrial and academic environment (J. Fu & Ma, 2019; Huszar et al., 2015; Lucyshyn et al., 2021; Oliaei et al., 2016; Shen et al., 2008). The result with balanced pressure drops in the polymer injection phase for the case study with two identical cavities is as expected. When simulating case studies in which the results give a difference in pressure drop (generally, injection molds with multiple different cavities), it is desirable to balance them to avoid the possibility of incomplete filling of the injection mold cavities (Myers et al., 2023). The proposed simulation allows visualizing the injection of the polymer into the injection mold in an unbalanced manner, allowing the implementation of design alternatives that balance the filling phase before manufacturing. In the polymer injection phase, the location of the air outlets as far from the polymer inlet as possible is relevant to ensure the filling of the injection mold cavities and the elimination of air entrapment (Abdullah et al., 2023; Araújo et al., 2023). Additionally, the consideration of the behavior of the polymer through the Cross-viscosity model and the condition of the walls without slip capture the effect of viscosity concerning shear and proves to adequately represent the behavior of the non-Newtonian fluid when simulating the injection molding process.

The two-phase volume fractions show the visualization of the polymer flow front over time: the polymer that enters the injection mold and the air that remains enclosed within the mold, which must be displaced by the polymer to complete the injection phase. The finite volume (VOF) method monitors and localizes fluid-fluid contact by assigning volume fractions within the model, assigning a scalar value to each cell of the fluid domain depending on the value assigned to each fluid. For the case study, the finite volume method (VOF) presents a value of 1 for cells with only the polymer phase, 0 for cells with only the air phase, and values between 0 and 1 for cells with zones with an interface of both (Abdullah et al., 2023). The proposed simulation requires a longer resolution time than a steady-state simulation, which is the main reason for its limited use. However, the steady-state simulation only obtains the result of the injection pressure required to fill the injection mold without the possibility of visualizing the flow front of the polymer (interface zone visualization) over time (Páramo et al., 2019). For the simulation of the injection molding process in a transient state, the process is understood in detail despite the resolution time by having additional results of great interest to engineers, processors, and designers.

The results of analyzing and visualizing the polymer flow front in the injection phase show a balanced flow path from the sprue and the runners, visually confirming the equality in pressure drops. Additionally, the results of visualization of the polymer flow front make it possible to guarantee the correct sizing of the cross sections of the injection mold cavities by observing the filling of all zones of the fluid domain. In the current study, the injection phase occurs without observing zones where the polymer flow is interrupted. Otherwise, the proposed simulation would allow the identification of the zones where the flow is interrupted to modify the mold design or the polymer processability parameters and to avoid incomplete injection results. Visualization of the polymer flow front with the proposed simulation identifies zones with trapped air (zones with results of cells with interface), which suggests the opportunity to improve the design of the mold cavities or simply the addition of vents as future work (De Miranda & Nogueira, 2019; Galuppo et al., 2021).

The melted polymer temperature results show the temperature distribution during the polymer injection phase. Initially, the melted polymer (275°C) comes in contact with the walls of the injection mold at a lower temperature (75°C), initiating the cooling of the melted polymer. The proposed simulation allows checking in all areas of the fluid domain, especially in thin areas, the temperature drop of the melted polymer to prevent solidification during the injection phase, which would result in a short shot due to blockage of the injection mold with complete solidified polymer (Myers et al., 2023). The increase in the temperature of the melted polymer concerning its inlet temperature confirms that the proposed simulation captures the effect of melted polymer shear and its respective temperature increase due to friction. This scope of the simulation makes it possible to guarantee that the melted polymer does not exceed temperatures where the material can degrade, causing surface defects to appear in the injected part (Myers et al., 2023). In general, through the proposed simulation, the recommended ranges of processability (260°C-290°C) for the study material (PC+ABS) are guaranteed. Concerning the results obtained from simulation using the Moldflow® adviser software, where the reported temperature corresponds to values of the core of the melted polymer when reaching the different zones of the fluid domain, the simulation proposed in this study facilitates the visualization of the temperature of the melted polymer in the vicinity of the walls of the mold, allowing a clear understanding of the temperature distribution of the melted polymer throughout the thickness. In the current study, the maximum melted polymer temperature result using the Moldflow® Adviser software is higher than that obtained using the Ansys® workbench software, possibly by omitting heat transfer through the injection mold walls. However, the difference in the maximum temperature results of the melted polymer is minimal, attributable to the short time assumed for the injection phase, which makes the process quasi-isothermal without considerable implications on the results (Rusdi et al., 2016).

V. CONCLUSIONS

The simulation establishes a sophisticated tool capable of representing the injection phase within the injection molding process. There are some limitations to the applicability of this type of simulation on a larger scale, such as specialized software licensing costs, high computational requirements, and the necessary training of engineers involved in the injection molding process. However, increasing research, including the current study, demonstrates excellent qualitative and quantitative results through simulation that should encourage further development for its widespread use as an integral tool for designing the injection molding process, the product, and the mold from the first stages of the production process.

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