Optimization of the injection moulding process for plastics parts by using FEA

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Abstract. The paper presented the process of injection moulding for plastics with their innovative technologies and moulded plastic materials. The main goal of this research is to present a practical method for analysing the optimization parameters process of plastic injection moulding, such as filling time, melt temperature, mould temperature, maximum injection pressure, injection volume, cooling time, cycle, etc., The simulation was applied on a PC+ABS BAYBLEND T65 XF sample by using the FEA of Moldex3D Program.

1. Introduction

Plastic injection moulding (PIM) has known a large extension in the manufacturing of thermoplastics or thermoset parts from electronics to automotive, medicine to food packages. PIM are many benefits, such as infinite variety and intricate details, low per-piece cost, high output, more cost-effective than machining, and part of moulded pars besides the minimizing of cycle time at lower production costs [1].

The process is relatively simple and consists in feeding a typical material into a heated barrel and then forced in a mould cavity by a reciprocal screw when the moulded part is cooled and hardened at mould shape. The process is made under high-pressure which can alter the material used, and tools are made from steel and aluminium.

The plastic materials used in PIM can be divided into three categories thermoplastic, thermoset and elastomer, such:

- PS, PC, PVC, PET, PPO, ABS, ABS+PC, PMMA, PES (amorphous thermoplastic)
- PP, LDPE, HDPE, PA6, POM, PPA, PPS (semi-crystalline thermoplastic)
- PF (Phenolic Formaldehyde) as thermoset
- Rubber, LSR (Liquid Silicone Rubber) as an elastomer.

The technologies used in PIM and diverse and continuous in evolution with the manufacturing process to achieve maximum results and high quality at lower costs. The parts obtained by injection mould are wide-ranging, special characteristics and complex geometries that combine more innovative technologies, such as [2-5]:

- Liquid Silicon Rubber
- Multi-shot Injection
- Moulding

- Light-weighting Solutions
- Co-injection
- Clean-room Injection
- Clearmelt
- Coining
- HP-Resin Transfer Molding

There are many types of plastic injection moulding machines, which are composed of two parts, one is an injection unit and the other is a clamping unit. The injection moulding screws are designed with length to diameter ratios in the range of 15:1 to 20:1, while the moulding machines have clamping force between 150 to 4000kN.

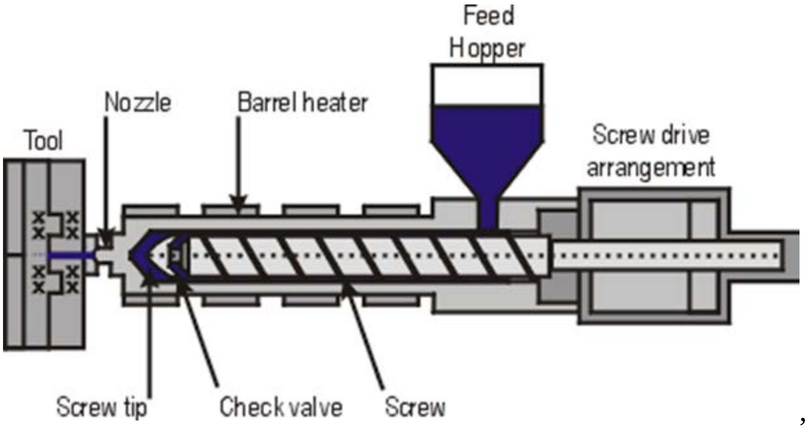

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Figure 1. Reciprocating screw injection moulding unit [3]

The calculation of basic parameters required for optimal injection moulding is necessary. The machining conditions are depended on which type of machine is used. So, the formula of these basic moulding parameters is [6]:

- Mould clamping force-F (tf):

$$F = \frac{p_i * A}{1000} \tag{1}$$

, where p_i (kgf/cm^2) is the cavity pressure inside the mould, A (cm^2) is the total projected mould area.

- Moulding shrinkage S (%):

$$S = 100\ \frac{l_c - l}{l_c} \tag{2}$$

, where l_c (mm) is mould dimension, and l (mm) is product dimension.

- Pressure loss Δp (Pa):

$$\Delta p = \frac{8 * L * \eta * Q}{\pi * R^4} \tag{3}$$

, where L (m) is length, η (cP) is viscosity, Q (m/s) is flow rate, and R (mm) is hydraulic radius.

The process of PIM is versatile and used in different applications or industries, which means much different machines types, such as:

- Fully Hydraulic IM machines for high production and higher clamping force
- All Electric IM machines for short injection time and best production cleanliness
- Hybrid IM machines for innovative mould design
- Vertical IM machines for over-moulding inserts
- Elastomer IM machines.

The main goal of this paper is to present a practical method to realize optimization of the injection moulding process applied to a sample of PC+ABS_BAYBLENDT65XF by FEA with Moldex 3D Program.

2. Optimization of PIM

Plastic injection moulding consists of some steps which are drying, mixing, melting, injection, packing, cooling and ejection, which are worked together.

The precision of moulded parts is directly influenced by machine selection, material properties and part design. There are five processing variables with real impact on injection moulding injection speed, plastic temperature, plastic pressure, cooling temperature and time. Cooling time represents a major factor in the total time cycle, which is a function of material properties, part wall thickness, mould wall temperature and melt temperature [8-10].

Production efficiency of injection moulding machine capacity time is very important and can be realized in some ways do as cycle time optimization, machine maintenance, oil maintenance, and mould chance. The optimization cycle times during an injection moulding process means resolving a few objectives:

- Cooling time optimization of mould
- Eliminate excess movement by strategically setting pause time to drop the part
- Reducing nozzle force.

Factors that affect the quality of a moulded part can be classified into four categories: part design, mould design, machine performance and processing conditions. Determination of optimal process parameters of PIM is critical for obtaining higher quality and productivity, with minimal production costs.

There are many techniques or methods used to analyse and optimise the PIM process performed in the domain of parameter setting of IM (injection moulding). These methods included specific mathematical models, Fuzzy logic, Case Base Reasoning (CBR), Finite Element Analyzing (FEA), Non-Linear Modeling, Linear Regression Analysis, Response Surface Methodology (RSM), Principal Component Analysis (PCA), and classical Taguchi method.

Taguchi method applied a special design of orthographic arrays to evaluate the all-factors space with small experiment numbers. The optimization process or product design consists of Concept Design, Parameter Design, and Tolerance Design. The method is based on the signal-to-noise (S/N) ratio instead of the average to convert the experiment result data into a characteristic size in the optimum setting analysis.

FEM is widely used in many engineering applications and allows entire designs to be constructed, refined, and optimized before the design because facilitates building the entire design, refines and optimizes before the design is manufactured. The accuracy of the critical parameter is high, allowing for to creation of virtual prototyping, a faster design cycle due to great productivity and increasing revenue.

Response Surface Method is based on the relationships between explanatory variables and one/more response variables and used statistical models as an approximation to reality.

Linear Regression Method is based on the statistical techniques for solving optimization problems, which explained the relationships between the dependent variable (y) with observed values of one/more independent variables (x1, n).

Grey Relational Analysis is based on normalized experimental data, where the Grey relational coefficient is calculated considering the correlation between the desired and actual experimental data. The conversion of multiple response process optimization problems in a single response optimization situation with objective function is possible by Grey relational grade.

Principal Component Analysis is used as a mathematical procedure to transform a few possibly correlated variables into a smaller number of uncorrelated variables, named principal components. So, the data is transformed into the new coordinate system by using an orthogonal linear transformation, where the first principal component is got by any projection of data as the greatest variance, and so on.

3. FEA of plastic injection moulding sample

The simulation has performed by Moldex 3D Viewer R16.0 software that was applied to a sample of ABS+PC BAYBLEND T65 XF with a size of 165x192x80 mm.

Moldex 3D is the world-leading CAE product for the PIM industry with excellent class analysis and technology. It allows deeply assessing the simulation and FEA for a large injection moulding process range and each to optimize product designs and machining. The simulation can determine the injection mould parameters and the proper installation for PIM.

The results of simulation and FEA for the sample are presented in the following Tables and Diagrams.

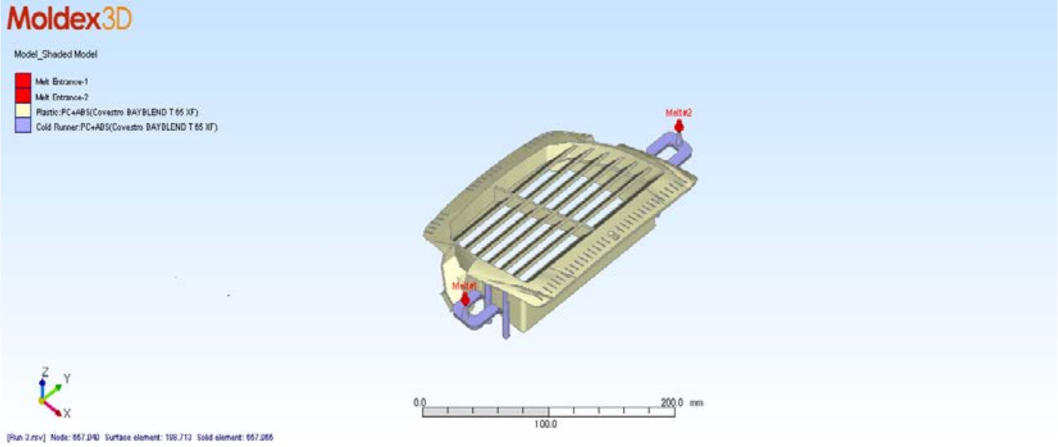

Figure 2. The 3D model of sample used for simulation

Table 1. Summary table-Mesh

Mesh Type	eDesign3
No. cooling channel	28
Part dimension	165x192x80 (mm)
Mold dimension	362x362x362 (mm)
Cavity (Part) volume	134.113 (cc)
Cold runner volume	8.70958 (cc)
Element number	657065
Part elements	657065
Node number	Node number

The injection moulding condition process of sample for simulation are presented in Table 2 and Table 3.

Table 2. Summary table-Process Conditions

Filling Time	2.50 (sec)
Melt Temperature	260.0 (ºC)
Mold Temperature	70.0 (ºC)
Maximum Injection Pressure	250.00 (MPa)
Injection Volume	142.823 (cc)
Flow rate profile Section-1	30.00 %
Flow rate profile Section-2	94.92 %
Flow rate profile Section-3	70.11 %
Maximum Packing Pressure	250.00 (MPa)
Cooling Time	18.00 (sec)
Cycle Time	40.50 (sec)
VP Switch by volume (%) filled	98.00 (%)

Table 3. Summary table-Process Conditions (continued

VP Switch by volume (%) filled	98.00 (%)
Mold Opening Time	5.00 (sec)
Ejection temperature	118.0 (ºC)
Air Temperature	25.0 (ºC)
Cooling Time	18.00 (sec)
Cycle Time	40.50 (sec)

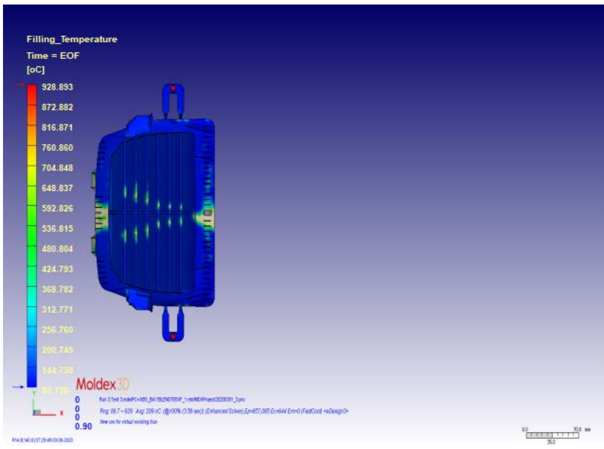

Figure 3. Filling- Temperature

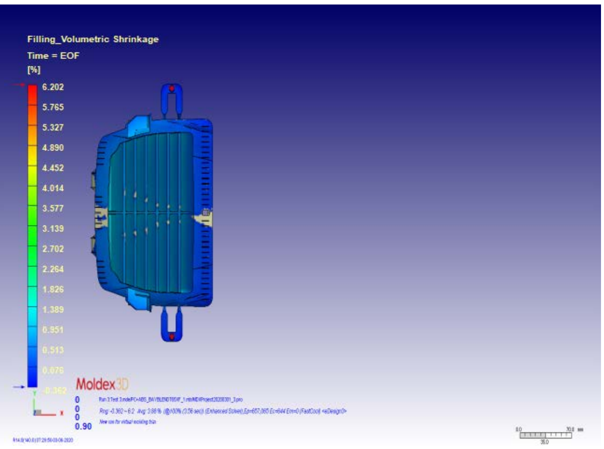

Figure 4. Filling – Volumetric Shrinkage

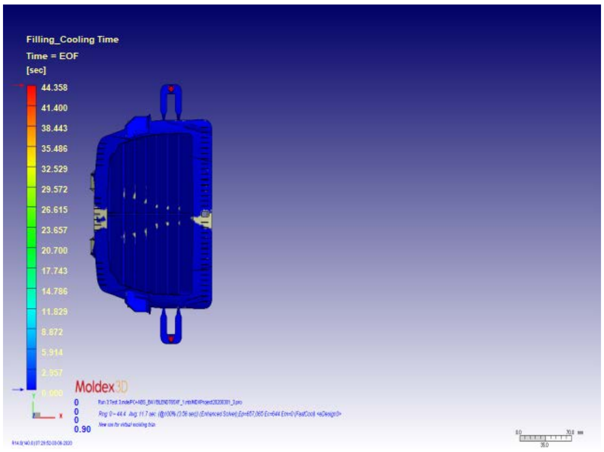

Figure 5. Filling – Cooling Time

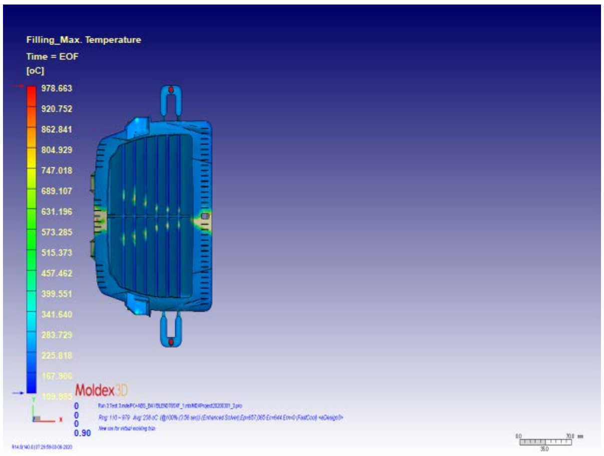

Figure 6. Filling – Max. Temperature

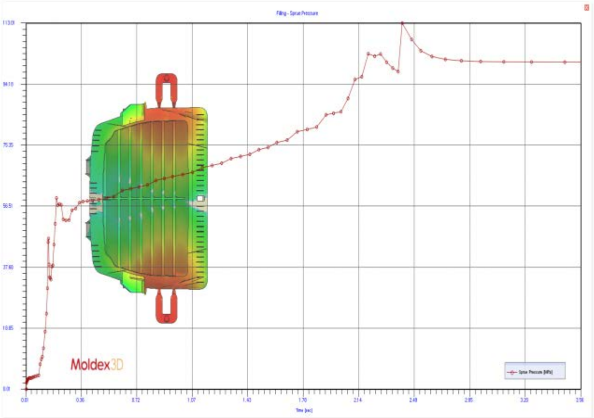

Figure 7. Filling-XY_Sprue Pressure

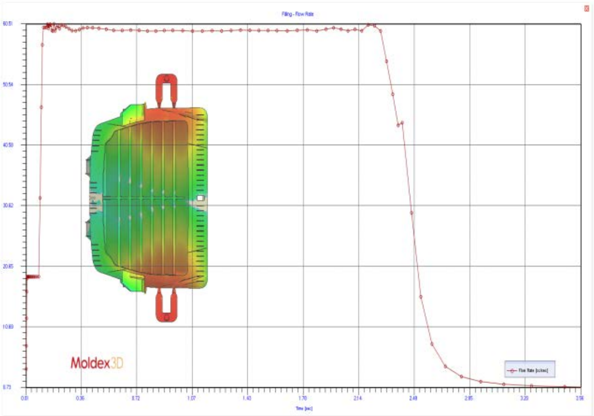

Figure 8. Filling-XY_Flow Rate

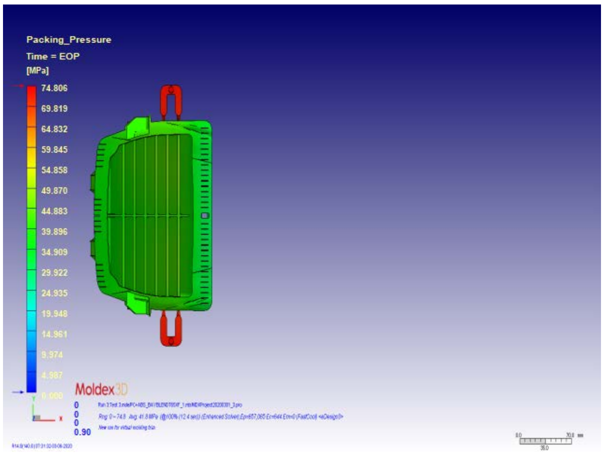

Figure 9. Packing – Pressure

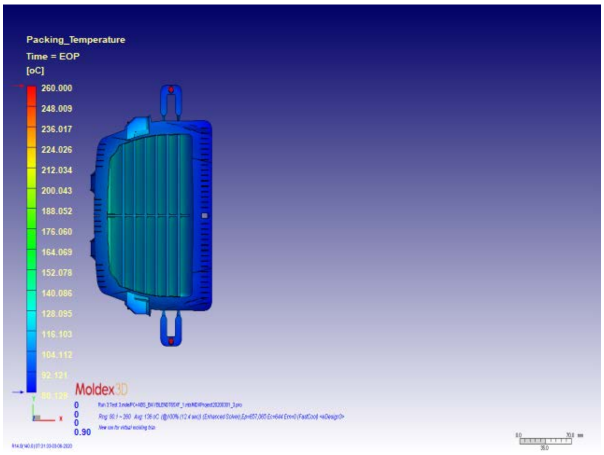

Figure 10. Packing – Temperature

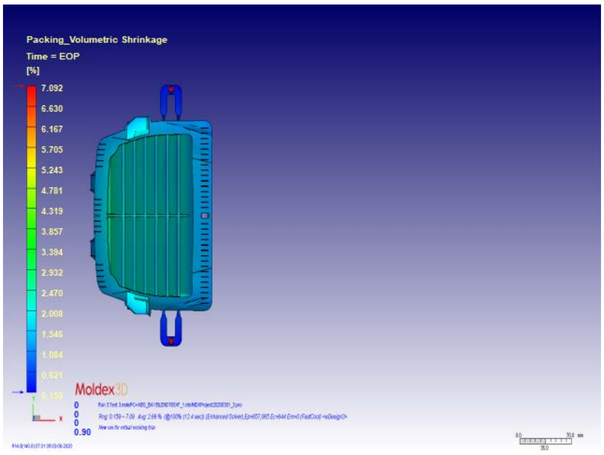

Figure 11. Packing – Volumetric Shrinkage

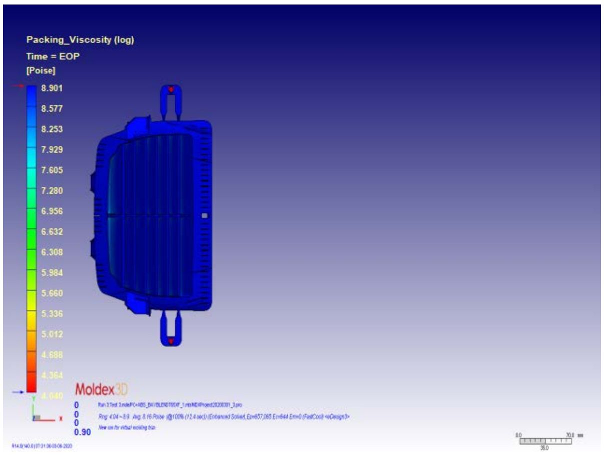

Figure 12. Packing – Viscosity (log)

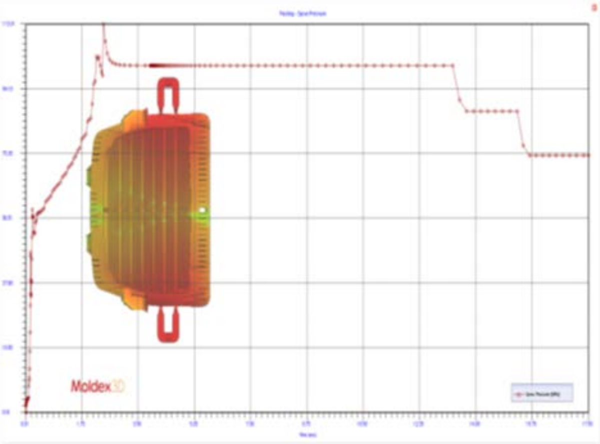

Figure 13. Packing-XY_Sprue Pressure

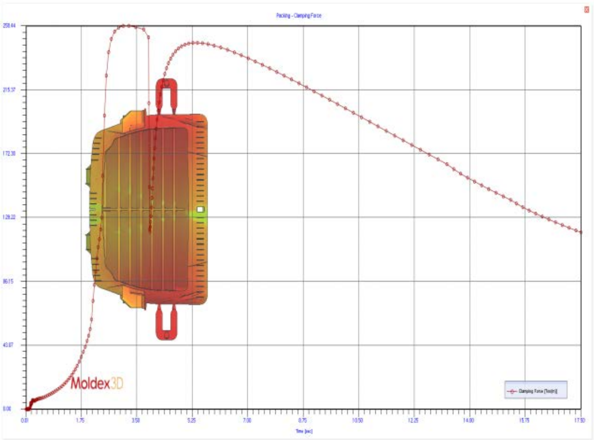

Figure 14. Packing-XY_ Flow Rate

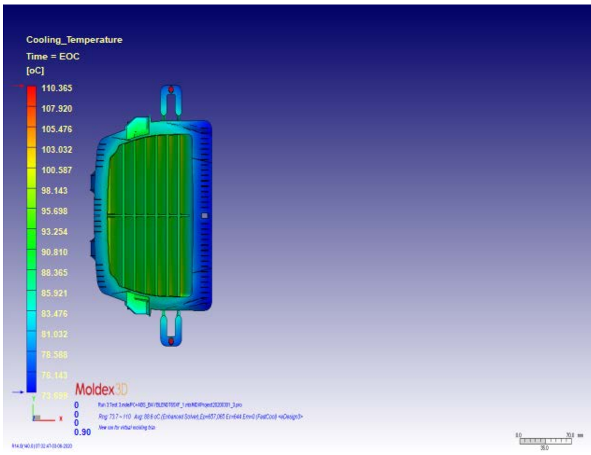

Figure 15. Cooling – Temperature

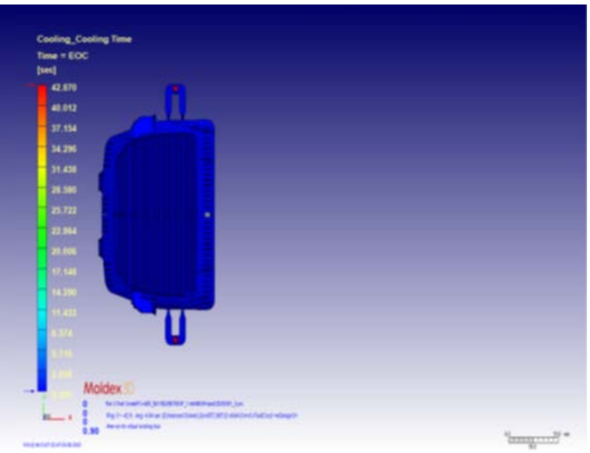

Figure 16. Cooling – Cooling Time

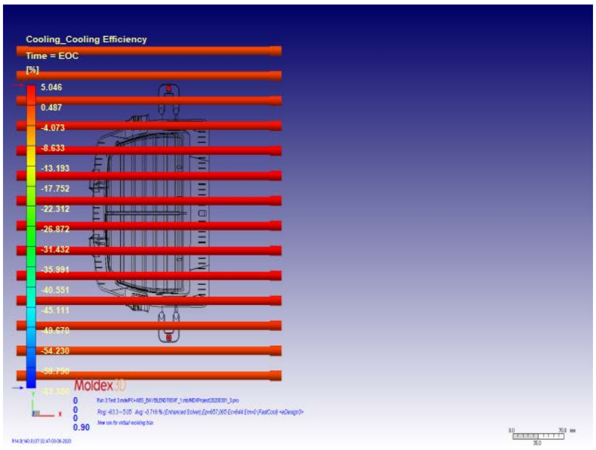

Figure 17. Cooling – Cooling Efficiency

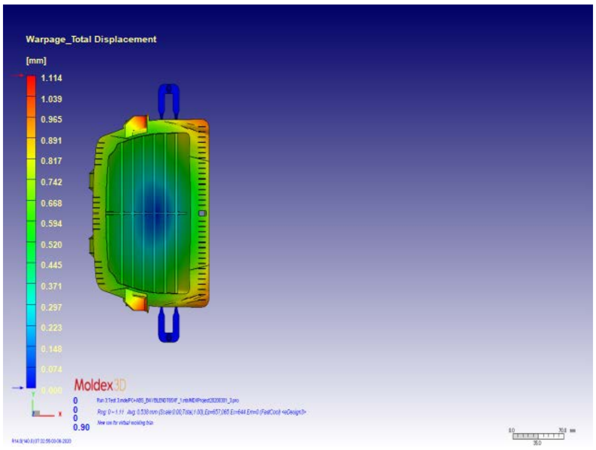

Figure 18. Warpage - Total Displacement

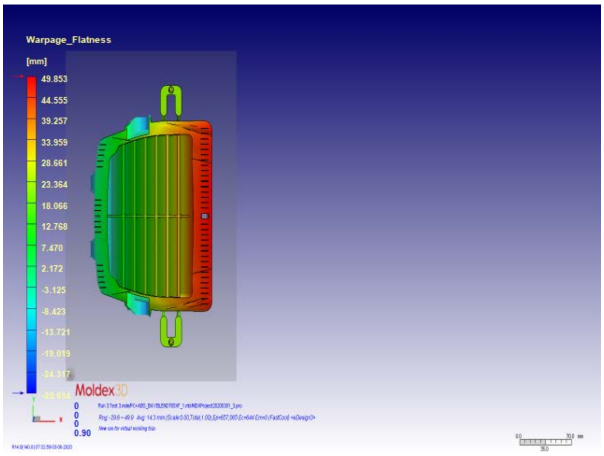

Figure 19. Warpage – Flatness

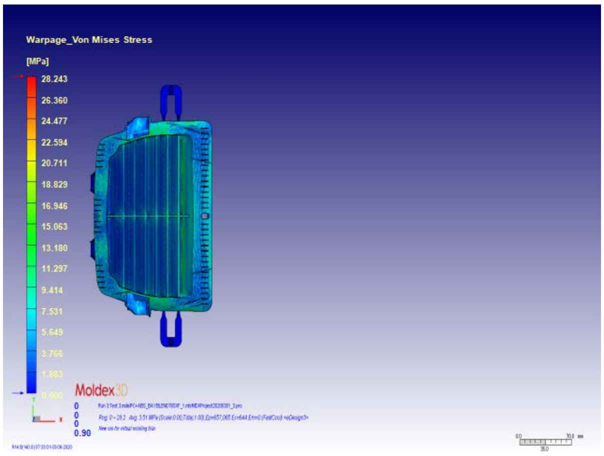

Figure 20. Warpage - Von Mises Stress

The FEA diagrams are divided into 4 steps of plastic injection moulding filling, packing, cooling and warpage, which determine the basic parameters process. These parameters are filling time, melt temperature, mould temperature, volumetric shrinkage, maximum injection pressure, injection volume, colling time and cycle time. flow rate, etc. Volumetric shrinkage is shown in the part volume change percentage due to PVT changing as the part is cooling from high pressure, high temperature to normal room temperature. A positive value means volume shrinkage, while a negative value represents volume expansion leads to over-pack. Also, non-uniform volumetric shrinkage will go to warpage and distortion of moulded parts.

Figures 3-8 are showing the simulation results for filling, where the pressure distribution of the cavity is shown in different colours at the current instant. It is based on pressure drop and distribution. In 3D calculation, the temperature distribution showed the temperatures in all three dimensional for the full cavity. Filling cooling time is analysed for computed mould cavity surface temperature and the estimated centre temperature of the sample enough to be ejected. The analysis results for Figures 9-14 for packaging, and Figures 15-20 for cooling and warpage, have a similar interpretation.

The simulation data can be a real base for optimizing the PIM and other possible mistakes in the design process or products.

4. Conclusions

The simulation with Moldex 3D for the injection process of plastics determined the main parameters process needed for the processing of the sample in function to raw plastics established, geometric part, injection moulding machine and cycle time required.

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