E.T.S. of Industrial Engineering,
Computer Science and Telecommunications

DESIGN OF A HUBCAP AND REHOLOGICAL ANALISIS OF PLASTIC MOLD INJECTION

Degree in Mechanical Engineering

Final Degree Project

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I would like to thank first of all my parents for everything they have taught me and my friends, classmates and teachers for all the patience they have had with me in recent years.

Gabriel Petrica Kodrea

SUMMARY

The objective of this project is the design of a universal 17-inch hubcap destinated for industrial manufacturing. In this document will be made the geometric design of the hubcap, and a rheological analysis of the plastic injection inside the cavity will be carried out to determine the choice of a suitable material for manufacturing.

KEY WORDS

Hubcap – decorative disk on an automobile wheel

Design – a plan or drawing produced to show the look a function of an object

Preliminary design – first drawing done

Mold – is the counterpart

Rheological analysis – analysis of a fluid's flow

Sprue bushing – hardened-steel mold components that accept an extrusion nozzle

ABS – styrene butadiene acrylonitrile

PP – polypropylene

PC – polycarbonate

Mesh – group of connectivity points that create a simulation model

Boundary conditions – conditions that has to be satisfied at all or part of the boundary

Cycle time – necessary time needed to produce one piece

SOLIDWORKS PLASTICS – simulator for analyzing plastic parts and injection molds

Draft angle – is a taper applied to a vertical wall of the mold facilitating part ejection

Filling time – time needed to fill the cavity

Pressure – forces inside the cavity

Stress – internal forces of the material

Displacements – part contractions after cooling

Clamping force – force needed to keep the

Vent pressure – eject pressure of the trapped air

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1. INTRODUCTION

Currently, the market offers a wide variety of accessories both functional and aesthetic within the automotive sector. One of the cheapest and most used accessories are the hubcaps trimming steel rims. These accessories are marketed in different sizes being the most common measures of 14, 15 and 16 inches.

Within the market of manufacture, distribution and sale of steel wheels there is a small niche of customers who, whether it is by necessity or own choice, are forced to use 17-inch steel wheels for their vehicles. In these cases, the market does not offer any model of hubcaps for 17-inch wheels creating a possibility of creating a new product.

The manufacture of the hubcaps is done by the plastic injection process, being the commonly used materials acrylonitrile butadiene styrene (ABS) and polypropylene (PP). The manufacturing process of this product is known within the industry and is easily automated.

Figure 1 Presentation design

1.1. GENERAL DESCRIPTION OF THE PROJECT

The development of this project is focused on designing a hubcap with a perspective to meet the needs of a small market niche where there is no similar product. The manufacture of the product should focus on the plastic injection process, adapting the design to the existing tools in the injection machine market.

1.2. PART DESIGN OBJECTIVES

The design of the product is mainly focused on making a hubcap that can be marketed with the function of beautifying an existing product. The product must be functional (offering enough strength and grip properties within the environment of use), aesthetic (improving the overall appearance of the vehicle and rims), economic (being able to be competitive within the market) and have the minimum environmental impact.

2.3. MOLD OBJECTIVES

The mold design has to meet the following specifications:

- Cavity – contain the negative shape of the finished product plus increased concentration
- Size – have a suitable size for the injection machine
- Anchors – being able to anchor to the mold holder of the injection machine
- Cooling – Being able to properly cool the part and improve the injection cycle
- Material – make the mold with the right material
- Thermal conductivity – Having the proper thermal conductivity

2.4. SIMULATION OBJECTIVES

One of the most important factors when designing a product is the choice of material or materials that will be used in its manufacture. The material will be very important in terms of production costs, product properties or environmental impact.

In the injection of plastics, a wide variety of commercial materials from different manufacturers worldwide are used, being one of the pioneers in the sector, the plastics distribution company *DSM Engineering Materials.*

The main objective of the simulation is to perform a rheological analysis of three of the materials available in the DSM *Engineering Materials* commercial database and that are updated in the *Solidworks Plastics Premium program.*

From the *Solidworks Plastics Premium* program database, the following test materials are chosen from the material groups of acrylonitrile butadiene styrene (ABS), polypropylene (PP), and polycarbonate (PC):

- *RONFALIN FF-50 - acrylonitrile butadiene styrene (ABS)*
- *PP412 MN 40 - polypropylene (PP)*
- *XANTAR 18 R - polycarbonate (PC)*

These three materials will be the basis of simulation of the rheological study with the aim of obtaining the main parameters of injection, packaging and deformation of the designed part and comparing them in order to choose a commercial injector capable of manufacturing the piece.

2. STATE OF ART AND CONTEXT OF PLASTIC INJECTION MOLDING

2.1. WHAT IS PLASTIC INJECTION?

Plastic injection is the non-continuous process by which die-cast plastic is introduced into a mold in order to extract a subsequently cooled and solidified part. The versatility of this process offers a wide range of production possibilities for parts of various shapes and sizes. Generally, the characteristics of the parts produced will depend on the characteristics of the material to be used.

2.2. HISTORY OF PLASTIC INJECTION MOLDING

Until 1872 the demand for the manufacture of billiard balls was covered by elephant ivories, and about 12,000 animals were slaughtered per year to meet the demand. That's when Mr. John Wesley Hyatt invents a machine to make billiard balls using a plastic injection process. This advance is due to the research carried out by John Wesley Hyatt two years earlier when he patented the most advanced material of the time, celluloid.

However, it is not until the 1940s that James Watson Hendry develops an injection machine that uses Archimedes' trunk to inject the hot material into a mold. This advance allowed injection machines to better control the injection of plastics into molds and obtain more consistent results.

In the 1960s and 1970s the definitive extension of plastic in all sectors occurs, and polycarbonate reaches the moon in 1969. It is from this moment that the use of plastic materials extends massively to the automotive sector and later to other sectors until today.

2.3. IMPORTANCE OF PLASTICS IN INDUSTRY

The plastics industry plays a key role in the development, evolution and recovery of the European Union's economy. Together, raw material producers, plastic converters, plastics recyclers and machine builders constitute a value chain that provides jobs for 1.5 million people across Europe in more than 55,000 companies, mainly SMEs belonging to European countries.

The importance of the plastics industry sector is reflected by the following key figures:

- Jobs – 1.5 million jobs
- Turnover - 350,000 million euros
- Companies – 55,000 European companies
- Trade balance - 13,000 million euros
- Public finances - €30 billion
- Value added – 7th position in the value-added sector
- Recycling – 9.4 million tons

Global plastics production has skyrocketed over the past 50 years, and especially in recent decades. In fact, in the last ten years we have produced more plastic than in all of human history.

According to data from STATISTA.COM in 2020 a total of 55 million tons of plastic have been produced in Europe and in the world a total of 367 million tons, with the largest producer of plastics being the Asian giant, China, with about 30% of global production.

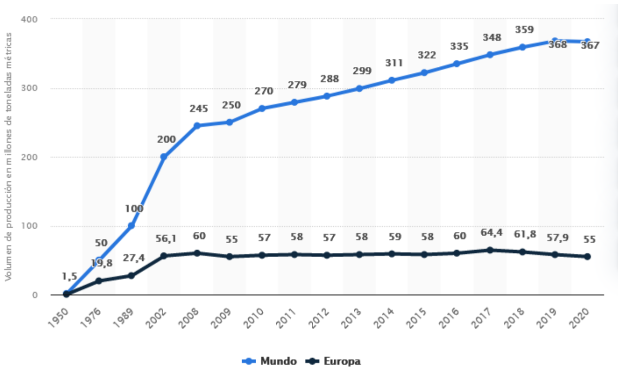


Figure 2 Evolution of plastic consumption in Europe and all over the world

The following graphs show the economic contribution of plastics within the European Union and also the scale of consumers. The trade balance of exports and imports in the European Union reached 7.5 billion euros, and plastic processing a total of 5.6 billion euros. The largest consumers are Germany, Italy, France, Spain, the United Kingdom and Poland.

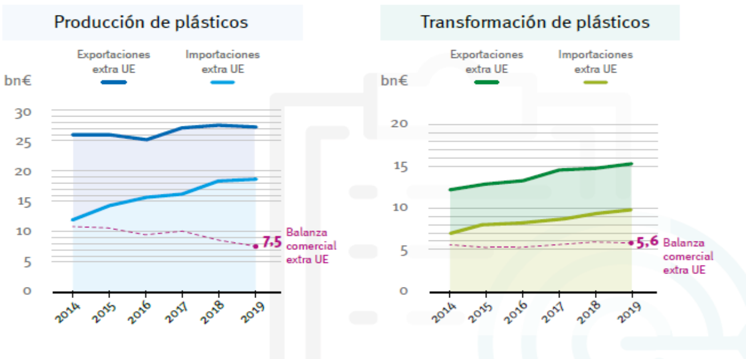


Figure 3 Plastic Import and Export in Europe of produced plastics and recycled plastics

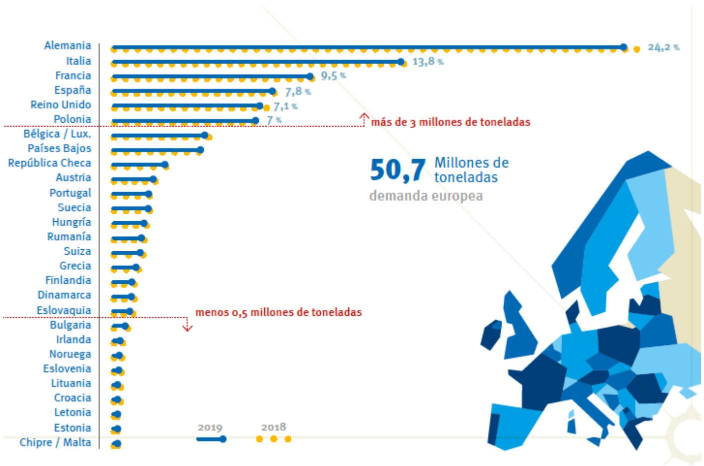


Figure 4 Scale of plastic consumption into the UE

Although at European level the production of plastics remains constant, the global trend is the considerable increase in the production of plastics due to the development of underdeveloped countries that request an increase in these products. The following graph shows the consumption of plastics according to the different sectors.

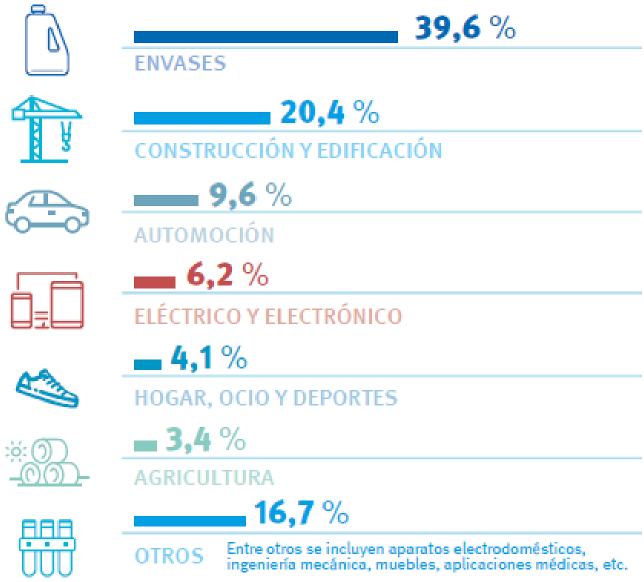


Figure 5 Plastic consumption for each sector of industries

(Packaging, Construction, Automation, Electronics, Agriculture, others..)

The following graph represents the consumption of plastics according to the type of material.

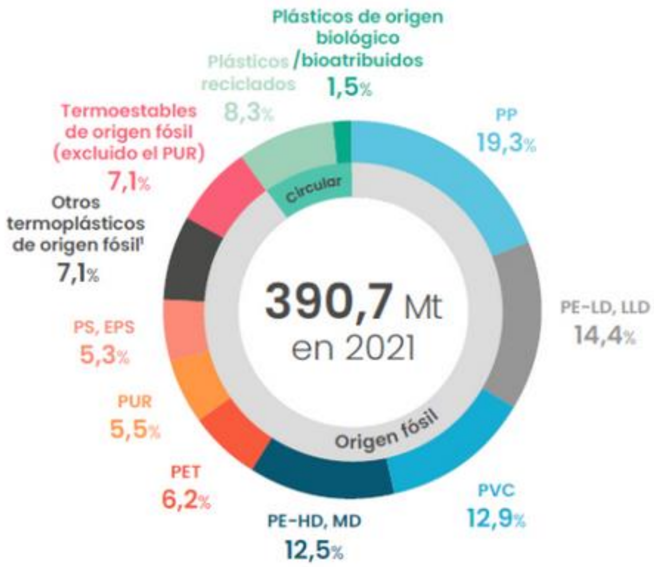


Figure 6 Percent of plastic consumption by type of plastic (biological plastics,

PP, PE-LD, PVC, PE-HD, PET, PUR, PS, TERMOPLASTICS, RECYCLED)

2.4. METHODOLOGY OF PLASTIC INJECTION

Similar to other molding processes, the process consists of melting the material and then introducing it into a mold with the shape of the negative of the piece so that when solidifying it adopts the desired shape. During this process the material previously plasticized and raised to the molding temperature is introduced into the mold through a laminar flow at high pressure and speed where a heat transfer process occurs to the point of solidification and subsequently the expulsion temperature. The process consists of the following stages:

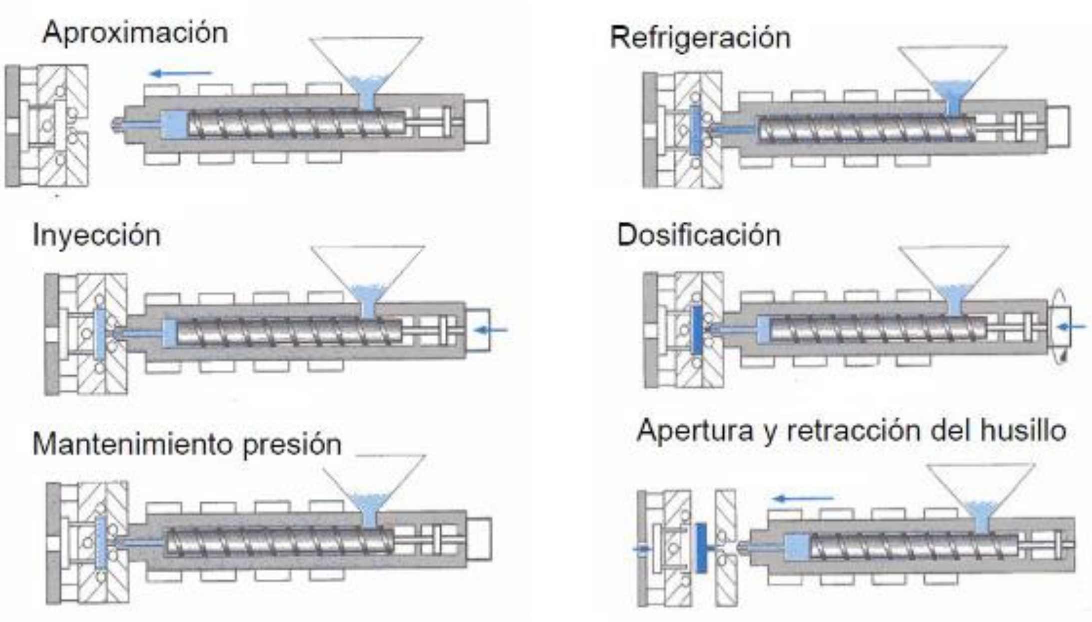


Figure 7 Main steps for plastic injection (Nozzle approximation to sprue brushing, Injection, Packing, Refrigeration, Dosage, Mold opening)

2.4.1. USE OF MATERIAL

The material is introduced into the hopper of the injection machine after a previous heat treatment and drying. The electrical resistances of the injection machine and the pressure exerted by the spindle generate an increase in the temperature of the material to the point of reaching the melting temperature and then the temperature at which the fluid is to be injected.

The material in liquid state can be injected into the mold only after it has reached the crystalline melting temperature. The crystalline melting temperature or *Tm* is the temperature, or small temperature range, in which crystals disappear into a semi-crystalline polymer and this rapidly passes from semi-crystalline solid to very viscous liquid.

2.4.2. DOSING OR INJECTION OF MATERIAL

In the filling phase the molten plastic is pushed by the spindle into the mold where it will occupy the gaps of the cavities that are found. This phase is the dynamic phase of the injection where the injection rate and the limit pressure or threshold are programmed. These parameters will depend mainly on the characteristics of the material to be injected and the design of the part.

2.4.4. PACKING

In the packing phase, the material that has filled the cavity receives a pressure from the spindle that forces the material to reduce its specific volume and increase its density within the cavity by the action of the pressure exerted by the spindle. When the plastic material flow has completed the cavity, any attempt to continue filling the mold with flow would cause an increase in pressure at all points of the mold.

In this second phase of packing, the maintenance pressure or second pressure must be programmed and the time necessary to maintain the pressure without unnecessarily lengthening the packing time obtaining an acceptable dimensional quality.

2.4.5. REFRIGERATION

The cooling phase during the plastic injection molding process is important to be able to extract the finished part from the mold and ensure a good surface finish. Cooling is a complex process that requires ducts inside the mold that ensure a constant cooling temperature to avoid internal stresses within the material or surface imperfections.

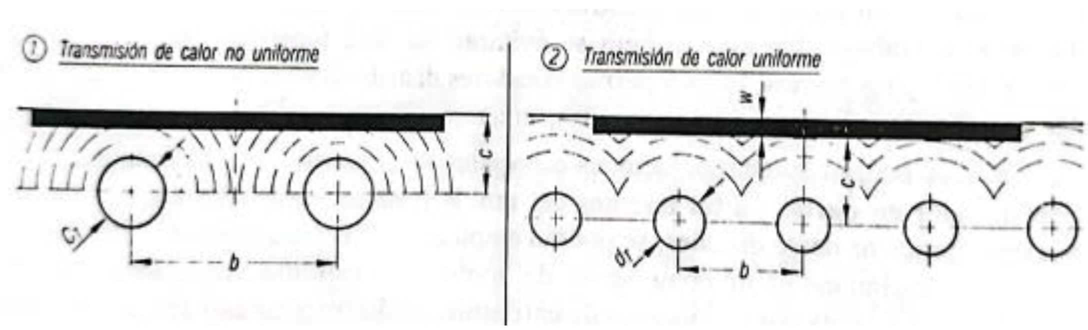


Figure 8 Refrigeration channels (1. Uniform transmission 2. Non-Uniform transmition)

2.4.6. MOULD OPENING AND CLOSING

The mold opening and closing phase is carried out at the end and beginning of injection of each piece. During this phase the part ready to be removed is ejected from the mold mechanically.

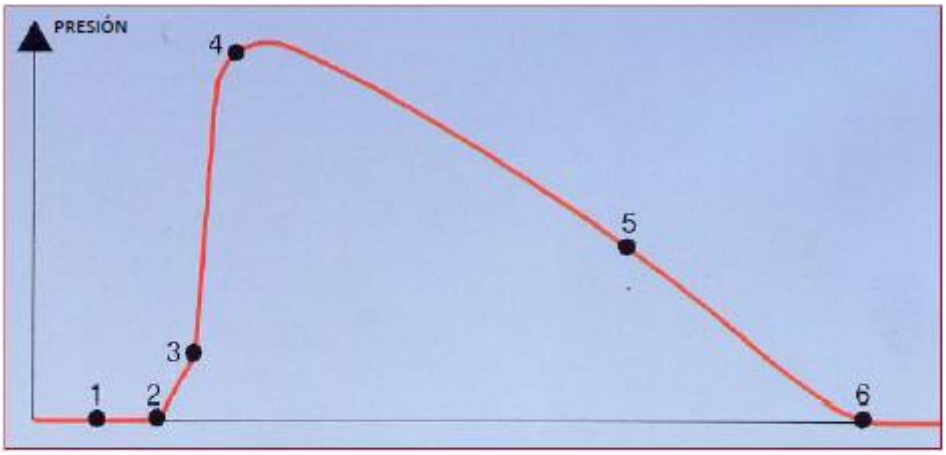


Figure 9 Pressure inside the mold along the injection cycle

- 1-3: Injection phase.
- 3-4: Compression.
- 4-5: Maintenance of pressure.

- 5-6: Cooling

2.4.7. PLASTIC INJECTION CYCLE

The injection cycle in a conventional machine is usually constituted by the following times and movements:

- Mold closing time, during which the closing system acts, the machine executes the necessary movement and closes the mold.
- Advance time of the injection unit. During this time the injection unit, which until then is separated from the mold, advances until the nozzle rests on the mold drinker (entry point to the mold).
- Filling or injection time, in which the piston or spindle advances performing the injection of the material.
- Compaction time (or molding or holding time), during which the mold remains closed and the polymer begins to cool in the mold.
- Recoil time of the injection unit. When the entrance to the cavity solidifies the injection unit goes back and begins the rotary movement of the spindle to plasticize the material for the next stage, simultaneous with the cooling phase, opening the mold and extraction of the part and thus accelerating the total cycle time.
- Cooling time, necessary to cool the polymer that occupies the cavities of the mold.
- Mold opening time, during which the mold is opened. This time is approximately constant for each machine.

- Part extraction time, during which the molded parts are removed from the molding cavities.

- Time with the mold open, which is usually very short, but which can sometimes be considerable, for example, when metal inserts need to be placed in the mold.

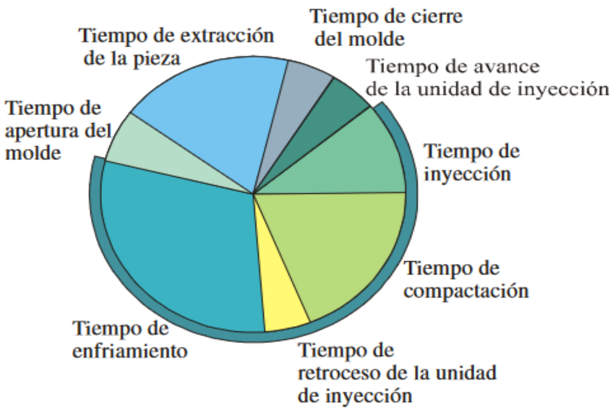


Figure 10 Injection cycle (mold closing time, Nozzle approximation, Injection time, Packing time, Dosage time, Cooling time, Opening mold time and Part ejection time)

2.4.8. FEEDING SYSTEM

The feed system is the part of the mold responsible for moving the molten plastic from the injection unit to the mold cavity. It consists of three parts: drinker, feeding channels and injection inlet.

The design of the feed system will depend on several factors related to the geometry of the part, the material, the number of mold parts, the type of process (degree of automation), etc. The aim is a correct filling of the cavity, minimizing waste, and reducing as much as possible the surface visual impact.

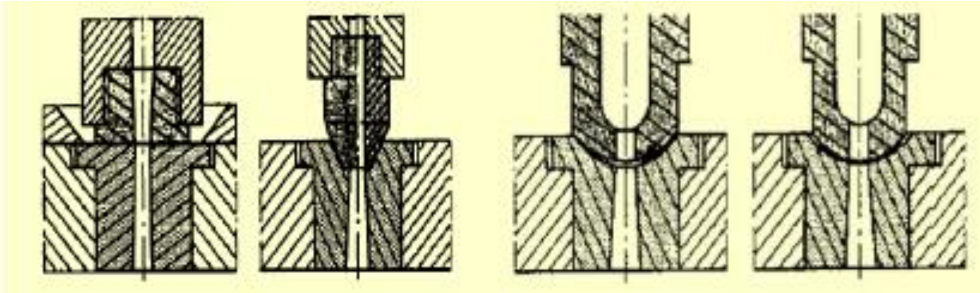


Figure 11 Types of Sprue bushings and Nozzles

2.4.9. SPRUE BUSHING

The injection sprue bushing is a truncated conical hole that is usually made in the fixed plate of the mold and that allows the passage of the flow of material from the nozzle of the injection machine to the channels and cavities of the mold, when closing the machine.

The sprue bushing drill is conical in shape, with the largest diameter being towards the side of the mold cavity. The smallest diameter of the sprue bushing should be somewhat larger than the diameter of the nozzle.

The length of the sprue bushing must be as short as possible, but it must reach the partition line of the mold. In most cases, a length/diameter ratio between 5 and 9 is correct.

Figure 12 Sprue Bushing

2.4.10. INJECTION INLET

The injection inlet is the hole through which the melted plastic enters the mold cavity. The main design objective of this element is to provide a uniform and continuous flow front that ensures the filling of the mold with the highest possible final quality of the part.

To choose the injection site, the following aspects must be considered:

- Allow for easy flow
- Originate a continuous flow front
- Place it on the thickest walls
- Reduce welding lines
- Similar flow lengths

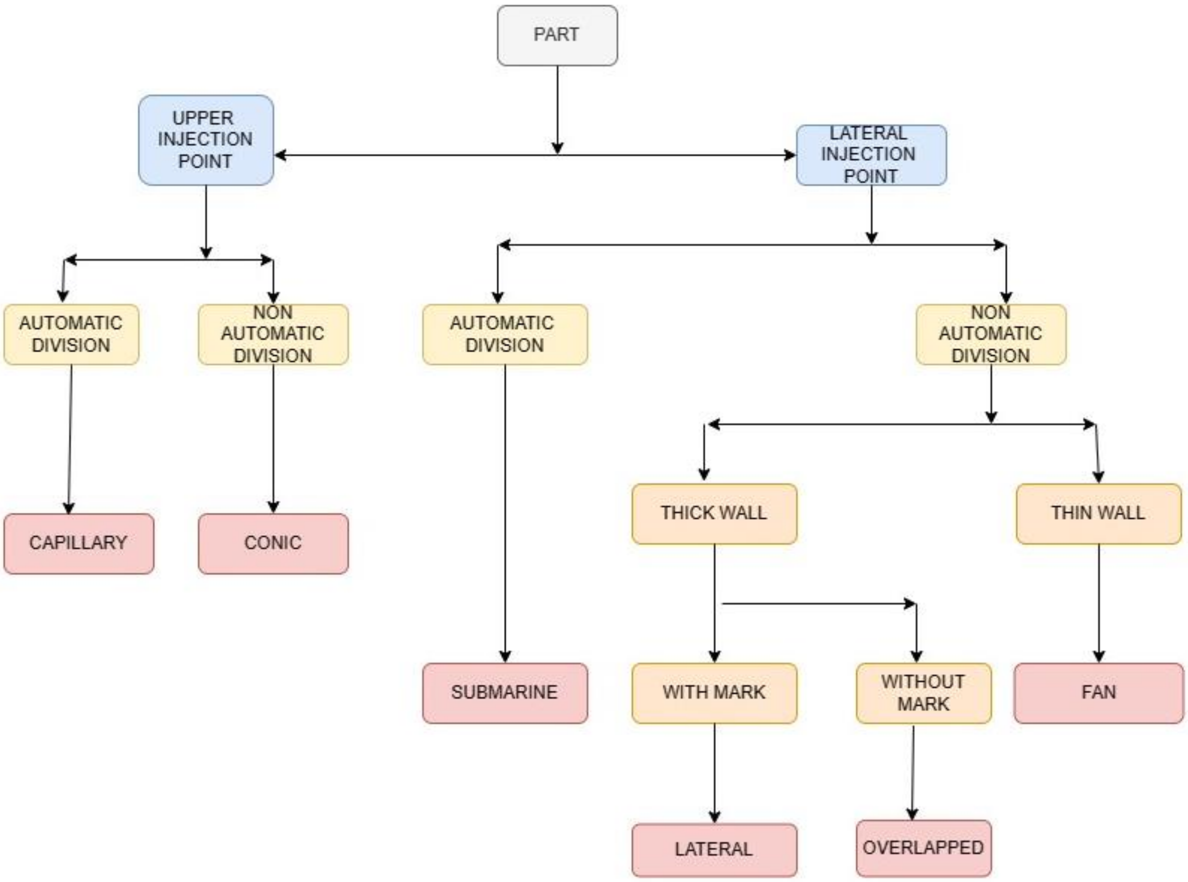


Figure 13 Types of plastic injection

2.4.11. EXPULSION SYSTEM

Once the piece has reached the ejection temperature, the mold opens, leaving the piece adhered to the moving part. The ejection system is responsible for separating the piece from the moving part taking advantage of the opening stroke of the mold. Once removed, the part is dropped (for example, to a conveyor belt) or removed manually or by a robot (usually if it is large or delicate parts). They are the elements that contact the piece and push it out of the mold. The most suitable type of ejector will depend on the geometry of the part. They can be:

- Tubular
- Solid or laminar
- Ejector plates

2.5. MOULDS

A mold consists of at least two halves, one half positive and one negative, which together form the molding cavity. These halves are joined by pressure when the mold is closed, touching each other on a flat surface that is often called the mold partition plane. When you render a section of the mold, the parting surface in the drawing can be reduced to a single line called the partition line.

The partition plane is perpendicular to the direction in which the closing force acts. Cross-sectional area of cavities or "projected area of cavities “is the projection of molding cavities onto the partition plane. The product of the pressure of the polymer inside the cavity by the cross-sectional area of the cavity will be equal to the force that tends to separate the two halves of the mold.

The cross-sectional area of the part depends on the position in which the molding cavity is placed in the mold. Sometimes molds are used in three parts. In these the feed channels and molding cavities are in different planes.

The molds in three parts are more expensive, although they have the advantage that the filling of the cavities can be more symmetrical and the pieces obtained have better quality.

As the polymer fills the closed mold, the air that was filling the molding cavity must be evacuated. Usually, this air escapes through the partition line of the mold or through the clearance that remains between the mold and the extractor nipples.

When this is not possible the mold must have a series of small holes, generally made along the partition plane that allow the evacuation of the air, but not of the molten polymer (with a diameter close to 0.025 mm).

In injection molds it is very important that the temperature of the part is as uniform as possible during cooling. Therefore, the mold contains a series of cooling channels through which the cooling liquid, usually water, circulates. These channels must be designed so that they allow cooling of the part at an adequate rate and in a uniform manner.

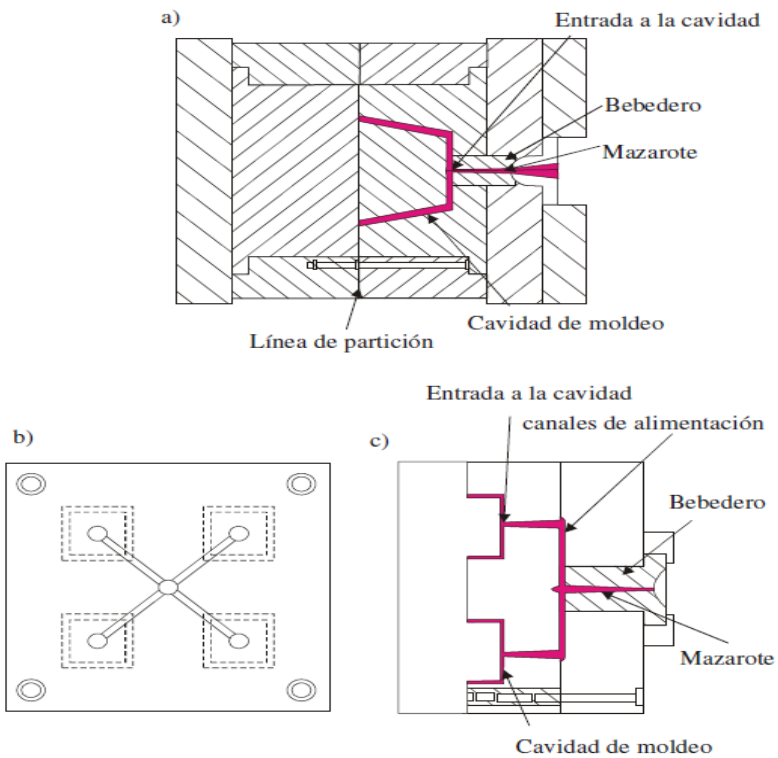


Figure 14 Generic mold example

2.7. INJECTION TECHNIQUES

2.7.1. INJECTION OF MULTIPLE MATERIALS

The injection of several different materials into the same molding cavity, or "sandwich" injection, consists of injecting through a single sprue bushing two different materials that come from two different injection units. Through this procedure, parts can be obtained in which the material of the surface layer has a special finish, while the core material accepts reinforced materials, of lower density (foams) or lower quality or price, to achieve a more rigid, lighter or more economical structure.

Through this technique, excellent finishes are obtained, with total distinction between core and leather, and diversity of textures and touches. On the other hand, both machines and moulds are relatively expensive and a very precise adjustment of the operating conditions is necessary.

The molding operation in the case of using two materials is carried out, initially the mold is closed with the two injection units (A and B) loaded with material, and both screws in the delayed position. The material pass switching valve in the closed position for both circuits.

The fundamental problem is the proper dosage of each of the materials, as well as the fluidity and filling pressures, since turbulent flow must be avoided to prevent the materials from mixing improperly.

2.7.2. INJECTION OF THERMOSETS

Injection technology has been extended to thermoset molding. Although the fundamentals of the technique are the same as for thermoplastics, the injection of thermosets requires a series of modifications in the cycles and equipment comparing to the molding of thermoplastics.

Thermosets start crosslinking at relatively low temperatures. When increasing the temperature there is initially a decrease in the viscosity of these compounds, and a subsequent increase in it as a result of the crosslinking process. The initial viscosity decrease must occur in the plasticizing cylinder, which is usually between 60 and 120 ºC, where the material acquires sufficient fluidity to be transported to the mold. The mold is at much higher temperatures, between 150-180 ºC, and it is there that the material lattices and acquires a certain shape. Temperature control, therefore, must be much more precise than in thermoplastic molding.

Thermoset injection resin formulations are specially designed to crosslink slowly at cylinder temperature and quickly at mold temperature. In the case of thermoset molding, higher injection pressures will be needed, both for material compaction and mold filling. Therefore, thermoset injection machines must have high closing forces.

Finally, on many occasions, as a result of crosslinking reactions, some volatile is released, so the molds must be properly designed and contain vents.

2.7.3 GAS ASSISTED INJECTION

The gas-assisted injection process is used to obtain injected parts with hollow parts inside. It could be said that it is a modality of the injection of multiple materials, in this case polymer and gas. It consists of a partial or sometimes complete filling of the cavity with a conventional polymer, followed by the pressure injection of an inert gas inside. This gas, usually nitrogen, pushes the molten thermoplastic material until the cavity is full, so that the inside of the part is hollow.

The gas is introduced through the nozzle of the machine or with some other device directly inside the part. In any case, the gas will advance through the central part of the piece, which is still molten (or lower viscosity than the bark or skin).

2.8. PLASTIC INJECTION SIMULATION TECHNIQUES

The main plastic injection simulation programs are expanded in section "**5. SIMULATION PROCESS**"

2.9. LATEST TRENDS IN PLASTIC INJECTION

Currently in the year 2023 and with a perspective for the coming years, the following topics are being developed in the field of plastic injection:

- *Sustainability and recycled materials: The plastics* industry is focused on providing solutions to reduce the environmental impact of the production of plastics.

- *Additive mold manufacturing:* 3D printing technology is increasingly being used for the production of plastic injection molds.

- *Automation and digitalization: An increase* in the automation of plastic injection production processes is expected to increase the performance and efficiency of material consumption.

- *Innovation in materials:* new plastic materials with improved properties are constantly being developed, such as greater resistance, greater rigidity, better thermal resistance, etc ...

3. PRODUCT DESIGN

3.1. DESIGN PROCESS.

The next diagram defines de steps that a designer has to follow to achieve a product that could be realized to the market.

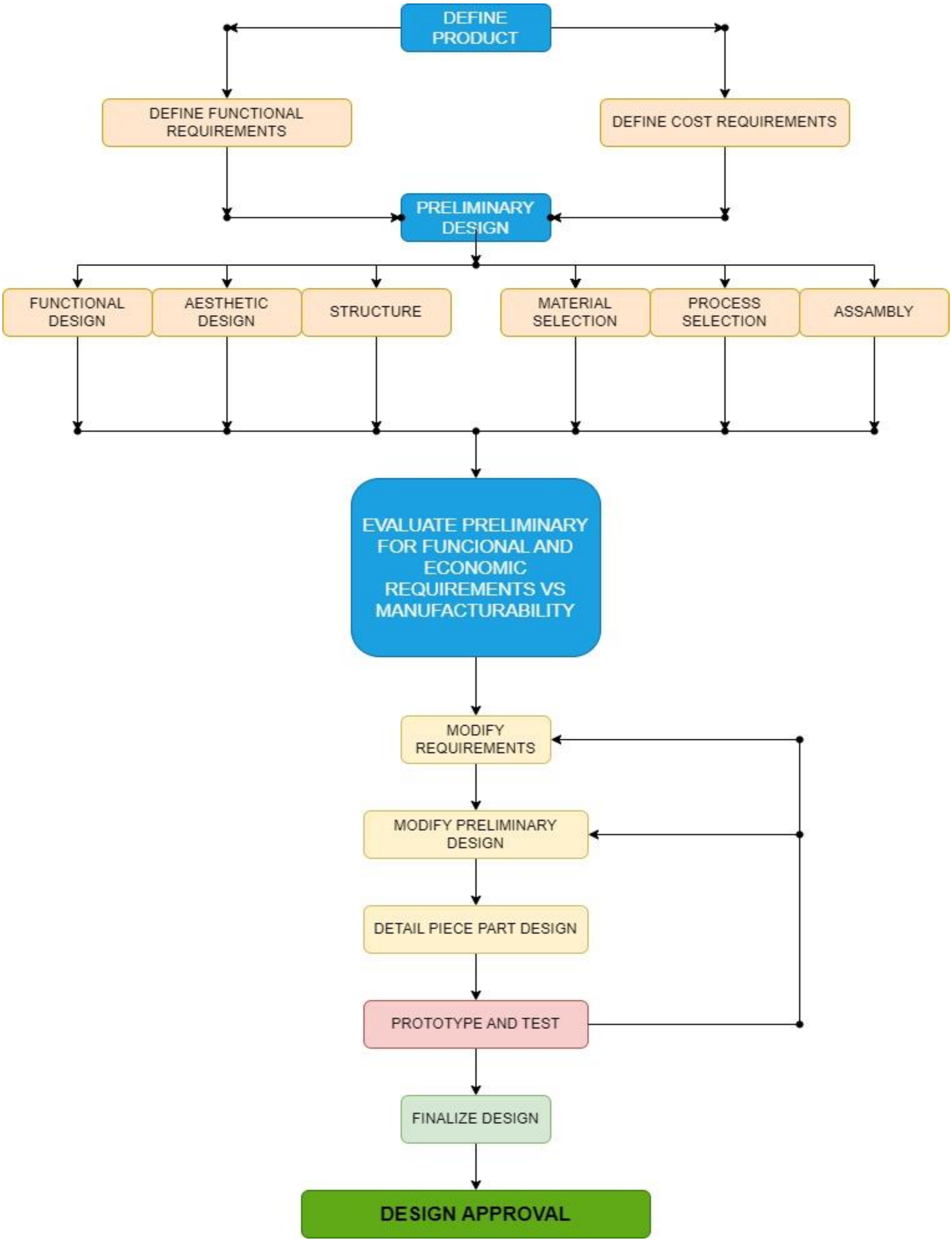


Figure 15 Design process

3.2. DESIGN CHECK LIST

The following lists are a compilation of the most important data that define the product to be designed. They are a reminder for designers when defining the product. This data should be expanded as the design is developed.

Table 1 Physical requirements

Physical requirements	
Length	***431.8 mm***
Width	***3 to 5 mm***
Height	***431.8 mm***
Volumetric Capacity	***350 to 500 cm^3***
Must fit with	***WHEEL***
Critical dimensions	***R17***
Max/Min Weight	***350-550 gr***
Max/Min density	***0.8-1.2 gr/cm^2***
Tight Tolerances	***IT11***

Table 2 General requirements

General requirements	
Life expectancy	***5 YEARS***
Available	***YES***
Quantity required	***UNITS 400,000***
Target factory cost	***-***
Material	***POLYMER***

Process	***INJECTION***
Patents	***YES***
Flammability	***LOW***
Labels	***NO***
Safety hazards/ warning	***YES***
Product for export	***YES***

Table 3 Appearance Requirements

Appearance requirements	
Industrial design	***YES***
Aesthetic	***NO***
Human engineering	***NO***
Match existing product line	***NO***
Transparent	***NO***
Color	***YES***
Inside surface finish SPE-SPI	***UNKNOWN***
Outside surface finish SPE-SPI	***UNKNOWN***
Texture	***NO***
Plated/metallized	***NO***
Painting	***YES***
Hot stamping	***NO***
Parting line	***NO***
Pinch off	***NO***
Trim	***NO***

Gate location	***NO***
Ejector location	***YES***

Table 4 Mechanical requirements

Mechanical requirements		
Tensile Loading	*Load*	***NO***
	Type	***-***
	Duration	***-***
Flexural Loading	*Load*	***YES***
	Type	***UNKNOWN***
	Duration	***LIFE LONG***
Stiffness (Flexural modulus)	***YES***	
Compressive loading	***UNKNOWN***	
Creep (maximum allowable)	***UNKNOWN***	
Deflection, maximum allowable	***UNKNOWN***	
Impact strength	*Room temperature*	***YES***
	High temperature	***NO***
	Low temperature	***YES***
Shear strength	***NO***	
Hardness	***YES***	
Abrasion resistance	***YES***	

Table 5 Environmental requirements

Environmental requirements		
Operating temperature	*Maximum*	***45 ^oC***
	Minimum	***-20 ^oC***
	Duration	***LIFE LONG***

Thermal expansion	***NO***	
Chemical resistance	*Continuous contact*	***YES***
	Intermittent contact	***YES***
	Occasional contact	***YES***
Outdoor exposure	***YES***	
Painting system	*Solvent attach*	**-**
	Oven temperature	***YES***
	Steam permeability	**-**

Table 6 Electrical Requirements

Electrical requirements	
Volume resistivity	***NO***
Surface resistivity	***NO***
Dielectric constant	***NO***
Dissipation factor	***NO***
Dielectric loss	***NO***
Arc resistance	***NO***
Electrically conductive	***NO***
Transparent to microwaves	***NO***
EMI/RFI shielding	***NO***

Table 7 Regulatory agency approvals required

<table>
<tr><th colspan="3">Regulatory agency approvals required</th></tr>
<tr><td>Food and Drug Administration (FDA)</td><td colspan="2">NO</td></tr>
<tr><td>National Sanitation Foundation (NSF)</td><td colspan="2">NO</td></tr>
<tr><td rowspan="3">Underwriters Laboratories (UL)</td><td>Flammability rating (UL-94)</td><td>YES</td></tr>
<tr><td>Temperature index (UL-746)</td><td>YES</td></tr>
<tr><td>Other</td><td>UNKNOWN</td></tr>
<tr><td>American Society of Testing and Materials (ASTM)</td><td colspan="2">YES</td></tr>
<tr><td>U.S. Pharmacopeia (UPS)</td><td colspan="2">NO</td></tr>
<tr><td>Occupational Safety and Health Administration (OSHA)</td><td colspan="2">YES</td></tr>
<tr><td>American National Standards Institute (ANSI)</td><td colspan="2">YES</td></tr>
<tr><td>Department of Transportation (DOT)</td><td colspan="2">YES</td></tr>
<tr><td>Society of Automotive Engineers (SAE)</td><td colspan="2">YES</td></tr>
<tr><td>National Electrical Manufacturers Association (NEMA)</td><td colspan="2">NO</td></tr>
<tr><td>State or local building codes</td><td colspan="2">NO</td></tr>
<tr><td>Federal Communication Commission (FCC)</td><td colspan="2">NO</td></tr>
<tr><td>Military specifications</td><td colspan="2">NO</td></tr>
</table>

Others	***UNKNOWN***	
Export or foreign	*Canadian Standards Association (CSA)*	***YES***
	International Standards Organization (ISO)	***YES***
	Others	***UNKNOWN***

Table 8 Assembly requirements

Assembly requirements		
To be assembled to	***WHEEL***	
Assembly to be	*Permanent*	***NO***
	Serviceable	***YES***
	Leakproof	***NO***
Type of assembly required	*Mechanical (screw or inserts)*	***NO***
	Mechanical (press or snap fit)	***YES***
	Adhesive	***NO***
	Solvent	***NO***
	Heat Sealing	***NO***
	Electromagnetic bonding	***NO***

	Molded threads or fasteners	***NO***
	Flexibility in design of mating part	***YES***
Special fixture required	***NO***	
Machining required	***NO***	
Special tests	***YES***	

Table 9 Special designs features

Special Designs Features	
Bearing (low friction) surface	***NO***
Sterilizable (ETO, radiation, steam)	***NO***
Integral hinge	***NO***
Threads	***NO***
Undercuts	***NO***
Insert molding	***NO***
Two or more colors	***NO***
Dual or co-extrusion	***NO***
Other	***NO***

3.3. PRELIMINARY DESIGN

Based on what was stated in the previous section in the CHECK LIST tables, a preliminary design is carried out that will serve as a model and basis for the simulations. The geometry of the hubcap design will serve as the cavity of the mold to be injected and the simulations carried out on the geometry will be compared depending on the materials chosen.

Figure 16 Hubcap presentation

3.4. ASSEMBLY DESIGN

The main function of the product design is to improve the aesthetics of the 17-inch steel wheels. The hubcap must be mounted on the steel rims by applying pressure to the inner carabiners of the workpiece and thanks to an inner steel ring.

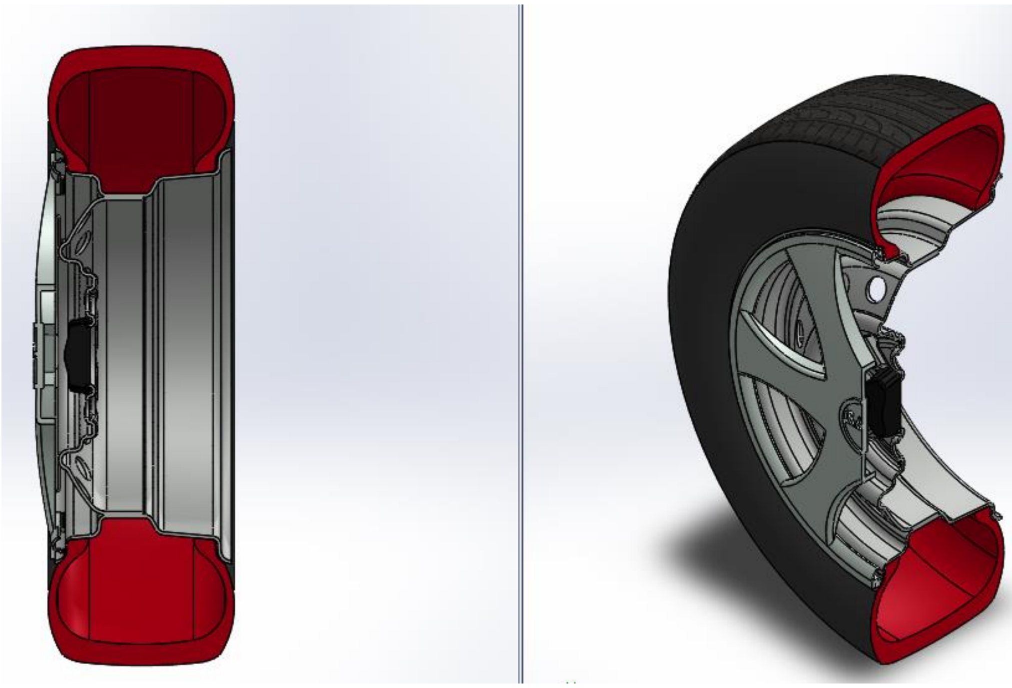


Figure 17Hubcap assembly

4. MATERIALS.

In the following sections, the theoretical bases of the properties of each of the materials to be simulated will be developed in order to understand the behavior during the injection phase and the intrinsic properties of each material.

4.1. GENERIC PROPERTIES OF MATERIALS.

In this section a synthesis of the generic properties of each of the three groups of materials is made in order to understand the behavior of each type of material.

4.1.1. STYRENE BUTADIENE ACRYLONITRILE (ABS).

ABS plastics are polymerized from the three monomers acrylonitrile, butadiene, and styrene. The family name is based on the first letter of each of these monomers.

4.1.1.1 MOLECULAR STRUCTURE OF CONSTITUENT MONOMERS.

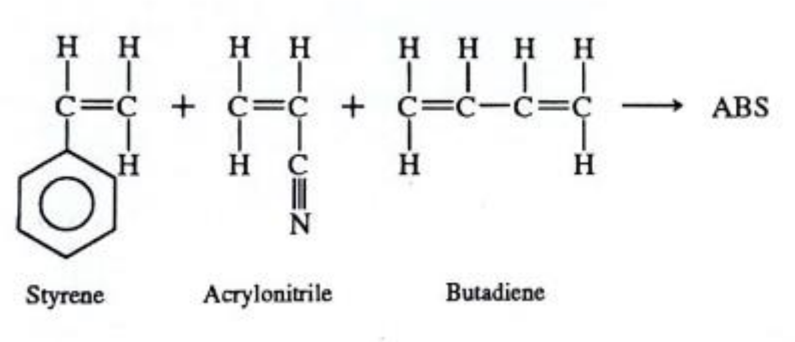


Figure 18 ABS molecular structure

4.1.1.2. GENERAL CHARACTERISTICS.

- This material is obtained by dispersion of butadiene in phase of SAN (STYRENE-ACRYLONITRILE).
- ABS maintains the same advantages as high-impact polystyrene (HIPS). Toughness, chemical resistance and heat resistance.
- Opaque material.
- According to its concentration there are two categories of ABS, rigid with a content of 10% to 20% in rubber used for molding or with proportions of 60% rubber for surface finishes by painting or metallization.
- Mirror surface finishes for molding
- Modeling parts with very small tolerances

4.1.1.3 PROPERTIES (ABS).

CONSULT ANNEX.

4.1.2. POLYPROPYLENE (PP).

During polymerization, the CH_3 groups characteristic of this olefin ca be incorporated in the macromolecule in spatially different ways. The resulting products have different properties.

4.1.2.1 MOLECULAR STRUCTURE

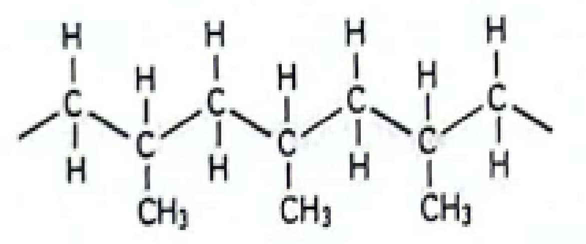


Figure 19 Polypropylene molecular structure

4.1.2.2 GENERAL CHARACTERISTICS.

- Semi-crystalline and opaque material with crystallinity rate of 50% to 60%.
- It presents a good behavior to fatigue and flexion.
- Insoluble in water, but permeable to hydro carbonated substances such as fats, oils or gasoline.
- Electrical insulation
- Good chemical stability and quality for food applications.

4.1.2.3. PROPERTIES (PP).

CONSULT ANNEX.

4.1.3. POLYCARBONATE (PC).

The basis of polycarbonate, best known as an engineering plastic, is bisphenol A obtained from phenol and acetone. Polycarbonate is manufactured by transesterification of bisphenol A with diphenyl carbonate at elevated temperatures or by dissolving bisphenol A in Pyridine and reacting with phosgene at 30ºC/86ºF.

4.1.3.1. MOLECULAR STRUCTURE.

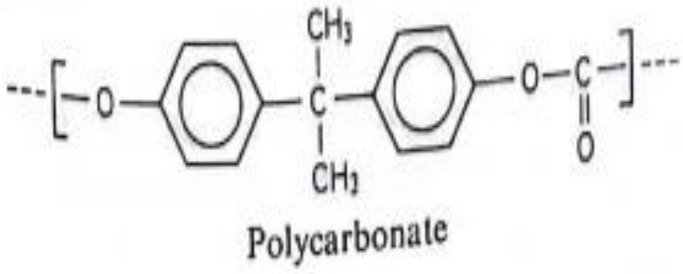


Figure 20 Polycarbonate molecular structure

4.1.3.2 GENERAL CHARACTERISTICS.

- High molecular weight polymer.
- Amorphous and transparent material that in large thicknesses takes yellow color.
- It presents a quasi-static behavior until rupture.
- Good shock resistance.
- Wide temperature ranges from -150ºC to +135ºC.
- It absorbs very small amounts of water.
- Low shrinkage rate.
- Good insulating properties both thermal and electrical.

4.1.3.3 PC PROPERTIES.

CONSULT ANNEX.

4.2. GENERIC INJECTION MOLDING GUIDES.

In this section the main parameters of control of the materials chosen in a generic way will be presented. These data are the basis for performing the first simulations and interpreting the results obtained.

4.2.1. STYRENE BUTADIENE ACRYLONITRILE (ABS).

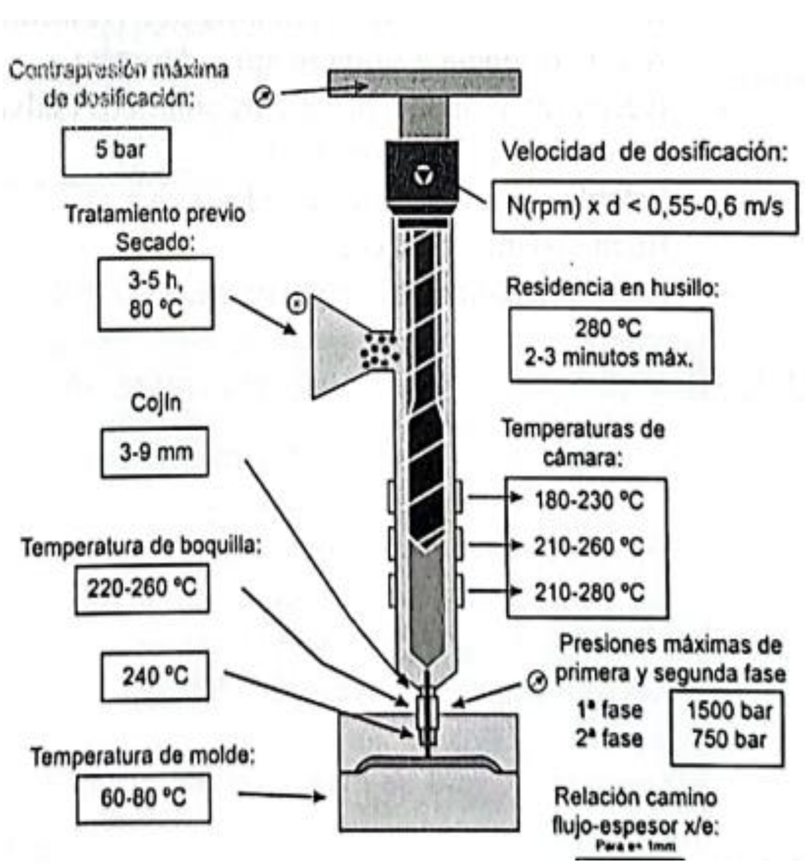


Figure 21 Generic instructions for ABS materials injections

4.2.2. POLYPROPYLENE (PP)

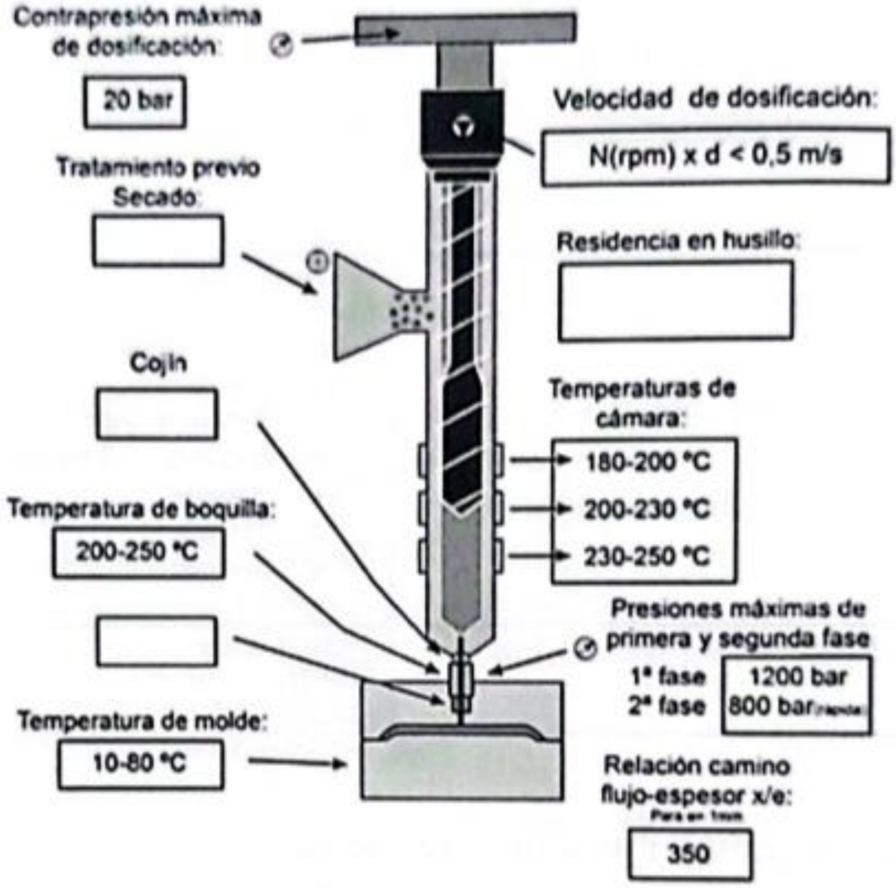


Figure 22 Generic instructions for PP materials injections

4.2.3 POLYCARBONATE (PC)

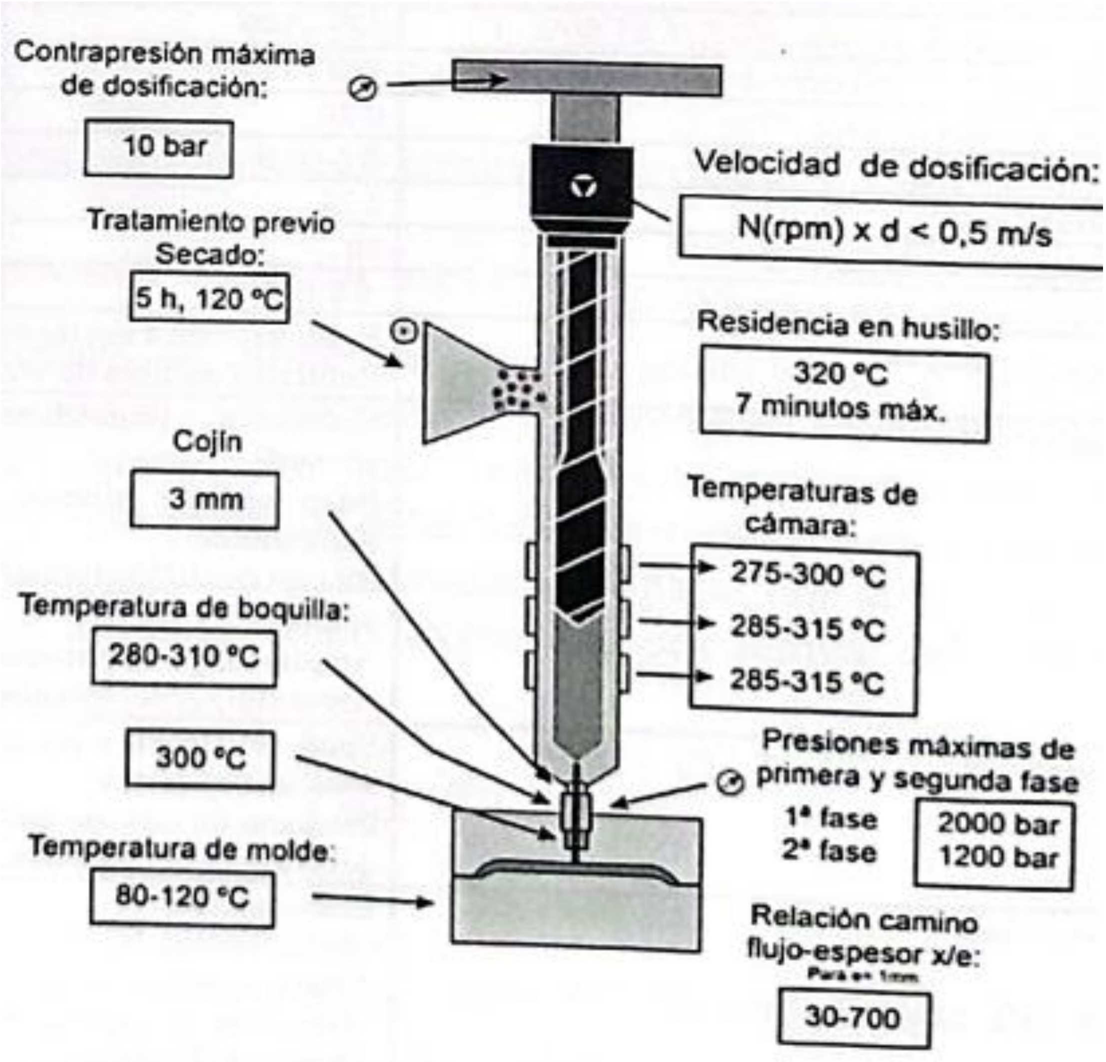


Figure 23 Generic instructions for PC materials injections

4.3. GENERAL MATERIAL DATA WITHIN SOLIDWORKS

This section will display the primary data used by the SOLIDWORKS Plastics program during injection calculations.

4.3.1. RONFALIN FF-50

ABS : DSM Engineering Plastics / RONFALIN FF-50	
Temperatura del material	240 °C
Temperatura del molde	52 °C
Temperatura de eyección	100 °C
Temperatura de transición	105 °C
Viscosidad : 7-Parameters Modi	9.91e+10 373.1 0 24.46 51.6 52970 0.32
PVT : Modified Tait Equation	0.000986 7.21e-07 1.61e+08 0.004766 0.000986 3.4e-07 2.06e+08
Densidad sólida	No disponible
Calor específico : Constant	2546 J/(Kg-K)
Conductividad térmica : Constan	0.2 W/(m-K)
Módulo elasticidad : Constant	2500 2500
Coef. Poisson : Constant	0.35 0.35
Coeficiente de dilatación térmica	8.6e-05 8.6e-05
Módulo de relajación de cizallam	No disponible
Curado del modelo	No disponible
Temperatura de no flujo	No disponible
Índice de fluidez (MFR)	33 g/10min
% Fibras	No disponible
Tasa de cizallamiento máx.	35600 1/s
Tensión de cizallamiento máx.	0.2968 MPa
Coeficiente de tensiones ópticas	No disponible
Parámetros Leonov	No disponible
Parámetros WLF	No disponible
Módulo de cizallamiento paralelo	925.926 MPa
Datos cinéticos de cristalización	No disponible
Coeficientes de pérdida de unión	No disponible
Origen de datos e información	SIMPOE

Figure 24 Database data for RONFALIN FF50

4.3.2. PP 412MN 40

PP : DSM Engineering Plastics / 412 MN 40	
Temperatura del material	220 °C
Temperatura del molde	50 °C
Temperatura de eyección	120 °C
Temperatura de transición	135 °C
Viscosidad : 5-Parameters Modifie	0.0008269 6042 44040 0.092 0
PVT : Modified Tait Equation	0.00120305 9.2e-07 8.80937e+07 0.00481935 0.00110775 5.1e-07
Densidad sólida	No disponible
Calor específico : Constant	2834 J/(Kg-K)
Conductividad térmica : Constant	0.129 W/(m-K)
Módulo elasticidad : Constant	1300 1300
Coef. Poisson : Constant	0.38 0.38
Coeficiente de dilatación térmica :	8.7e-05 8.76e-05
Módulo de relajación de cizallamie	1e+07 1e+10 1.06e+09 1.06e+08 1.08e+07 0.01 0.1 1 10
Curado del modelo	No disponible
Temperatura de no flujo	No disponible
Índice de fluidez (MFR)	No disponible
% Fibras	No disponible
Tasa de cizallamiento máx.	61300 1/s
Tensión de cizallamiento máx.	0.2527 MPa
Coeficiente de tensiones ópticas	No disponible
Parámetros Leonov	No disponible
Parámetros WLF	No disponible
Módulo de cizallamiento paralelo :	471.014 MPa
Datos cinéticos de cristalización	No disponible
Coeficientes de pérdida de unión	No disponible
Origen de datos e información	SIMPOE; Generic PVT Data

Figure 25 Database data for PP 412 MN 40

4.3.3. XANTAR 18 R.

PC : DSM Engineering Plastics / Xantar 18 R	
Temperatura del material	300 °C
Temperatura del molde	90 °C
Temperatura de eyección	150 °C
Temperatura de transición	144 °C
Viscosidad : 5-Parameters Modifie	3.1213e-07 12067 734900 0.17 0
PVT : Modified Tait Equation	0.000857889 6.14982e-07 1.13077e+08 0.00351214
Densidad sólida	No disponible
Calor específico : Constant	1710 J/(Kg-K)
Conductividad térmica : Constant	0.24 W/(m-K)
Módulo elasticidad : Constant	2300 2300
Coef. Poisson : Constant	0.38 0.38
Coeficiente de dilatación térmica :	6.5e-05 6.5e-05
Módulo de relajación de cizallamie	No disponible
Curado del modelo	No disponible
Temperatura de no flujo	No disponible
Índice de fluidez (MFR)	23 g/10min
% Fibras	No disponible
Tasa de cizallamiento máx.	40000 1/s
Tensión de cizallamiento máx.	0.4834 MPa
Coeficiente de tensiones ópticas	5.6e-11 8.2e-13 1/Pa
Parámetros Leonov	533 149.1 0.0177 94.5 0.00232 0.00211
Parámetros WLF	2.75 138 533
Módulo de cizallamiento paralelo :	833.333 MPa
Datos cinéticos de cristalización	No disponible
Coeficientes de pérdida de unión	No disponible
Origen de datos e información	SIMPOE

Figure 26 Database data for XANTAR 18R

4.4. SPECIFIC DATA

CONSULT ANNEX.

5. SIMULATION PROCESS

Simulating the behavior of the fluid within the cavity of an injection mold is a very complex process employed to reduce the uncertainty of the plastic injection process. Currently within the sector different programs are used to predict the behavior of the fluid inside the cavity. The main programs used in the industry to simulate injection processes are:

- **MOLDFLOW** – Developed by Autodesk, it is one of the most popular programs widely used for plastics simulation.
- **SIGMASOFT** – It is an injection process simulation program used to predict and optimize the performance of plastic molds and injection systems.
- **CADMOULD** – It is a plastic injection simulation solution developed by Simcon.
- **MOLDEX3D** – Plastic simulation software developed by CoreTech System
- **ANSYS POLIFLOW** – It is a material flow simulation program that includes capabilities for the simulation of injection molding processes.
- **SOLIDWORKS PLASTICS** – Mold and plastic flow simulation software used in the manufacturing industry.

The simulations performed in this project are performed with the **SOLIDWORKS PLASTICS** extension.

5.1. INTRODUCTION TO SOLIDWORKS PLASTICS.

SolidWorks Plastics is a very intuitive tool that is fully integrated into the SolidWorks design program, making it easy and fast to design any part and evaluate the process of filling a cavity and redesign the part.

The operation of the SolidWorks Plastics tool is similar to that of other existing tools on the market and also supports any other geometry that has not been designed in the program itself.

Computer-aided rheological simulations help to know the behavior of grass during the injection molding process from mathematical models based on the *Finite Element Method (FEM).*

The main types of analysis that can be performed that can be performed are:

- *Filling analysis* – Allows to predict the behavior of the material flow during the filling of the mold cavity.

- *Analysis of the balance of the castings* - It is useful to know the sections of the most suitable feeding channels more suitable in the filling of the molds with several cavities, to achieve that the filling is carried out at the same time and the compactions obtained are the same for all the pieces.

- *Analysis of contractions and compactions* – Studies the contractions, as well as the profile of the second pressure, to ensure the most accurate dimensioning in the injected parts.

- *Cooling analysis* – Simulates the behavior of the injection process taking into account the heat exchange produced between the part and the cooling circuits.

The use of SolidWorks Plastics helps to know how the plastic flow advances during the filling of the cavity according to the location of the filling point (material inlet), the geometry of the part. The polymer used and the processing conditions (melting temperature, molding temperature and injection time). In summary, it predicts the behavior that the plastic material will have during the injection process and helps to know the possible defects.

5.2. RHEOLOGICAL ANALYSIS PROCESS OF PLASTIC INJECTION

The stages that are followed in the realization of the analysis of an injection process are five: CAD design of the mold cavity in three dimensions, meshing, definition of the boundary conditions, mathematical analysis and presentation of the results (post processing).

Initially, the CAD model of the mold cavity and, in some cases, the material inlet and cooling systems is used. The CAD model can be imported directly into the simulation program from other design software (IGES, STL STEP, etc.).

The imported model must be meshed to obtain a discretized model of simple elements that can be treated later with the Finite Element Method (FEM). After being discretized, the variables or boundary conditions that define the type of analysis must be assigned.

The calculation module is responsible for simulating the behavior of the pastic during the injection cycle. The numerical results obtained are post-processed later and can be displayed in colors on the CAD model.

- **First stage** – The CAD model must be designed in three dimensions of the mold cavity with or without distribution and material input systems. It is also possible to import the file from any other compatible program

- **Second stage** – We proceed to the meshing of the geometry to be studied to divide it into small triangles joined by their vertices or nodes, which allows the application of the Finite Element Method (FEM). The SolidWorks program distinguishes between surface meshing and solid mesh (Shell/Solid mesh).

- **Third stage** – The boundary conditions are assigned to define all the variables necessary to perform the analysis: inlet temperature of the material in the cavity, the cooling temperature, the temperature of the mold, the type of material to be injected and the mold material, etc ...

- **Fourth stage** – By means of calculation algorithms, the results for each of the elements are determined. These results are stored in a file for later post-processing. In these conditions it is very difficult to draw conclusions due to the large number of numerical results obtained. This stage goes unnoticed in SolidWorks.

- **Fifth stage** – Corresponds to the post-processing stage. It consists of treating all the information obtained and representing it graphically on the CAD model. The post-processing allows to see the results on the same cavity indicating by means of colors how the different parameters vary such as pressure, temperature, tensions, deformations or places where it is expected that they will occur, etc ...

The correct execution of each of the stages within the rheological study is decisive to obtain coherent results on the design of the piece to be manufactured.

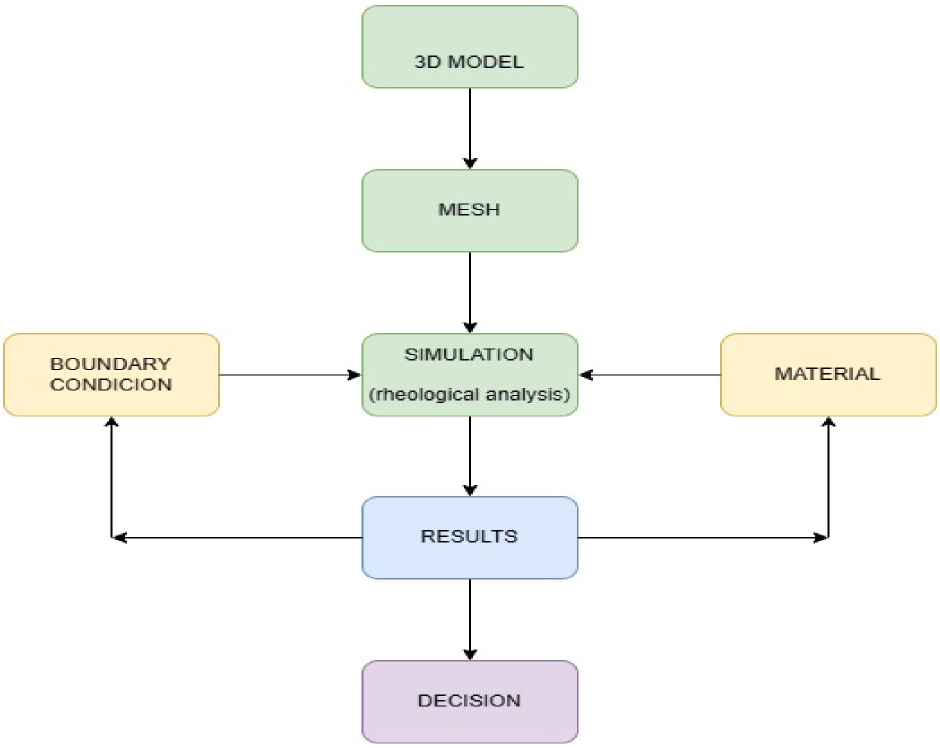


Figure 27 Rheological analysis process

5.3. DEVELOPMENT OF RHEOLOGICAL ANALYSIS WITH SOLIDWORKS PLASTICS. SIMULATION.

5.3.1. CREATION OF THE MOLD CAVITY. PIECE.

The creation of the cavity requires that the design of the part must be validated taking into account the necessary scaling of the cavity to counteract the contractions of the part after the filling process. The scale of each of the cavities should be considered according to the variation of the specific volume of each material to be used. This implies the need for scaling for each simulation. In addition, a study of the exit or demolding angles is necessary.

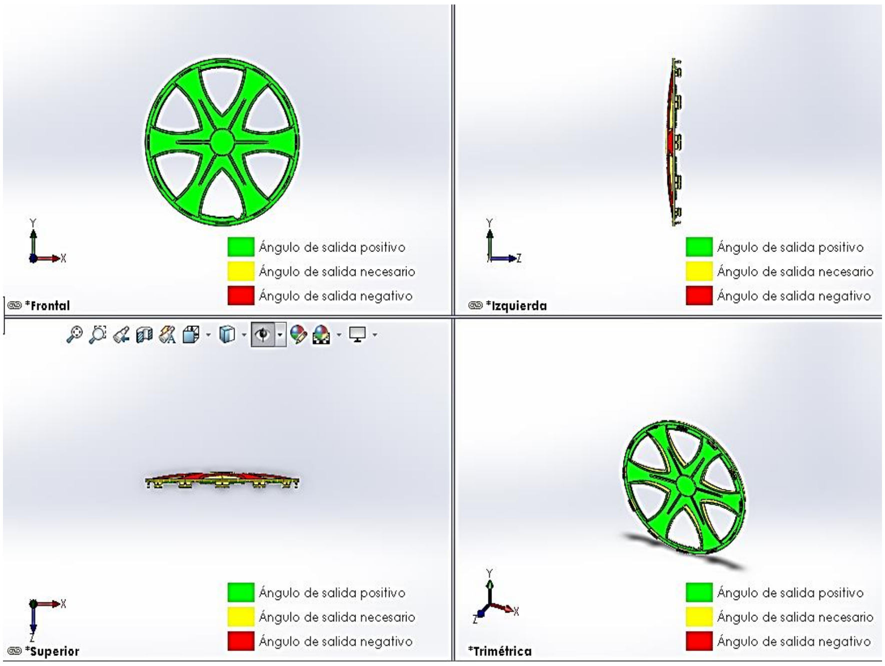


Figure 28 Draft angle (red color needs a negative angle and green color needs a positive angle)

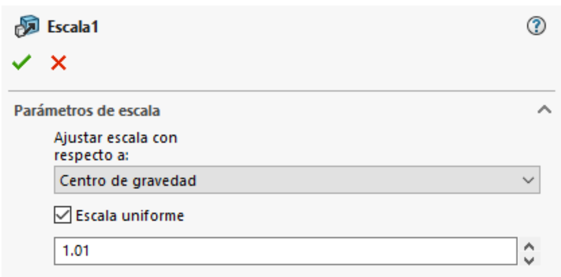


Figure 29 Mold scale

5.3.2. DEFINE THE INJECTION SITE.

The SolidWorks Plastics program extension calculates the injection point position that best matches the geometry of the part, although the designer can choose the injection point.

Figure 30 Inlet flow channel and injection point

More data on the injection site and the contribution of the injection site to filling can be found in the RESULTS ANNEX.

5.3.3. SELECTION OF MATERIAL.

SolidWorks Plastics has an extensive database of commercial polymers that can be used to simulate plastic injection without defining polymers. In analysis it is carried out with the following materials from the program's database:

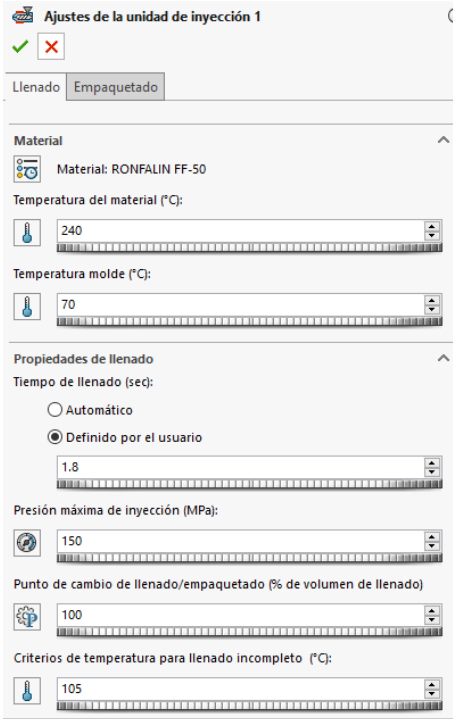


Figure 31 Injection condition and material

5.3.4. SPECIFY PROCESSING CONDITIONS.

The definition of each of the analyses to be performed is independent according to the type of material. The processing conditions are defined on basis of the data provided by the manufacturer, the theoretical data obtained from other authors and according to the commercial specifications of injection machines.

5.3.5 RUN THE SIMULATION.

The three simulations will be run with the three analysis modules (FILLING, PACKAGING AND DEFORMATION).

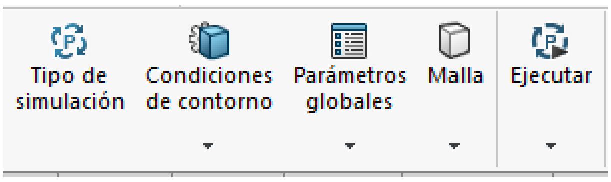


Figure 32 Simulation type, Boundaries conditions, Global parameters, Mesh and Run

5.3.6. RESULTS.

The results section presents a summary of the results obtained in the simulations of the three materials.

Table 10 Main results

TABLE OF MAIN RESULTS			
CONTROL PARAMETERS	*RONFALIN FF50 (ABS)*	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
Filling time(s)	*2.03 (s)*	*2.18 (s)*	*2.18 (s)*
Pressure at the end of filling (Mpa)	*32.37 (Mpa)*	*8.58 (Mpa)*	*42.65 (Mpa)*
Cooling time(s)	*73.01 (s)*	*63.18 (s)*	*35.17 (s)*
Pressure at the end of packaging (Mpa)	*19.1 (Mpa)*	*3.16 (Mpa)*	*34.64 (Mpa)*
Volume contraction at the end of packaging (%)	*9,23 (%)*	*17,16 (%)*	*10,59 (%)*
Total stress displacements (mm)	*3.41 (mm)*	*1.72 (mm)*	*3.04 (mm)*
Sink marks size (mm)	*0.18 (mm)*	*0.39 (mm)*	*0.25 (mm)*

Sink marks profile (mm)	*0.06 (mm)*	*0.04 (mm)*	*0.05 (mm)*
Mass of the piece (gr)	*552,17 (gr)*	*487,83 (gr)*	*636,72 (gr)*
Clamping force (TONNE)	*286 (TONNE)*	*82 (TONNE)*	*386 (TONNE)*

Table 11 Secondary results

SECONDARY RESULTS TABLE			
CONTROL PARAMETERS	*RONFALIN FF50 (ABS)*	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
Temperature increase at the end of filling (C^o)	*8.63 (C^o)*	*0.77 (C^o)*	*20.9 (C^o)*
Shear stresses at the end of filling (Mpa)	*6.77 (Mpa)*	*0.06 (Mpa)*	*2.39 (Mpa)*
End of fill shear rate (1/s)	5056.86 (1/s)	10076.15 (1/s)	4147.15 (1/s)
Temperature at the end of packaging (C^o)	240 (C^o)	220 (C^o)	299.97 (C^o)
Solidification time(s)	60.04 (s)	76.2 (s)	39.5 (s)
Region solidified at the end of packaging	OK/NOK	OK/NOK	OK/NOK

Residual stresses at the end of packaging (Mpa)	104.97 (Mpa)	71.4 (Mpa)	112.79 (Mpa)
Flow front temperature (C^{o})	243.93 (C^{o})	220.59 (C^{o})	307.56 (C^{o})

Table 12 Common results

COMMON RESULTS TABLE			
CONTROL PARAMETERS	*RONFALIN FF50 (ABS)*	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
Vent Pressure (Mpa)	*6.39 (Mpa)*	*3.46 (Mpa)*	*3.25 (Mpa)*
Contribution to the filling of injection points	*OK/NOK*	*OK/NOK*	*OK/NOK*
Facility of filling	*EASY*	*EASY*	*EASY*
Welding lines	*148.47 ^{o}*	*148.47 ^{o}*	*148.47 ^{o}*
Air bags	*X*	*X*	*X*
Region solidified at the end of filling	*OK/NOK*	*OK/NOK*	*OK/NOK*
Region solidified at the end of packaging	*OK/NOK*	*OK/NOK*	*OK/NOK*

5.3.7. COMPARISON RESULTS

In the results comparison section, a selection criterion based on multiple factors is used in order to determine which material is best suited to a plastic injection process for this piece. To determine which is the best material, a scale of points is assigned depending on whether the result is "Favorable", "Indifferent" or "Unfavorable".

The scale used for the Main Results will be 3 points for "Favourable", 1 point for "Indifferent" and 0 points for "Unfavorable".

Table 13 Comparison of main results

TABLE OF MAIN RESULTS			
CONTROL PARAMETERS	*RONFALIN FF50 (ABS)*	*PP 412MN 40 (PP)*	*XANTAR 18R (PC)*
Filling time(s)	*3*	*1*	*0*
Pressure at the end of filling (Mpa)	*3*	*0*	*1*
Cooling time(s)	*0*	*1*	*3*
Pressure at the end of packaging (Mpa)	*3*	*0*	*1*
Volume contraction at the end of packaging (%)	*3*	*0*	*1*
Total stress displacements (mm)	*0*	*3*	*1*

Sink marks size (mm)	*3*	*0*	*1*
Sink marks profile (mm)	*3*	*0*	*1*
Mass of the piece (gr)	*1*	*3*	*0*
Clamping force (TONNE)	*3*	*0*	*1*
PUNCTUATION	22	8	10

The scoring scale for secondary outcomes will be 2 points for "Favorable", 1 point for "Indifferent" and 0 points for “Unfavorable”.

Table 14 Comparison of secondary results

SECONDARY RESULTS TABLE			
CONTROL PARAMETERS	*RONFALIN FF50 (ABS)*	*PP 412MN 40 (PP)*	*XANTAR 18R (PC)*
Temperature increase at the end of filling (C^o)	*1*	*2*	*0*
Shear stresses at the end of filling (Mpa)	*0*	*2*	*1*
End of fill shear rate (1/s)	*0*	*2*	*1*
Temperature at the end of packaging (C^o)	*1*	*0*	*2*

Solidification time(s)	*1*	*0*	*2*
Region solidified at the end of packaging	*0*	*1*	*2*
Residual stresses at the end of packaging (Mpa)	*1*	*2*	*0*
Flow front temperature (C^0)	*1*	*2*	*0*
PUNCTUATION	*5*	*11*	*8*

The comparison scale for common outcomes will simply be to assign 1 point to each of the parameters that most favor the design.

Table 15 Comparison of common results

COMMON RESULTS TABLE			
CONTROL PARAMETERS	*RONFALIN FF50 (ABS)*	*PP 412MN 40 (PP)*	*XANTAR 18R (PC)*
Vent Pressure (Mpa)	*0*	*0*	*1*
Contribution to the filling of injection points	*0*	*0*	*1*
Facility of filling	*0*	*0*	*1*
Welding lines	*0*	*1*	*0*
Air entrapments	*1*	*0*	*0*
Region solidified at the end of filling	*1*	*0*	*0*

Region solidified at the end of packaging	*0*	*0*	*1*
PUNCTUATION	*2*	*1*	*4*

In the following table we have a synthesis of the analysis of the selection based on several factors, being the most favorable material the RONFALIN FF50 (ABS).

Table 16 Comparison of all results

RESULTS COMPARISON TABLE			
RESULTS	*RONFALIN FF50 (ABS)*	*PP 412MN 40 (PP)*	*XANTAR 18R (PC)*
MAIN RESULTS	*22*	*8*	*10*
SECONDARY OUTCOMES	*5*	*11*	*8*
COMMON RESULTS	*2*	*1*	*4*
TOTAL SCORE	*29*	*20*	*22*

5.3.8. CYCLE TIMES AND GRAPHS.

The following tables and graphs represent an approximation to the scheme of the injection cycle of each of the simulated materials.

Table 17 Cycle time for RONFALIN FF50

TIME CYCLE	
RONFALIN FF50 (ABS)	***TIME(s)***
FILLING	2,03
PACKING	15
COOLING	73,01
PLASTIFICATION	60,04
MOLD OPEN	24,4
PART EJECTION	8,9
MOLD CLOSING	21,4
TOTAL TIME FOR CYCLE	144,74

Table 18 Cycle time for PP 412MN 40

TIME CYCLE	
PP 412MN 40 (PP)	***TIME(s)***
FILLING	2,18
PACKING	15
COOLING	63,18
PLASTIFICATION	76,02
MOLD OPEN	24,4
PART EJECTION	8,9
MOLD CLOSING	21,4
TOTAL TIME FOR CYCLE	113,66

Table 19 Cycle time for XANTAR 18 R

TIME CYCLE	
XANTAR 18 R (PC)	***TIME(s)***
FILLING	2,18
PACKING	15
COOLING	35,17
PLASTIFICATION	39,05
MOLD OPEN	24,4
PART EJECTION	8,9
MOLD CLOSING	21,4
TOTAL TIME FOR CYCLE	107,05

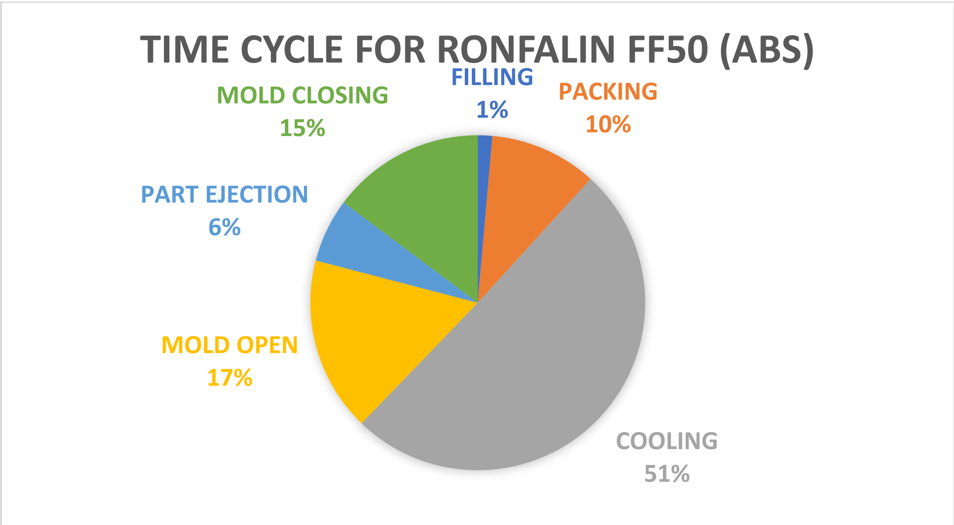


Figure 33 Cycle time for RONFALIN FF50

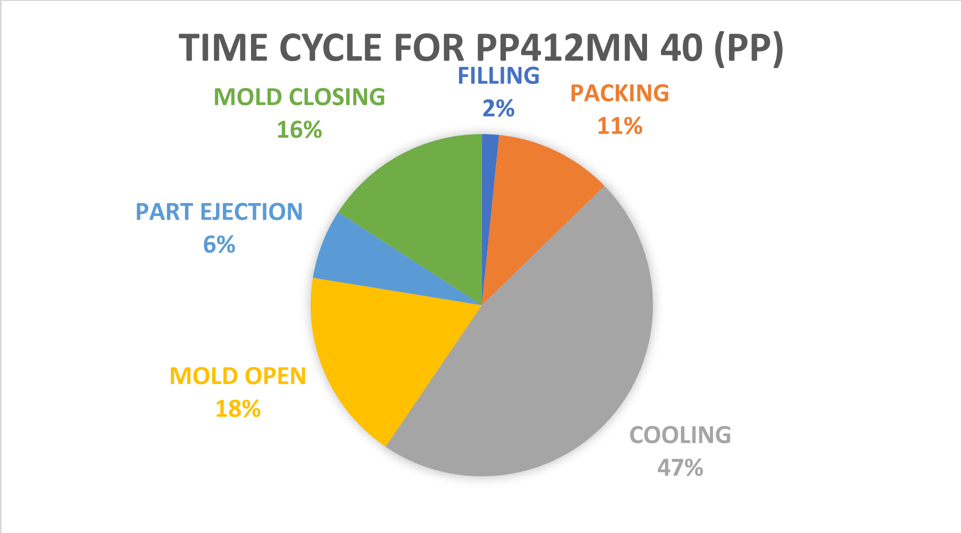


Figure 34 Cycle time for PP412MN 40

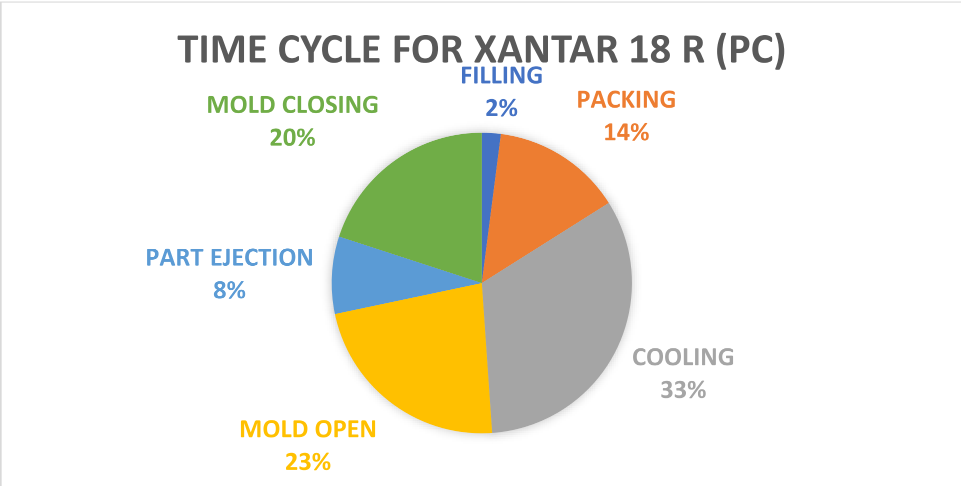


Figure 35 Cycle time for XANTAR 18 R

5.3.9. RESULTS OF REDESIGN AND COMPARISON.

The redesign results section presents a summary of the results obtained in the simulation of the *RONFALIN FF50* material after modifying the part and in comparison, with the previous results.

Table 20 Main results for redesign

TABLE OF MAIN RESULTS		
CONTROL PARAMETERS	*RONFALIN FF50 (ABS) I*	*RONFALIN FF50 (ABS) II*
Filling time(s)	*2.03 (s)*	*3.88 (s)*
Pressure at the end of filling (Mpa)	*32.37 (Mpa)*	*53.77 (Mpa)*
Cooling time(s)	*73.01 (s)*	*37.88 (s)*
Pressure at the end of packaging (Mpa)	*19.1 (Mpa)*	*39.73 (Mpa)*
Volume contraction at the end of packaging (%)	*9,23 (%)*	*8,69 (%)*
Sink marks size (mm)	*0.18 (mm)*	*0.19 (mm)*
Sink marks profile (mm)	*0.06 (mm)*	*0.04 (mm)*
Mass of the piece (gr)	*552,17 (gr)*	*399,89 (gr)*
Clamping force (TONNE)	*286 (TONNE)*	*475.36 (TONNE)*

Table 21 Secondary results for redesign

SECONDARY RESULTS TABLE		
CONTROL PARAMETERS	*RONFALIN FF50 (ABS) I*	*RONFALIN FF50 (ABS) II*
Temperature increase at the end of filling (C^o)	*8.63 (C^o)*	*2.76 (C^o)*
Shear stresses at the end of filling (Mpa)	*6.77 (Mpa)*	*11.99 (Mpa)*
End of fill shear rate (1/s)	5056.86 (1/s)	2128.93 (1/s)
Temperature at the end of packaging (C^o)	240 (C^o)	239.98 (C^o)
Solidification time(s)	60.04 (s)	43.60 (s)

Region solidified at the end of packaging	OK/NOK	OK/NOK
Residual stresses at the end of packaging (Mpa)	104.97 (Mpa)	99.18 (Mpa)
Flow front temperature (C^{0})	243.93 (C^{0})	241.58 (C^{0})

Table 22 Common results for redesign

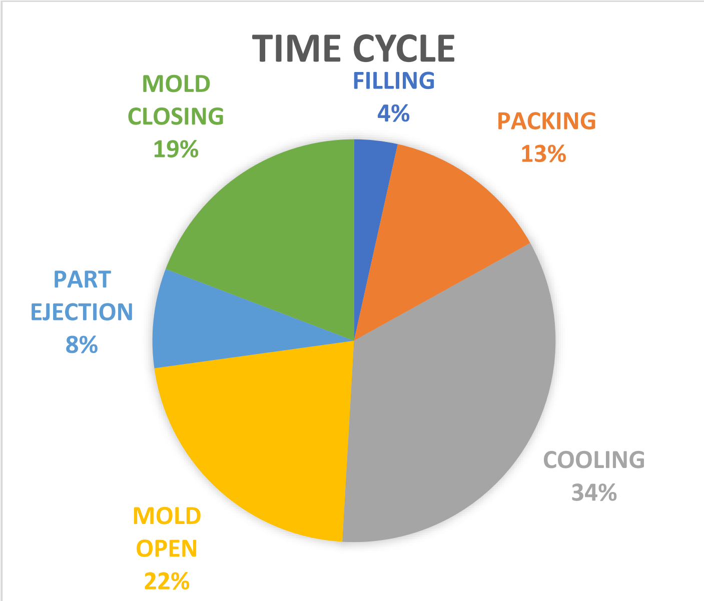
COMMON RESULTS TABLE		
CONTROL PARAMETERS	*RONFALIN FF50 (ABS) I*	*RONFALIN FF50 (ABS) II*
Vent Pressure (Mpa)	*6.39 (Mpa)*	*8.67 (Mpa)*
Contribution to the filling of injection points	*OK/NOK*	*OK/NOK*
Ease of filling	*EASY*	*EASY*

Welding lines	*148.47 º*	*148.47 º*
Air entrapments	*X*	*X*
Region solidified at the end of filling	*OK/NOK*	*OK/NOK*
Region solidified at the end of packaging	*OK/NOK*	*OK/NOK*

Table 23 Cycle time for redesign

TIME CYCLE	
RONFALIN FF50 (ABS) II	***TIME(s)***
FILLING	3,88
PACKING	15
COOLING	37,88
PLASTICIZATION	43,6
MOLD OPEN	24,4
PART EJECTION	8,9
MOLD CLOSING	21,4
TOTAL TIME FOR CYCLE	**111,46**

Table 24 Cycle time for redesign



6. CONCLUSION.

During the design process of the hubcap, a series of procedures have been carried out in order to bring the part as close as possible to a final result. This final result would be the basis for designing the injection molds.

The behavior of the fluid inside the cavity of the mold (designed part) is taken as a basis to be able to make an exhaustive analysis of the characteristics of the mold to be designed and manufactured. In the design of the mold, all the parameters obtained in the rheological simulation will be taken into account. These parameters will define the dimensions of the mold, the vents (if necessary), the heat transfer capacities, the cooling ducts and the machining of anchoring to the machine.

The development of the previous documents focuses on the definition of the cavity to be used for the final design of the mold, focusing on the choice of material to be used for injection. The materials that are analyzed are for commercial use and belong to the program's database.

During the simulation of the plastic injection molding process of the designed part, certain errors, successes, advantages and disadvantages have been discovered.

The main successes during the simulation have been the following:

- The cavity is easy to fill with almost any material
- Very short injection times can be used
- Total cycle times are relatively small
- Pressures remain very low
- No flow front temperature increases during injection
- The material fills the cavity without solidifying
- Residual stresses are relatively low
- No material deterioration
- Very good surface finishes
- Low locking forces

The main errors during the simulation were the following:

- Oversized part measurements
- Need for dimensional redesign of the part
- Unreliable anchoring system
- Very high cooling times
- Difficulty ejecting the piece
- Unsafe anchoring system
- The ejection temperature is reached before solidifying the part
- Larger than expected displacements

After analyzing the first simulations of plastic injection, the need to redesign the dimensions of the piece is observed. We proceed to reduce the thickness of the piece especially in the center of the disc. By re-simulating the part with the RONFALIN FF50 material we obtain a series of advantages and disadvantages.

The advantages are as follows:

- Decrease in part mass
- Considerable reduction in injection time

- Improved cooling
- Very good surface finish
- Improved cycle time
- Contraction close to theoretical data
- Decreasing temperature rise
- Small improvement of surface finish

The disadvantages are as follows:

- Increased injection time
- Increased injection pressures
- Increased residual stresses
- Increased locking forces
- Increased ventilation pressures

The final conclusion of the analysis shows that the materials used in the plastic injection process have totally different characteristics. In the case of the first simulations (before optimizing the part) anomalies can be observed that determine which material is most suitable for plastic injection molding. In the redesign of the part, the margin of improvement for the manufacture of the part can be observed. Definitely, although the design of the piece is very close to being able to be manufactured, some aspects such as the functionality of the anchor and the extraction of the piece from the mold should be reviewed.

The future lines to follow determine simulations and data analysis outside this project. The data to be analyzed should consider the functional design of the plastic injection mold and the machine that should be used for such operation.

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Tres, P. A. (200). *Designing plastic parts for assembly.* Munich: HANSER.

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Francisco javier Castany, A. M. (2018). *Diseño y desarollo de componentes de plastico inyectados (III): la maquina.* Zaragoza: Prensas de la universidad de Zaragoza.

Gianni Bodini, F. C. (1987). *Moldes y maquinas de inyeccion para la transformacion de plasticos Volumen II.* Milan: NEGRI BOSSI.

Gianni bondini, F. C. (1987). *Moldes y maquinas de inyeccion para la transformacion de plasticos Volumen I.* Milan: NEGRI BOSSI.

Gonzalez, S. G. (2019). *El gran libro de SOLIDWORKS.* Valencia: Marcombo.SA.

HARPER, C. A. (2006). *HANDBOOK OF PLASTIC PROCESSES.* New Jersey: wiley.

M. Joseph Gordon, J. (1993). *Total quality process control for Injection molding.* MUNICH: HANSER.

Rubin, I. I. (1990). *HANDBOOK OF PLASTIC MATERIALS AND TECHNOLOGY.* Canada: wiley.

Tres, P. A. (200). *Designing plastic parts for assembly.* Munich: HANSER.

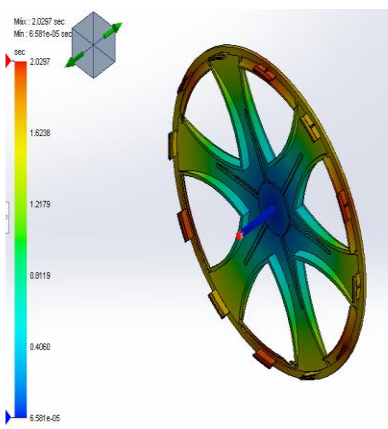
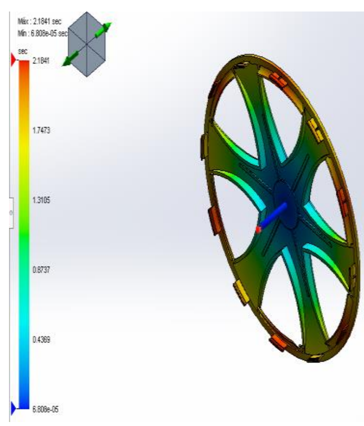
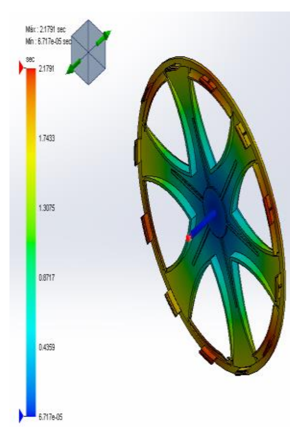
ANEXED I: SIMULATION RESULTS

INDEX

1. MAIN RESULTS OF ANALYSIS

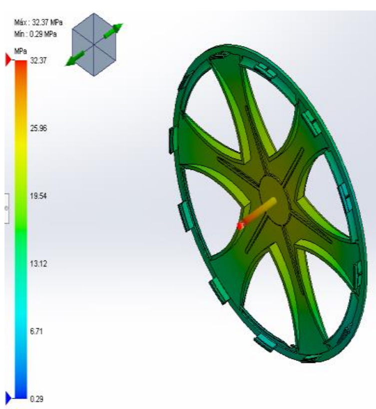
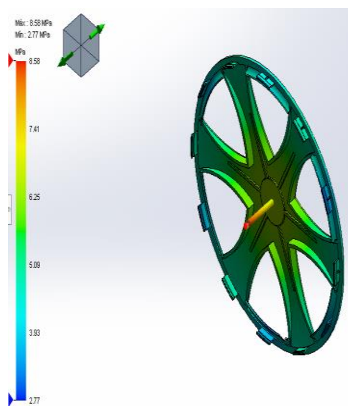
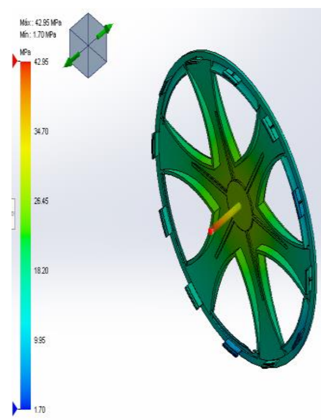
1.1. FILLING TIME

The filling time plot shows the profile of the plastic material as it flows through the mold part cavity during the filling stage of the injection molding process. The blue zones indicate the beginning of the flow front. The red areas indicate the end of the filling when the flow has stopped.

FILLING TIME		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
Max: *2.03 (s)* ***Min:*** *2.03 (s)* ***Average:*** *2.03 (s)*	***Max:*** *2.18 (s)* ***Min:*** *2.18 (s)* ***Average:*** *2.18 (s)*	***Max:*** *2.18 (s)* ***Min:*** *2.18 (s)* ***Average:*** *2.18 (s)*
NOTE: In all three cases we try to minimize the filling time without exceeding the maximum pressure that could damage the material.		

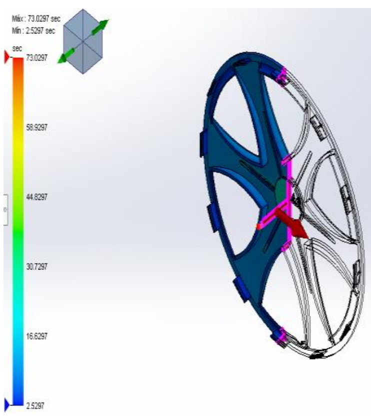
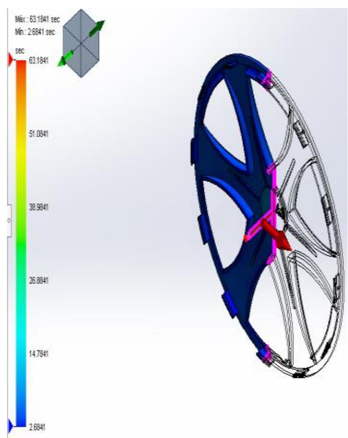
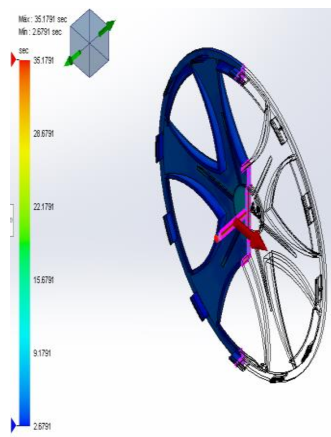
1.2. PRESSURE AT THE END OF FILLING

The injection pressure propagates through the molten plastic and causes a pressure drop that is distributed along the flow. The pressure at the end of filling is a good indication of the level of uniformity with which the cavity has been filled.

PRESSURE AT THE END OF FILLING		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 32.37 (Mpa)* ***Min**: 0.29 (Mpa)* ***Average**: 19.54 (Mpa)*	***Max:** 8.58 (Mpa)* ***Min:** 2.77 (Mpa)* ***Average:** 6.52 (Mpa)*	***Max:** 42.65 (Mpa)* ***Min:** 1.70 (Mpa)* ***Average:** 26.45 (Mpa)*
NOTE: The medium values are a visual appreciation. In neither case does the filling pressure exceed the maximum value admitted by the material.		

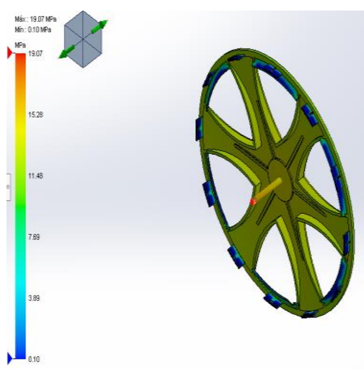
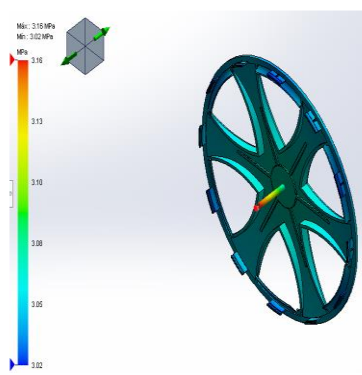
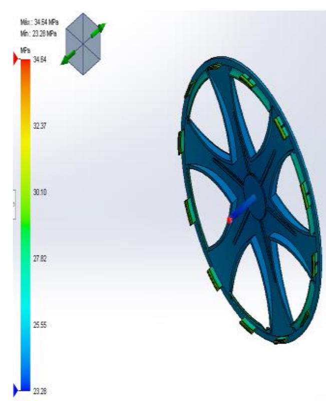
1.3. COOLING TIME

The cooling stage is intended for the reduction of the material temperature to the strain temperature under bending load, the ejection temperature. Cooling time typically accounts for 70% of the total cycle time.

COOLING TIME		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 73.01 (s)* ***Min**: 73.01 (s)* ***Average**: 73.01 (s)*	***Max:** 63.18 (s)* ***Min:** 63.18 (s)* ***Average:** 63.18 (s)*	***Max:** 35.17 (s)* ***Min:** 35.17 (s)* ***Average:** 35.17 (s)*
NOTE: The cooling times are quite high for the type of part to be manufactured.		

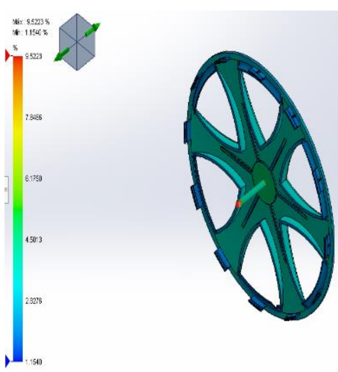
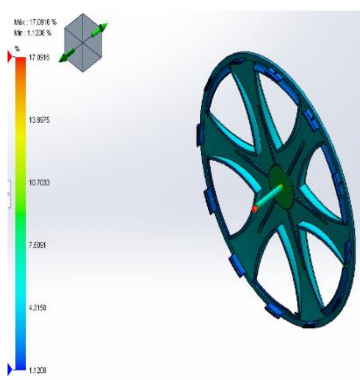
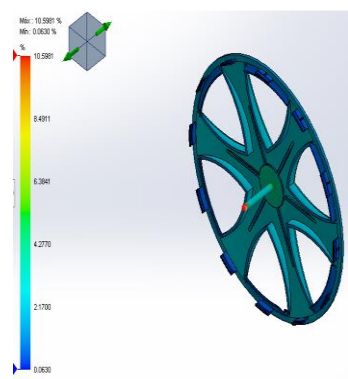
1.4. PRESSURE AT THE END OF PACKAGING

The pressure exerted on the cavity during the packaging stage is controlled by the spindle with reciprocating motion. This causes a relatively slow spindle feed rate to pack the cavity at that pressure. The packaging pressure propagates through the molten plastic and causes a drop in pressure distributed along the flow. The pressure drop is a function of the length of the flow, the wall thickness of the part and the viscosity of the material.

PRESS AT THE END OF PACKAGING		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
Max: *19.1 (Mpa)* ***Min***: *0.1 0 (Mpa)* ***Average***: *11.48 (Mpa)*	***Max:*** *3.16 (Mpa)* ***Min:*** *3.02 (Mpa)* ***Average:*** *3.08 (Mpa)*	***Max:*** *34.64 (Mpa)* ***Min:*** *23.28 (Mpa)* ***Average:*** *31.10 (Mpa)*
NOTE: The average value is a visual appreciation.		

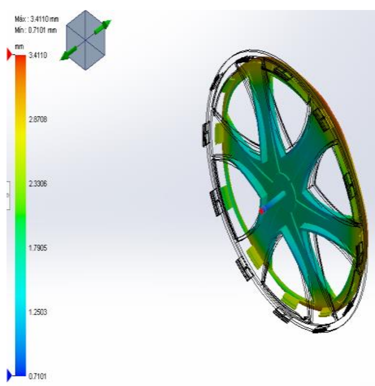
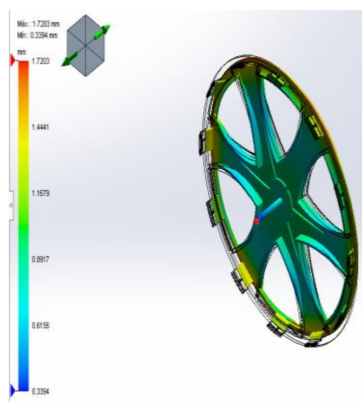
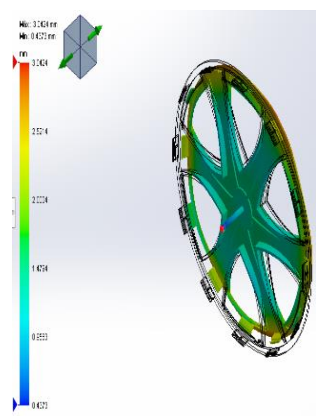
1.5. VOLUME SHRINKAGE AT THE END OF PACKAGING

Plastic materials are compressible because their specific volumes are a function of temperature and pressure. High shrinkage rates occur in areas of the plastic part that have not undergone proper packaging. You will encounter problems if the volume shrinkage plot at the end of the packaging indicates a significant number of red areas. The red areas indicate the presence of sink marks and could produce voids or deformations.

VOLUME CONTRACTION AT THE END PACKAGING		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 9.23 (%)* ***Min**: 1.15 (%)* ***Average**: 4.50 (%)*	***Max:** 17.16 (%)* ***Min:** 1.86 (%)* ***Average:** 14.11 (%)*	***Max:** 10.59 (%)* ***Min:** 0.06 (%)* ***Average:** 6.38 (%)*
NOTE: The average value is a visual appreciation. In all three cases the volume concentration is excessive. The values indicate some kind of anomaly.		

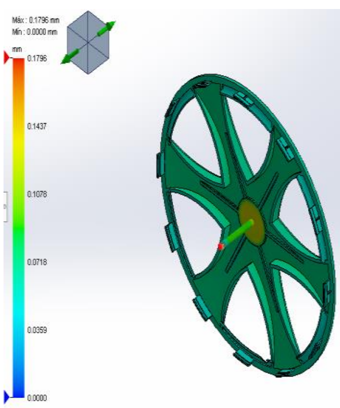
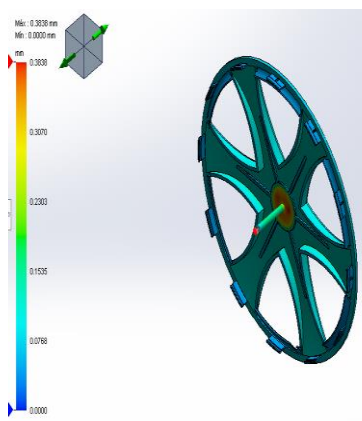
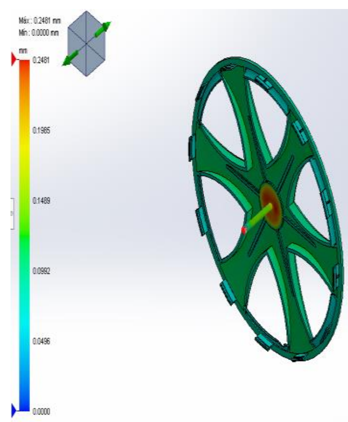
1.6. TOTAL STRESS DISPLACEMENTS

The deformation of a molded part is a complex phenomenon that can occur due to several causes, including but not limited to: non-uniform shrinkage, differential mold stress, non-uniform cooling speed, molecular and fiber orientation, variable packaging.

TOTAL STRESS DISPLACEMENTS		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 3.41 (mm)* ***Min**: 0.71 (mm)* ***Average**: 1.82 (mm)*	***Max:** 1.72 (mm)* ***Min:** 0.33 (mm)* ***Average:** 0.89 (mm)*	***Max:** 3.04 (mm)* ***Min:** 0.44 (mm)* ***Average:** 1.48 (mm)*
NOTE: The average value is a visual appreciation. In all three cases the deformation far exceeds the theoretical values of concentration. Possible anomaly.		

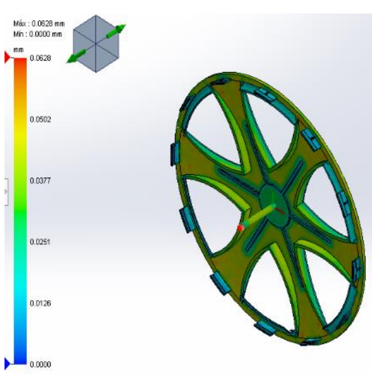
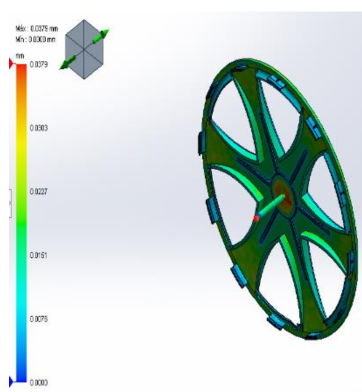
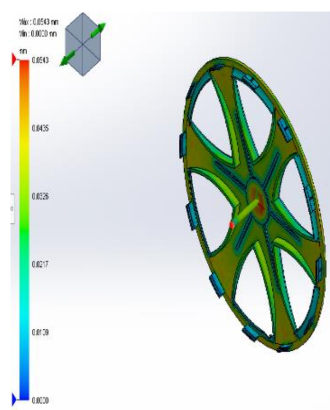
1.7. SIZE OF SINK MARKS

Sink Marks are depressions on the surface of an injection-molded piece of plastic. The root cause of shrinkage is that not enough polymer molecules have been packed into a piece to compensate for the shrinkage that occurs. Thicker sections of a piece cool at a slower rate than thinner sections, causing considerable shrinkage in thicker sections.

SIZE OF RECHUPES		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 0.18 (mm)* ***Min**: 0.00 (mm)* ***Average**: 0.11 (mm)*	***Max:** 0.39 (mm)* ***Min:** 0.00 (mm)* ***Average:** 0.19 (mm)*	***Max:** 0.25 (mm)* ***Min:** 0.0 0(mm)* ***Average:** 0.15 (mm)*
NOTE: The average value is a visual appreciation. In all three cases a good surface finish is appreciated.		

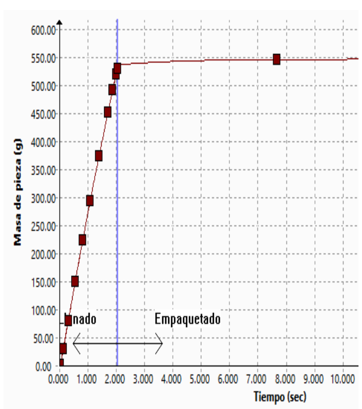
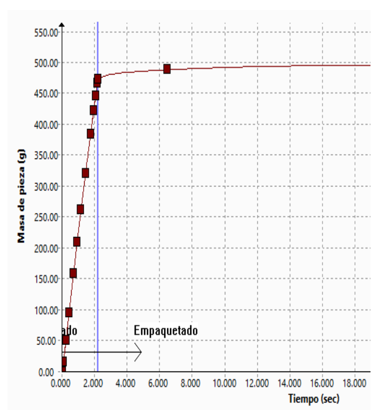
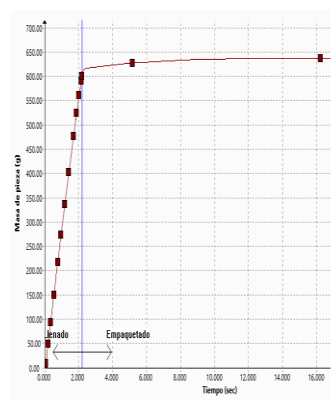
1.8. SINK MARKS PROFILE

The high degree of contraction in the internal volume moves the surface of the piece inwards, which forms a depression on the surface of the piece forming a profile of the depths of the sink marks.

RECHUPES PROFILE		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 0.06 (mm)* ***Min**: 0.00 (mm)* ***Average**: 0.04 (mm)*	***Max:** 0.04 (mm)* ***Min:** 0.00(mm)* ***Average:** 0.02 (mm)*	***Max:** 0.05 (mm)* ***Min:** 0.00 (mm)* ***Average:** 0.04 (mm)*
NOTE: The average value is a visual appreciation. In all three cases a good surface finish is appreciated.		

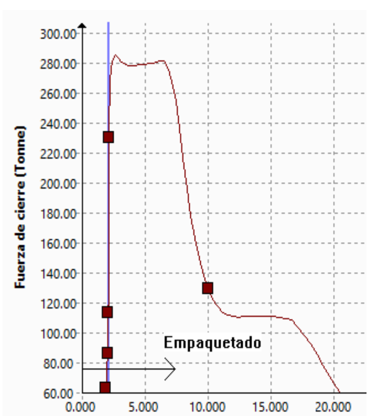
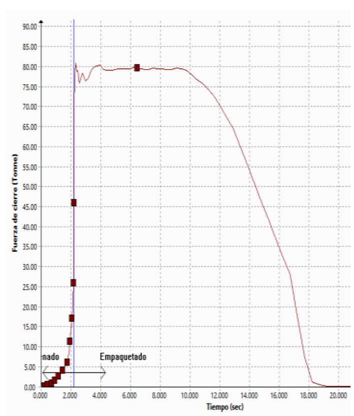
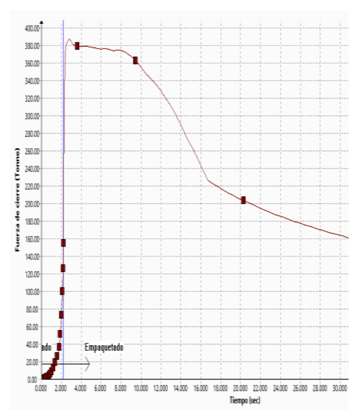
1.9. PART MASS

During the processes of filling and packaging, the material weight of the piece is in continuous variation until the mold opens. You can see in the results the evolution of the weight of the piece throughout the processes.

<table>
<tr><th colspan="3">PART MASS</th></tr>
<tr><td>RONFALIN FF50 (ABS)</td><td>PP 412MN 40 (PP)</td><td>XANTAR 18 R (PC)</td></tr>
<tr>
<td>
</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Max: 552.17 (gr)
Min: 552.17 (gr)
Average: 552.17 (gr)</td>
<td>Max: 487.83 (gr)
Min: 487.83 (gr)
Average: 487.83 (gr)</td>
<td>Max: 636.72 (gr)
Min: 636.72 (gr)
Average: 636.72 (gr)</td>
</tr>
<tr><td colspan="3"><u>NOTE:</u> The final mass of the piece is slightly above expectations. Possible anomaly.</td></tr>
</table>

1.10. CLAMPING FORCE

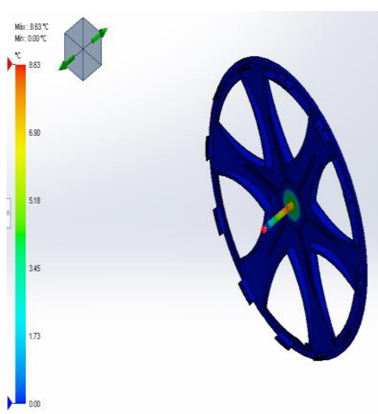
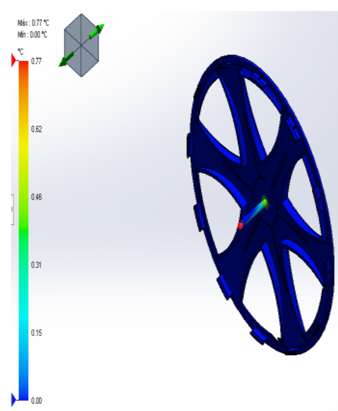
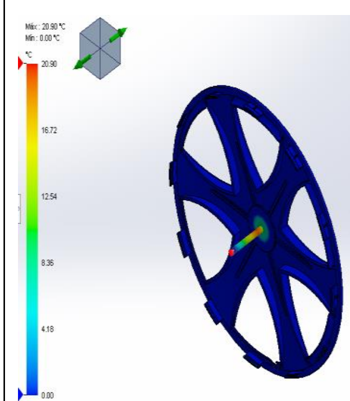
The available clamping force is the closing tonnage that the machine is capable to perform. The machine needs to have sufficient clamping force to keep the mold closed to withstand the plastic pressure that is developing within the mold cavities and cold casting.

<table>
<tr><th colspan="3">CLAMPING FORCE</th></tr>
<tr><td>RONFALIN FF50 (ABS)</td><td>PP 412MN 40 (PP)</td><td>XANTAR 18 R (PC)</td></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Max: 286.00 (tonne)
Min: 286.00 (tonne)
Average: 286.00 (tonne)</td><td>Max: 82.00 (tonne)
Min: 82.00 (tonne)
Average: 82.00 (tonne)</td><td>Max: 386.00 (tonne)
Min: 386.00 (tonne)
Average: 386.00 (tonne)</td></tr>
<tr><td colspan="3"><u>NOTE:</u> The resulting forces obtained are well below those expected. Possible anomaly.</td></tr>
</table>

2. SECONDARY RESULTS ANALYSIS

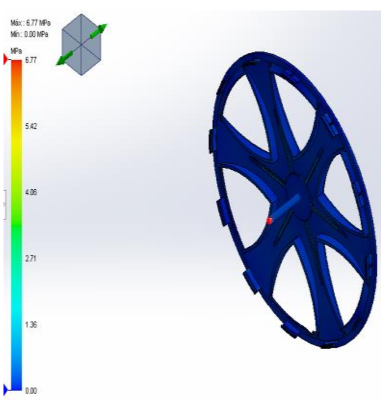
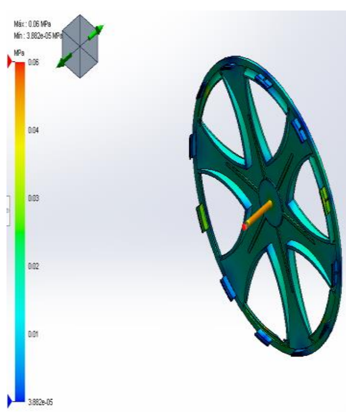
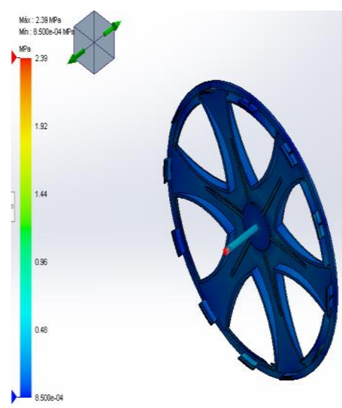
2.1. TEMPERATURE INCREASE AT THE END OF FILLING

This increase in temperature is due to high shear rates, which can increase the temperature of the material in the cavity above the set material temperature. The temperature increase may be due to too short a filling time, the use of small injection points or the characteristics of the material flow, under extreme conditions, the material can degrade.

TEMPERATURE INCREASE TO THE END OF FILLING		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 8.63 (C°)* ***Min**: 0.00 (C°)* ***Average**: 5.18 (C°)*	***Max:** 0.77 (C°)* ***Min:** 0.00 (C°)* ***Average:** 0.46 (C°)*	***Max:** 20.90 (C°)* ***Min:** 0.00 (C°)* ***Average:** 4.18 (C°)*
<u>NOTE:</u> The average value is a visual appreciation. Temperature increases are higher than expected. Possible anomaly.		

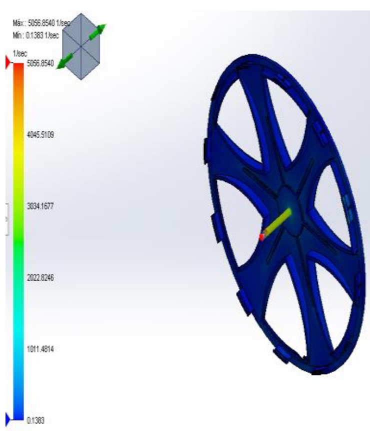
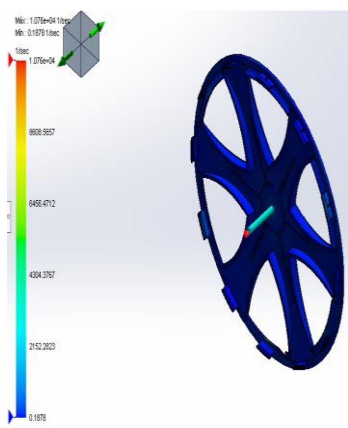
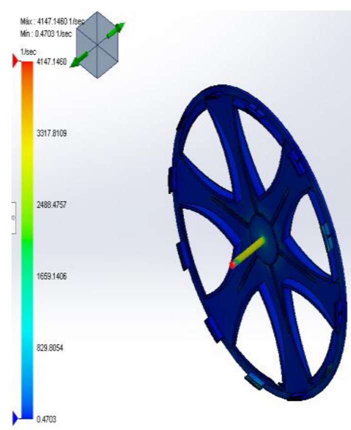
2.2. SHEAR STRESSES AT THE END OF FILLING

In the injection molding process, the polymer material undergoes shear heating during the filling stage. This increase in temperature is due to high shear rates, which can increase the temperature of the material in the cavity above the set material temperature.

SHEAR STRESSES TO THE END OF FILLING		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 6.77 (Mpa)* ***Min**: 0.00 (Mpa)* ***Average**: 4.6 (Mpa)*	***Max:** 0.06 (Mpa)* ***Min:** 0.00 (Mpa)* ***Average:** 0.03 (Mpa)*	***Max:** 2.39 (Mpa)* ***Min:** 0.00 (Mpa)* ***Average:** 0.93 (Mpa)*
<u>NOTE:</u> The average value is a visual appreciation. Acceptable values.		

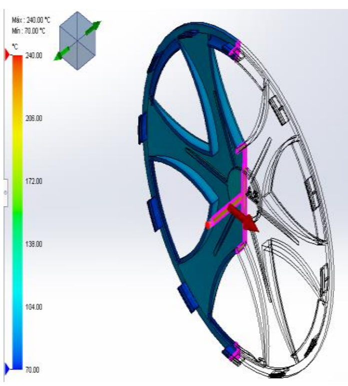
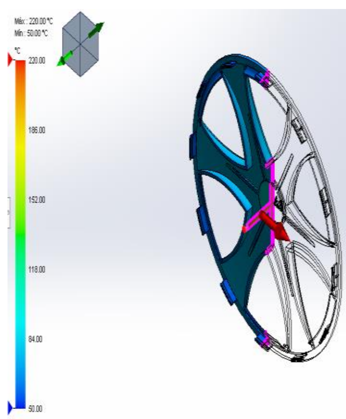
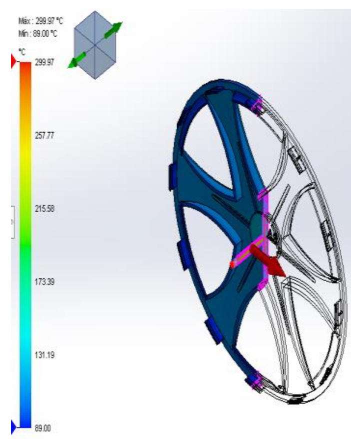
2.3. SHEAR RATE AT THE END OF PACKAGING

The shear rate measures the velocity of one layer of fluid as it passes over another layer moving at a different speed. The solidified plastic material in contact with the cavity wall does not move relative to the wall, which causes a shear rate of zero value (0.0 1/s).

SHEAR RATE To the END OF FILLING		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
Max: *5056.86 (1/s)* ***Min***: *0.14 (1/s)* ***Average***: *500.68 (1/s)*	***Max:*** *10076.15 (1/s)* ***Min:*** *0.18 (1/s)* ***Average:*** *4304.37 (1/s)*	***Max:*** *4147.15 (1/s)* ***Min:*** *0.47 (1/s)* ***Average:*** *437.83 (1/s)*
NOTE: The average value is a visual appreciation. Values indicate good fluency.		

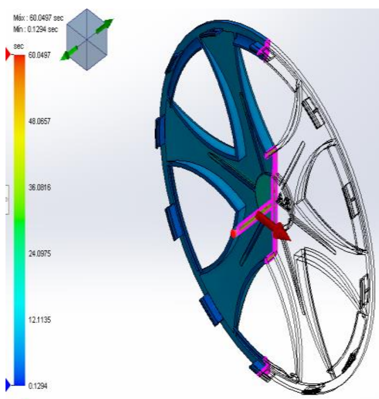
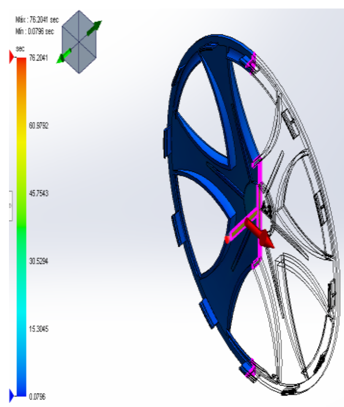
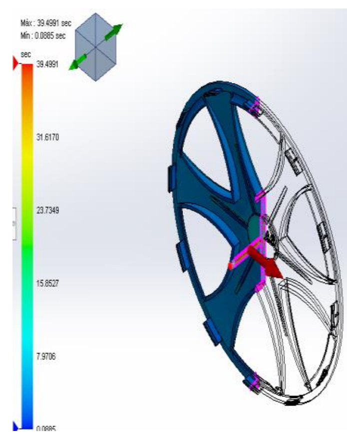
2.4. TEMPERATURE AT THE END OF PACKAGING

At the end of the packaging stage, the surface of the part has cooled to the mold temperature and the part appears blue. The internal volume of the part could still be molten, close to the crystalline transition of the material (T_g) or the temperature of the material (T_m).

TEMPERATURE AT THE END PACKAGING		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 240.00 (C°)* ***Min**: 70.00 (C°)* ***Average**: 172.00 (C°)*	***Max:** 220.00 (C°)* ***Min:** 50.00 (C°)* ***Average:** 186.00 (C°)*	***Max:** 299.97 (C°)* ***Min:** 89.00 (C°)* ***Average:** 215.57 (C°)*
NOTE: The average value is a visual appreciation. The values obtained are too high. Possible anomaly.		

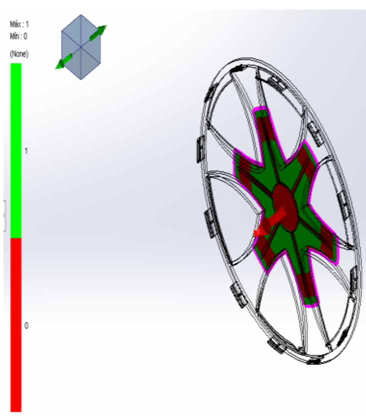
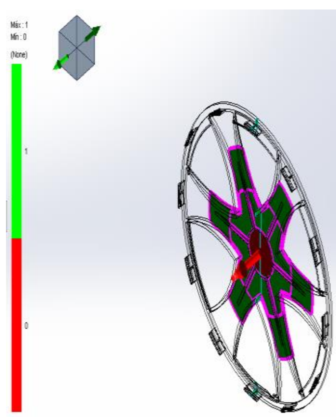
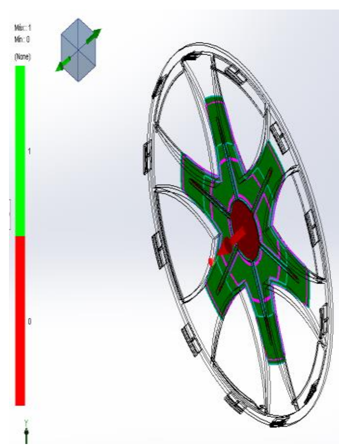
2.5. SOLIDIFICATION TIME AT THE END OF PACKAGING

The scale used for the solidification time at the end of post-filling indicates the time needed for the molten plastic material to cool to crystalline transition temperature. The time needed to reduce a molten material to crystalline transition temperature is not the time needed to cool the part to its ejection temperature.

SOLIDIFICATION TIME		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 60.0 4(s)* ***Min**: 60.04 (s)* ***Average**: 60.04 (s)*	***Max:** 76.20 (s)* ***Min:** 76.20 (s)* ***Average:** 76.20 (s)*	***Max:** 39.50 (s)* ***Min:** 39.50 (s)* ***Average:** 39.50 (s)*
NOTE: Values too high for the part type.		

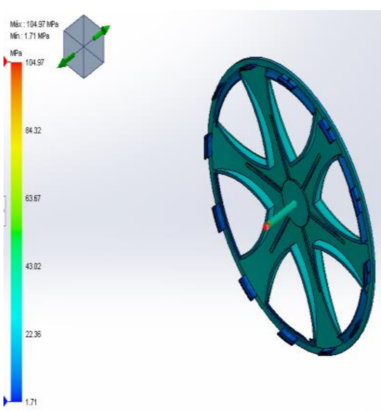
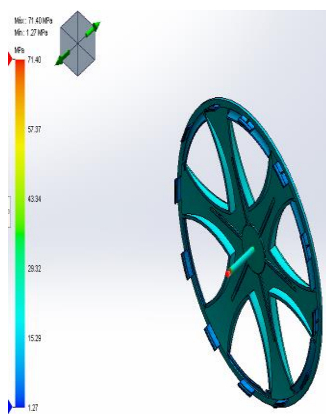
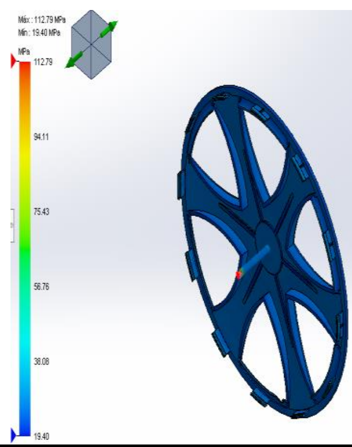
2.6. SOLIDIFIED REGION AT THE END OF PACKAGING

The tracing of the solidified region at the end of post-filling indicates the region of the material that have reached the crystalline transition temperature (green, value = 1). Red areas (value = 0) indicate that the material is above the crystalline transition temperature.

REGION SOLIDIFIED AT THE END OF PACKAGING		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 1 (OK)* ***Min**: 0 (NOK)* ***Medium**: -*	***Max:** 1 (OK)* ***Min:** 0 (NOK)* ***Medium: -***	***Max:** 1 (OK)* ***Min:** 0 (NOK)* ***Medium: -***
<u>NOTE:</u> Data indicate undesirable results. Regions too large without solidifying.		

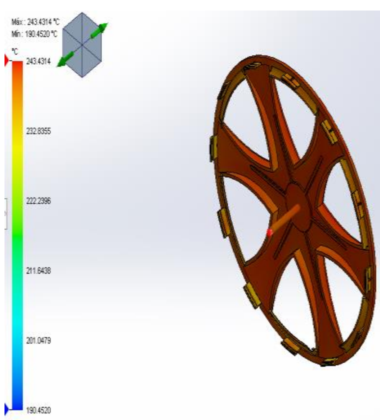
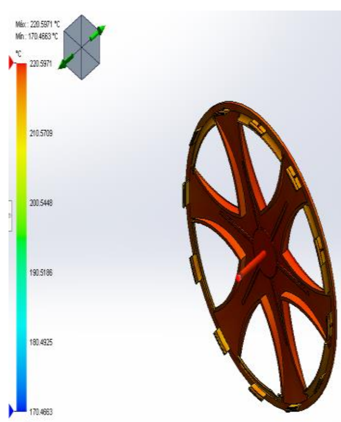
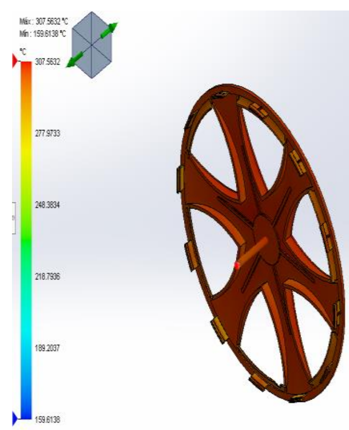
2.7. RESIDUAL STRESSES AT THE END OF PACKAGING

During the injection molding process, the polymer is exposed to thermal and physical stresses. Residual stresses are forces trapped within the polymer as it cools from the melted state to the crystalline transition temperature. Residual stresses are the result of non-uniform variations in cooling and pressure that take place in the viscoelastic polymer material during molding.

RESIDUAL STRESSES AT THE END OF THE POST FILLING		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 104.97 (Mpa)* ***Min**: 1.17 (Mpa)* ***Average**: 43.02 (Mpa)*	***Max:** 71.40 (Mpa)* ***Min:** 1.26 (Mpa)* ***Average:** 29.32 (Mpa)*	***Max:** 112.79 (Mpa)* ***Min:** 19.40 (Mpa)* ***Average:** 38.08 (Mpa)*
NOTE: The average value is a visual appreciation. The results are too high.		

2.8. FLOW FRONT TEMPERATURE

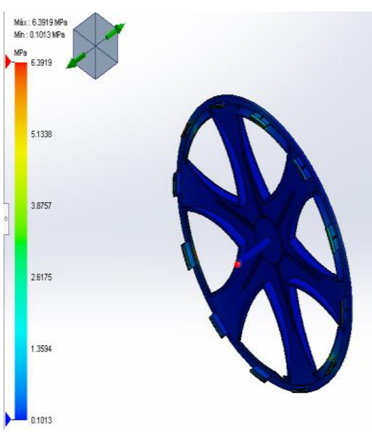
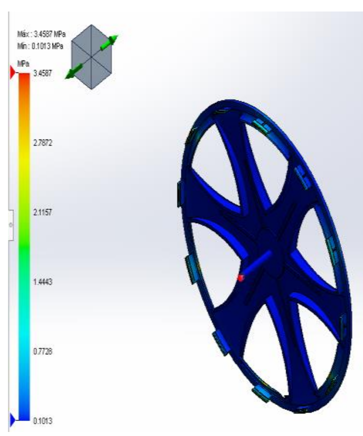
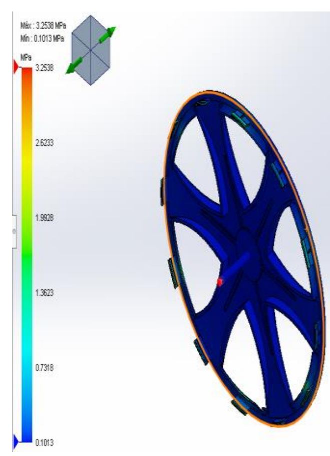
The flow front temperature during the injection molding process is the temperature of the material as it moves into the mold. This temperature may depend on shear or cooling stresses.

FRONT TEMPERATURE FLOW		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 243.93 (C°)* ***Min**: 190.45 (C°)* ***Average**: 240.12 (C°)*	***Max**: 220.59 (C°)* ***Min:** 170.46 (C°)* ***Average:** 217.13 (C°)*	***Max:** 307.56 (C°)* ***Min:** 159.61 (C°)* ***Average:** 299.98 (C°)*
NOTE: The average value is a visual appreciation. The values obtained are quite favorable.		

3. COMMON AND TERTIARY RESULTS OF ANALYSIS.

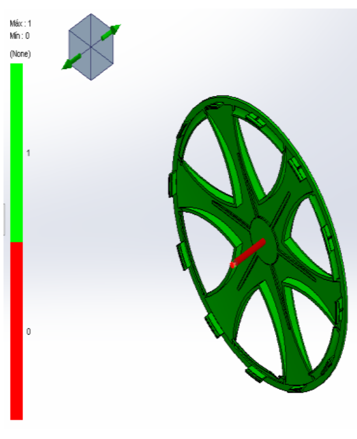
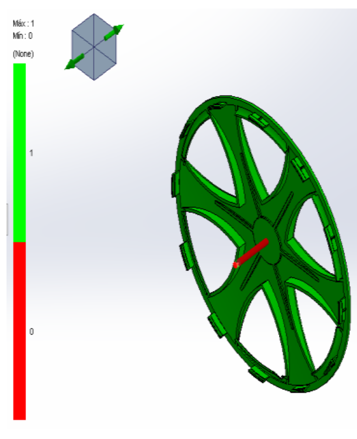
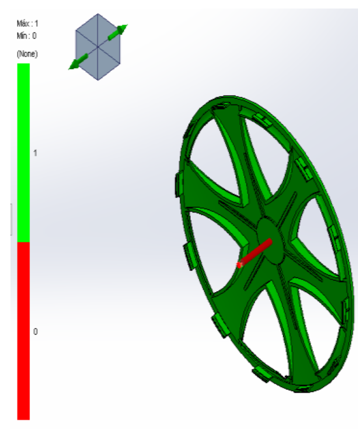
3.1. VENTILATION PRESSURE

As the piece fills, air from the cavity tries to escape. If it does not succeed, it will cause brown, gray or black discolorations on the surface of the piece due to burns or desertification. This occurs because gases and volatiles are trapped in the mold, causing the gases to compress and heat up in the first injection (filling) stage. It is possible to release the gases through vents and avoid these discolorations.

VENTILATION PRESSURE		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 6.39 (Mpa)* ***Min**: 0.10 (Mpa)* ***Average**: 1.36 (Mpa)*	***Max:** 3.46 (Mpa)* ***Min:** 0.10 (Mpa)* ***Average:** 0.77 (Mpa)*	***Max:** 3.25 (Mpa)* ***Min:** 0.10 (Mpa)* ***Average:** 0.73 (Mpa)*
NOTE: The average value is a visual appreciation. The values obtained indicate the need for ventilation holes in the molds.		

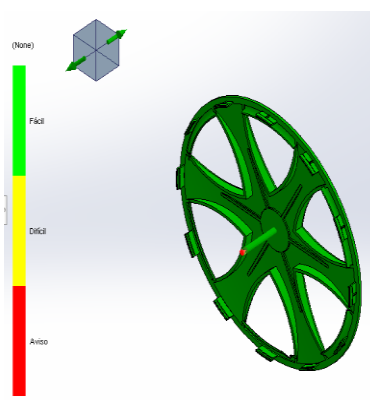
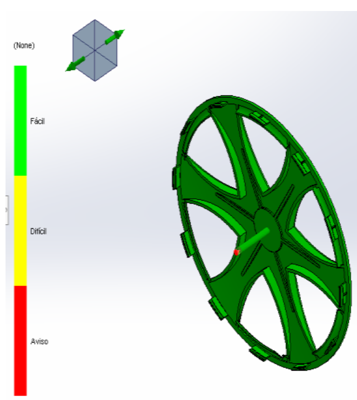
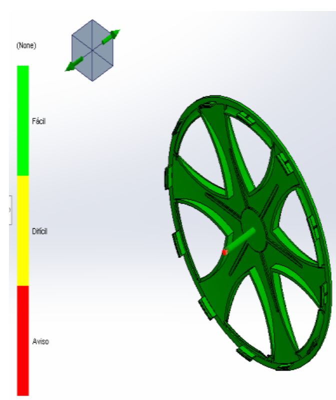
3.2. CONTRIBUTION TO THE FILLING OF INJECTION SITES

When only one injection site is used, the cavity is filled through it. When several injection sites are used, the cavity is partially filled with the material that is introduced through each of the points.

CONTRIBUTION TO FILLING OF THE INJECTION SITE		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
Max: *1 (OK)* ***Min***: *0 (NOK)* ***Medium***: *-*	***Max***: *1 (OK)* ***Min:*** *0 (NOK)* ***Medium: -***	***Max:*** *1 (OK)* ***Min:*** *0 (NOK)* ***Medium: -***
NOTE: Favorable results.		

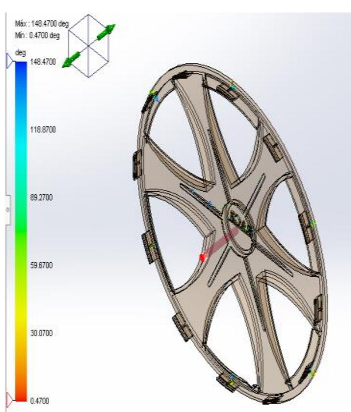
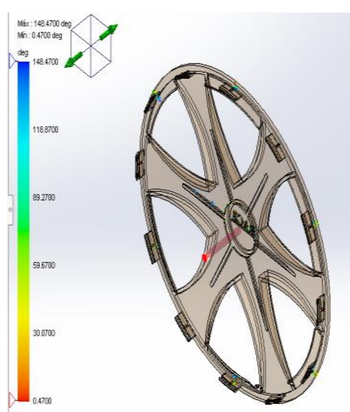
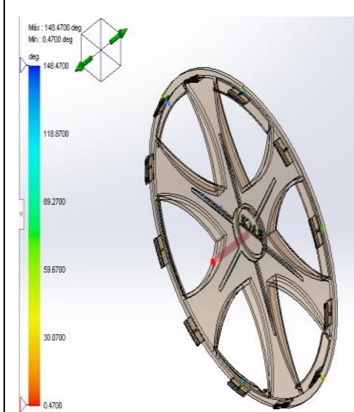
3.3 EASE OF FILLING

Green zones indicate areas that can be filled with normal injection pressures. Yellow zones indicate areas where the injection pressure exceeds 70 percent of the machine's maximum injection pressure. The red zones indicate areas where the injection pressure exceeds 85 percent of the machine's maximum injection pressure.

EASE OF FILLING		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: EASY* ***Min**: NOTICE* ***Medium**: -*	***Max:** EASY* ***Min:** NOTICE* ***Medium: -***	***Max:** EASY* ***Min:** NOTICE* ***Medium: -***
NOTE: Favorable results.		

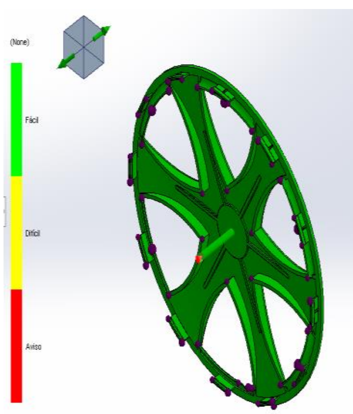
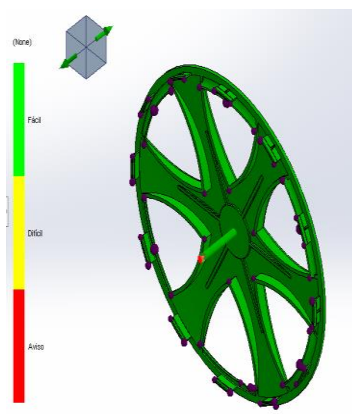
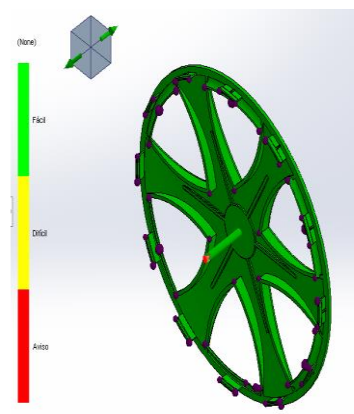
3.4. WELDING LINES

Welding lines are formed when two or more flow fronts of the molten plastic converge. Among the possible causes for its formation are the closing surfaces of the mold, the characteristics of the mold core, the existence of several injection points or variations in the thickness of the walls that cause an increase in speed or a stagnation of the flow front. Welding lines are generally weaker than areas without weld lines and usually cause visual defects. They can also act as stress concentrators in the molded part.

WELDING LINES		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 148.47 (deg)* ***Min**: 0.47 (deg)* ***Medium**: -*	***Max:** 148.47 (deg)* ***Min:** 0.47 (deg)* ***Medium:** -*	***Max:** 148.47 (deg)* ***Min:** 0.47 (deg)* ***Medium:** -*
NOTE: In all three cases the welding lines are generated in the same places.		

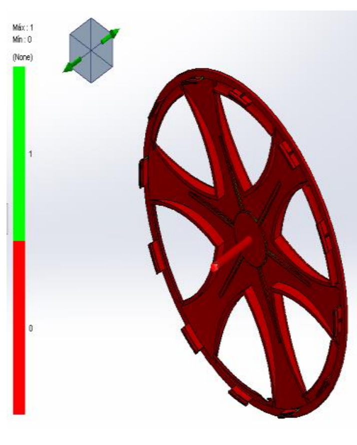
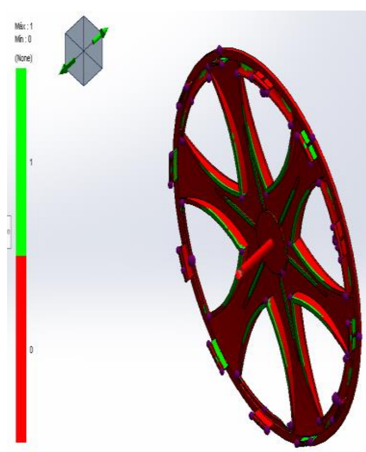
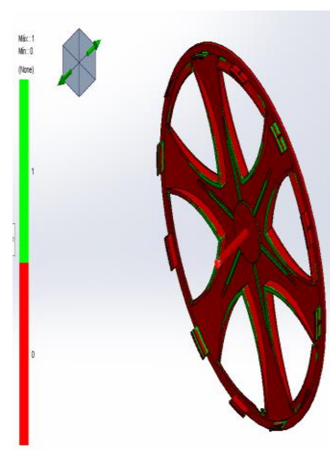
3.5. AIR ENTRAPMENTS

If the air from the mold cavity cannot be expelled into the atmosphere during the filling stage, the trapped air can cause the plastic material not to fill the volume where the air is trapped. This can result in an incomplete filling and packaging process at the location of the trapped air or even a hole in the part caused by trapped air.

AIR ENTRAPMENTS		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
Max: - ***Min***: - ***Medium***: -	***Max: -*** ***Min: -*** ***Medium: -***	***Max: -*** ***Min: -*** ***Medium: -***
NOTE: In all three cases we have the same locations of air traps.		

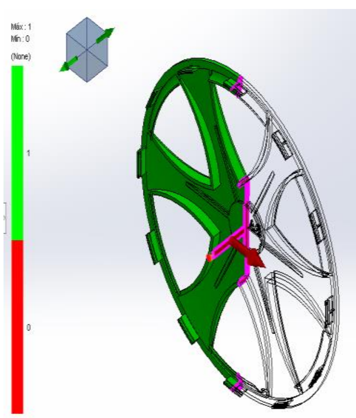
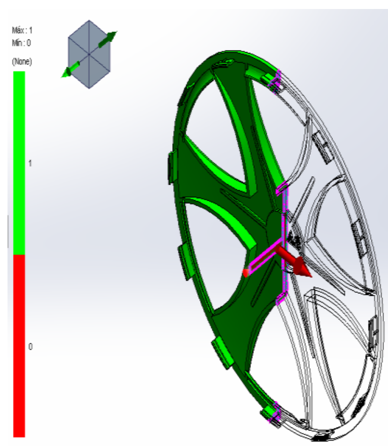
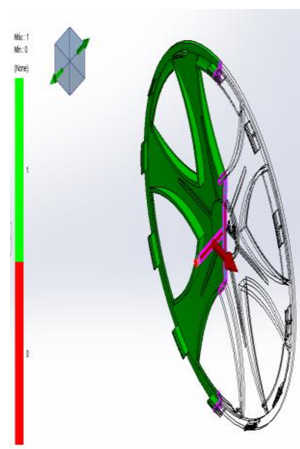
3.6. SOLIDIFIED REGION AT THE END OF FILLING

The tracing of the solidified region at the end of the filling indicates the areas of the part that have reached the crystalline transition temperature of the material. Green areas (value 1) indicate that the material has reached the crystalline transition temperature of the material. Red areas (value 0) indicate that the material still exceeds the crystalline transition temperature. The solidified region at the end of filling indicates the thickness of the solidified layer that increases during the source flow.

SOLIDIFIED REGION AT THE END OF FILLING		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 1 (OK)* ***Min**: 0 (NOK)* ***Medium**: -*	***Max:** 1 (OK)* ***Min:** 0 (NOK)* ***Medium: -***	***Max:** 1 (OK)* ***Min:** 0 (NOK)* ***Stocking:-***
NOTE: Favorable results.		

3.7. SOLIDIFIED REGION AT THE END OF PACKAGING

The tracing of the solidified region at the end of post-filling indicates the parts of the material that have reached the crystalline transition temperature (green, value = 1). Red areas (value = 0) indicate that the material is above its crystalline transition temperature.

SOLIDIFIED REGION AT THE END OF POST-FILLING		
RONFALIN FF50 (ABS)	*PP 412MN 40 (PP)*	*XANTAR 18 R (PC)*
		
***Max**: 1 (OK)* ***Min**: 0 (NOK)* ***Medium**: -*	***Max:** 1 (OK)* ***Min:** 0 (NOK)* ***Medium: -***	***Max:** 1 (OK)* ***Min:** 0 (NOK)* ***Medium: -***
NOTE: The central nucleus of the cavity presents anomalies.		

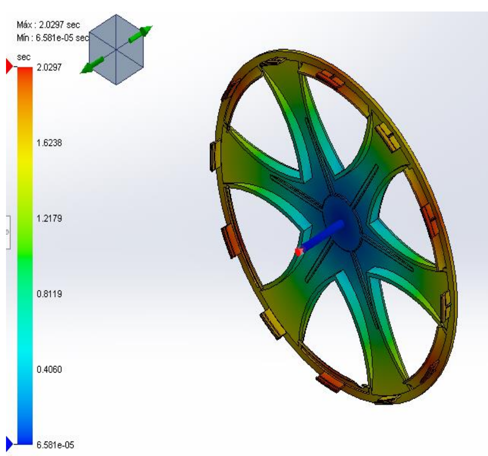
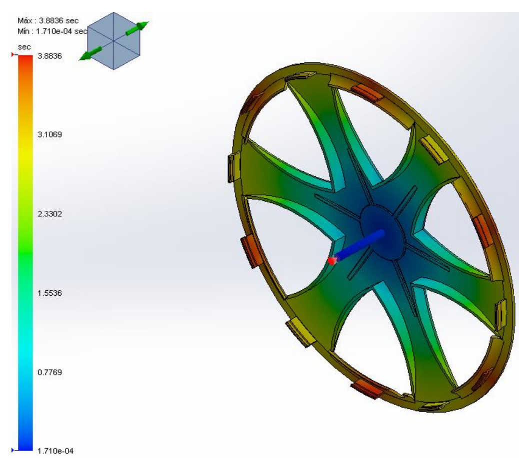
ANEXED II: SIMULATION RESULTS

INDEX

1. MAIN RESULTS OF ANALYSIS

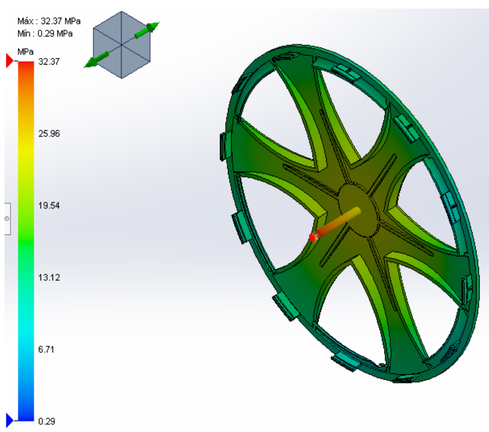
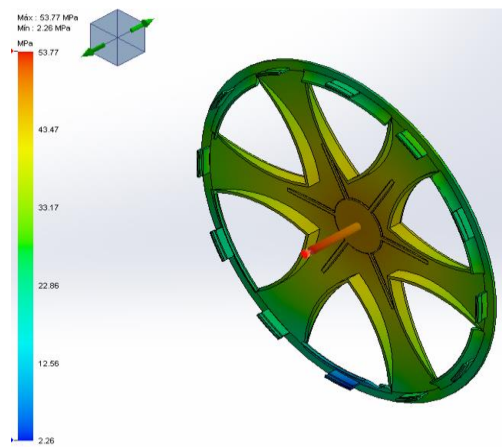
1.1. FILLING TIME

The filling time plot shows the profile of the plastic material as it flows through the mold part cavity during the filling stage of the injection molding process. The blue zones indicate the beginning of the flow front. The red areas indicate the end of the filling when the flow has stopped.

FILLING TIME	
RONFALIN FF50 (ABS) I	*RONFALIN FF50 (ABS) II*
	
Max: *2.03 (s)* ***Min:*** *2.03 (s)* ***Average:*** *2.03 (s)*	***Max:*** *3.88 (s)* ***Min:*** *3.88 (s)* ***Stocking:***
NOTE: Reducing the filling section should also increase the filling time to avoid excess pressure.	

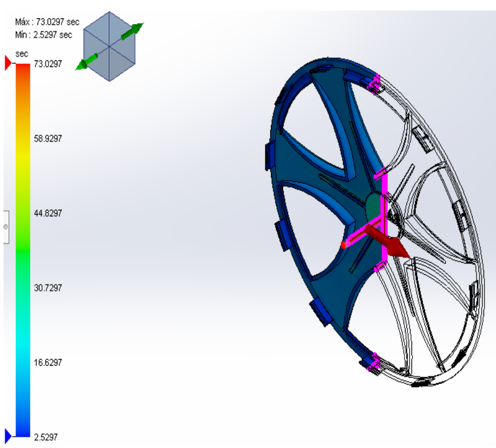
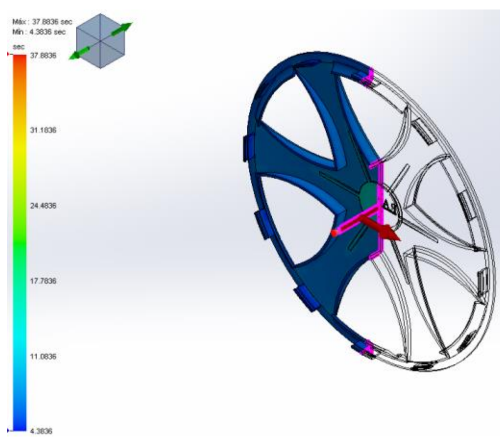
1.2. PRESSURE AT THE END OF FILLING

The injection pressure propagates through the molten plastic and causes a pressure drop that is distributed along the flow. The pressure at the end of filling is a good indication of the level of uniformity with which the cavity has been filled.

<table>
<tr><th colspan="2">PRESSURE AT THE END OF FILLING</th></tr>
<tr><td>RONFALIN FF50 (ABS) I</td><td>RONFALIN FF50 (ABS) II</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Max: 32.37 (Mpa)
Min: 0.29 (Mpa)
Average: 19.54 (Mpa)</td><td>Max: 53.77 (Mpa)
Min: 2.26 (Mpa)
Average: 25.17 (Mpa)</td></tr>
<tr><td colspan="2"><u>NOTE:</u> The pressure increase is as expected.</td></tr>
</table>

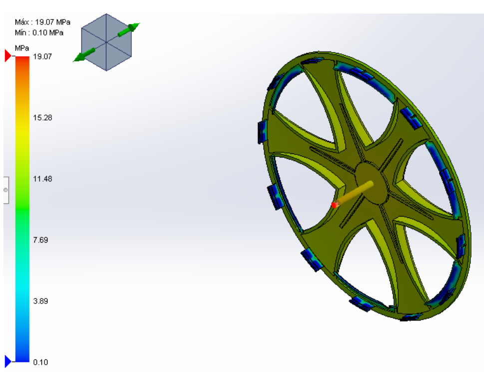
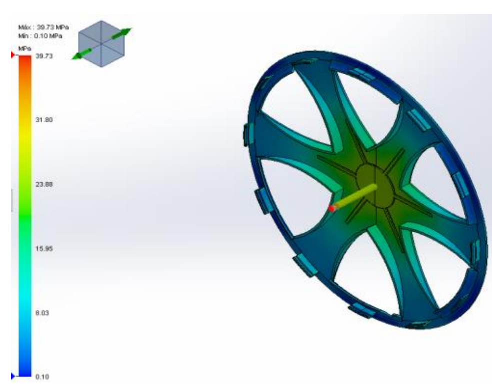
1.3. COOLING TIME

The cooling stage is intended for the reduction of the material temperature to the strain temperature under bending load, the ejection temperature. Cooling time typically accounts for 70% of the total cycle time.

<table>
<tr><th colspan="2">COOLING TIME</th></tr>
<tr><td>RONFALIN FF50 (ABS) I</td><td>RONFALIN FF50 (ABS) II</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Max: 73.01 (s)
Min: 73.01 (s)
Average: 73.01 (s)</td><td>Max: 37.88 (s)
Min: 37.88 (s)
Average: 37.88 (s)</td></tr>
<tr><td colspan="2"><u>NOTE:</u> There are considerable improvement in cooling time.</td></tr>
</table>

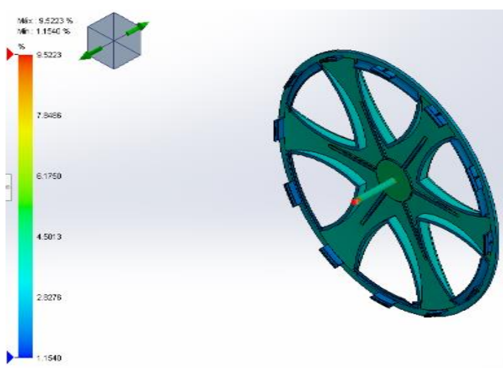
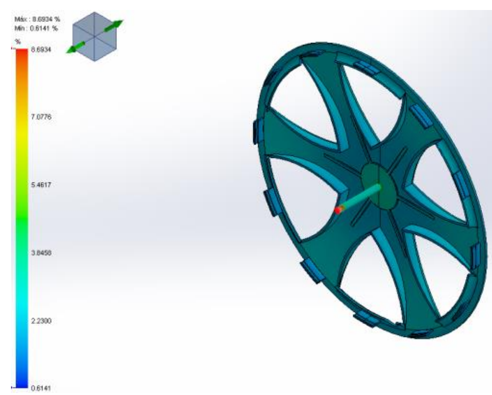
1.4. PRESSURE AT THE END OF PACKAGING

The pressure exerted on the cavity during the packaging stage is controlled by the spindle with reciprocating motion. This causes a relatively slow spindle feed rate to pack the cavity at that pressure. The packaging pressure propagates through the molten plastic and causes a drop in pressure distributed along the flow. The pressure drop is a function of the length of the flow, the wall thickness of the part and the viscosity of the material.

PRESSure AT THE END OF PACKAGING	
RONFALIN FF50 (ABS) I	*RONFALIN FF50 (ABS) II*
	
***Max**: 19.1 (Mpa)* ***Min**: 0.1 0 (Mpa)* ***Average**: 11.48 (Mpa)*	***Max:** 39.73 (Mpa)* ***Min:** 0.10 (Mpa)* ***Average:** 15.95 (Mpa)*
NOTE: The value average es a visual appreciation. There is an improvement in the distribution of pressures.	

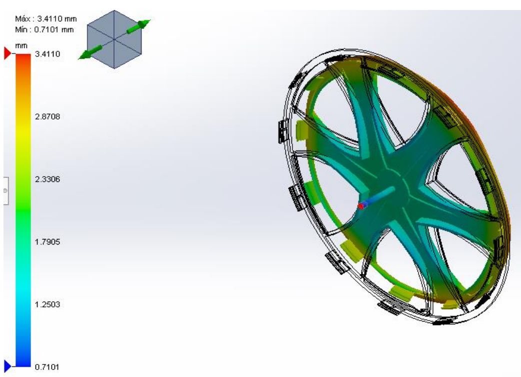
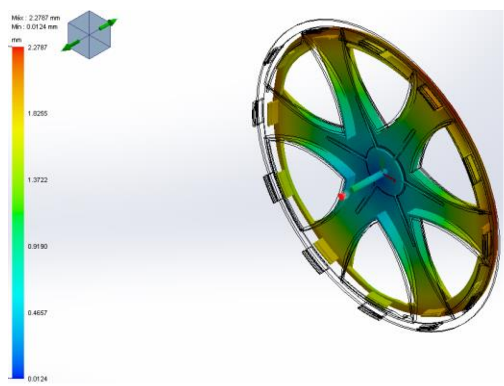
1.5. VOLUME SHRINKAGE AT THE END OF PACKAGING

Plastic materials are compressible because their specific volumes are a function of temperature and pressure. High shrinkage rates occur in areas of the plastic part that have not undergone proper packaging. You will encounter problems if the volume shrinkage plot at the end of the packaging indicates a significant number of red areas. The red areas indicate the presence of sink marks and could produce voids or deformations.

VOLUME CONTRACTION AT THE END PACKAGING	
RONFALIN FF50 (ABS) I	*RONFALIN FF50 (ABS) II*
	
***Max**: 9.52 (%)* ***Min**: 1.15 (%)* ***Average**: 4.50 (%)*	***Max:** 8.69 (%)* ***Min:** 0.61 (%)* ***Average:** 3.85 (%)*
NOTE: Hhas improved volume shrinkage.	

1.6. TOTAL STRESS DISPLACEMENTS

The deformation of a molded part is a complex phenomenon that can occur due to several causes, including but not limited to: non-uniform shrinkage, differential mold stress, non-uniform cooling speed, molecular and fiber orientation, variable packaging.

<table>
<tr><th colspan="2">TOTAL VOLTAGE DISPLACEMENTS</th></tr>
<tr><td>RONFALIN FF50 (ABS) I</td><td>RONFALIN FF50 (ABS) II</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Max: 3.41 (mm)

Min: 0.71 (mm)

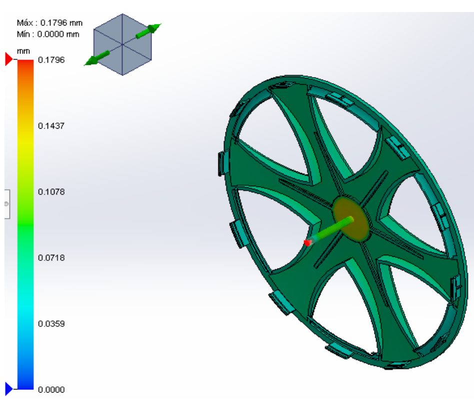
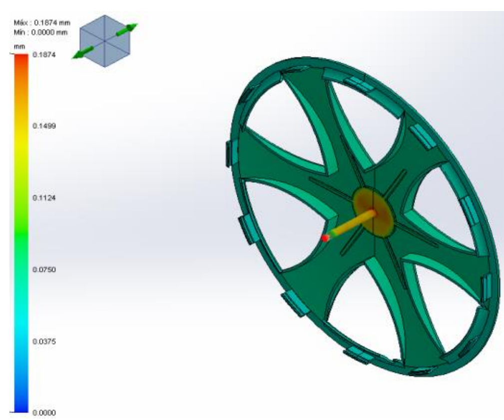
Average: 1.82 (mm)</td><td>Max: 2.28 (mm)

Min: 0.012 (mm)

Average: 1.37 (mm)</td></tr>
<tr><td colspan="2"><u>NOTE:</u> The contraction values are very close to the theoretical estimate.</td></tr>
</table>

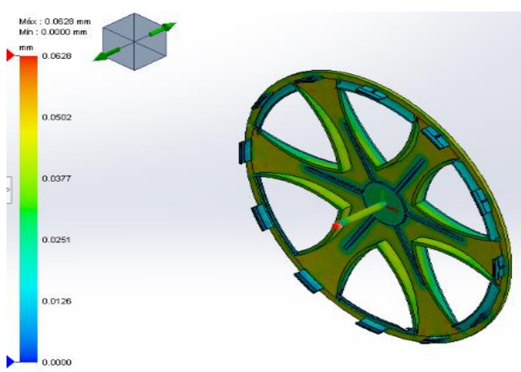
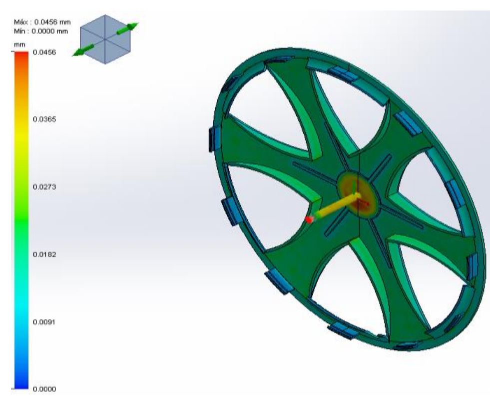
1.7. SIZE OF SINK MARKS

Sink marks are depressions on the surface of an injection-molded piece of plastic. The root cause of shrinkage is that not enough polymer molecules have been packed into a piece to compensate for the shrinkage that occurs. Thicker sections of a piece cool at a slower rate than thinner sections, causing considerable shrinkage in thicker sections.

SIZE OF RECHUPES	
RONFALIN FF50 (ABS) I	*RONFALIN FF50 (ABS) II*
	
***Max**: 0.18 (mm)* ***Min**: 0.00 (mm)* ***Average**: 0.11 (mm)*	***Max:** 0.19 (mm)* ***Min:** 0.00 (mm)* ***Average:** 0.08 (mm)*
NOTE: There is no markable difference in surface finish.	

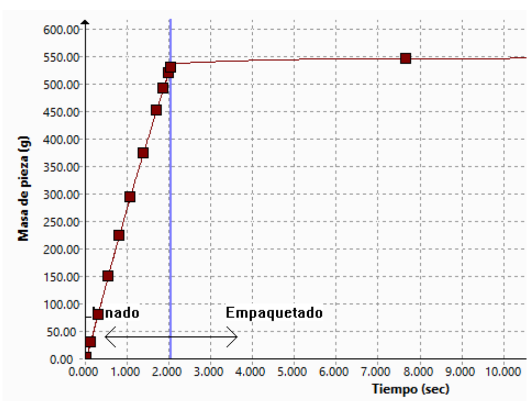
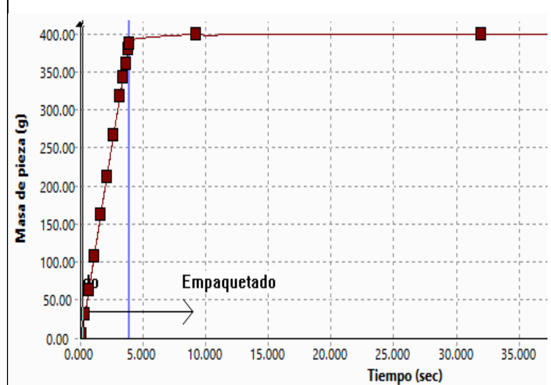
1.8. SINK MARKS PROFILE

The high degree of contraction in the internal volume moves the surface of the piece inwards, which forms a depression on the surface of the piece forming a profile of the depths of the sink marks.

RECHUPES PROFILE	
RONFALIN FF50 (ABS) I	*RONFALIN FF50 (ABS) II*
	
***Max**: 0.06 (mm)* ***Min**: 0.00 (mm)* ***Average**: 0.04 (mm)*	***Max:** 0.04 (mm)* ***Min:** 0.00 (mm)* ***Average:** 0.02 (mm)*
<u>NOTE:</u> There is no difference in surface finishing.	

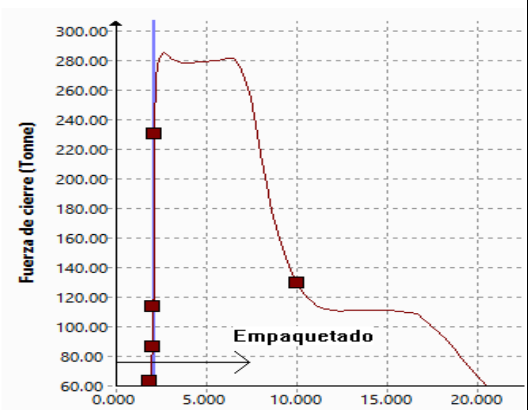
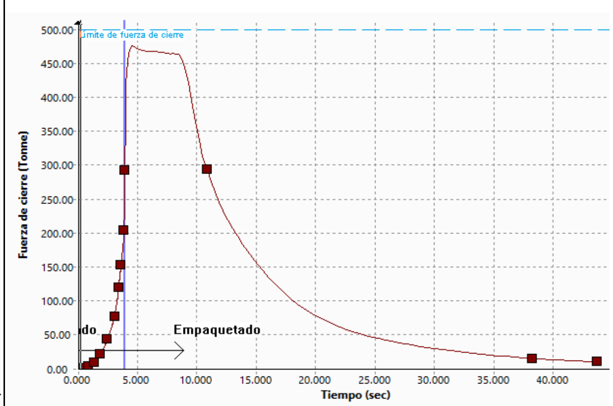
1.9. PART MASS

During the processes of filling and packaging the material weight of the piece is in continuous variation until the mold opens. You can see in the results the evolution of the weight of the piece throughout the processes.

PART MASS	
RONFALIN FF50 (ABS) I	*RONFALIN FF50 (ABS) II*
	
***Max**: 552.17 (gr)* ***Min**: 552.17 (gr)* ***Average**: 552.17 (gr)*	***Max:** 399.89 (gr)* ***Min:** 399.89 (gr)* ***Average:** 399.89 (gr)*
NOTE: Considerable improvement in the reduction of mass of the piece.	

1.10. CLAMP FORCE

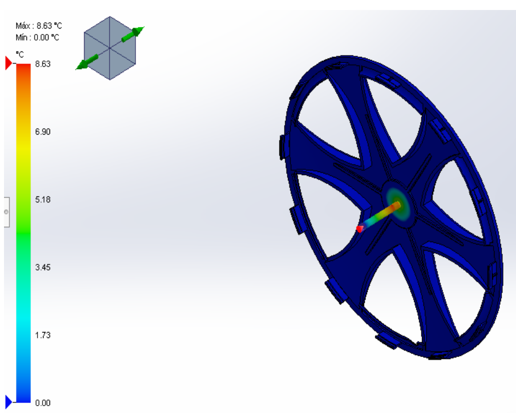
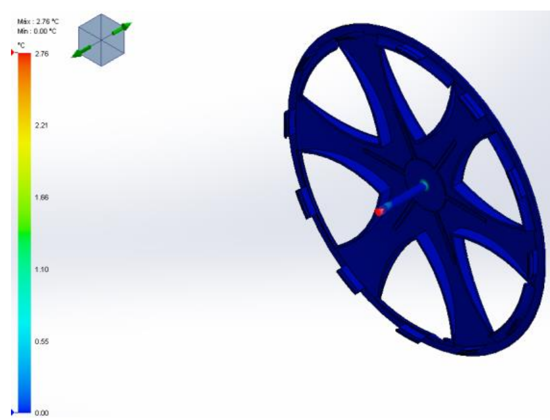
The available clamping force is the tonnage that the machine is capable of perform. The machine needs to have sufficient closing force to keep the mold closed to withstand the plastic pressure that is developing within the mold cavities and cold casting.

CLAMPING FORCE	
RONFALIN FF50 (ABS) I	*RONFALIN FF50 (ABS) II*
	
Max: *286.00 (tonne)* ***Min***: *286.00 (tonne)* ***Average***: *286.00 (tonne)*	***Max:*** *475.36 (tonne)* ***Min:*** *475.36 (tonne)* ***Average:*** *475.36 (tonne)*
<u>NOTE:</u> Considerable increase in closing force.	

2. SECONDARY RESULTS ANALYSIS

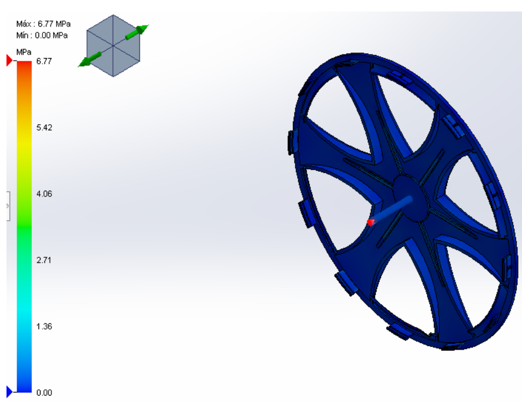
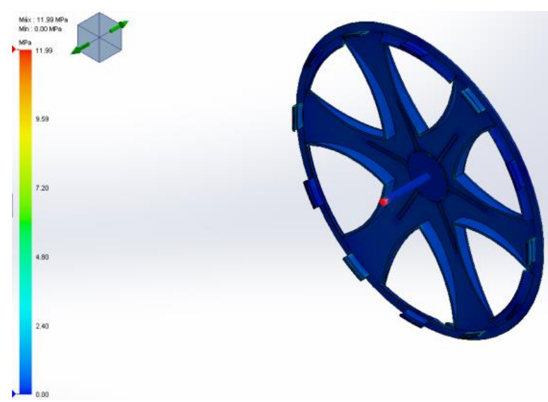
2.1. TEMPERATURE INCREASE AT THE END OF FILLING

This increase in temperature is due to high shear rates, which can increase the temperature of the material in the cavity above the set material temperature. The temperature increase may be due to a short filling time, the use of small injection points or the characteristics of the material flow. Under extreme conditions, the material can degrade.

<table>
<tr><th colspan="2">TEMPERATURE INCREASE
To the
END OF FILLING</th></tr>
<tr><td>RONFALIN FF50 (ABS) I</td><td>RONFALIN FF50 (ABS) II</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Max: 8.63 (C°)
Min: 0.00 (C°)
Average: 5.18 (C°)</td><td>Max: 2.76 (C°)
Min: 0.00 (C°)
Average: 1.25 (C°)</td></tr>
<tr><td colspan="2"><u>NOTE:</u> Considerable improvement in temperature variation.</td></tr>
</table>

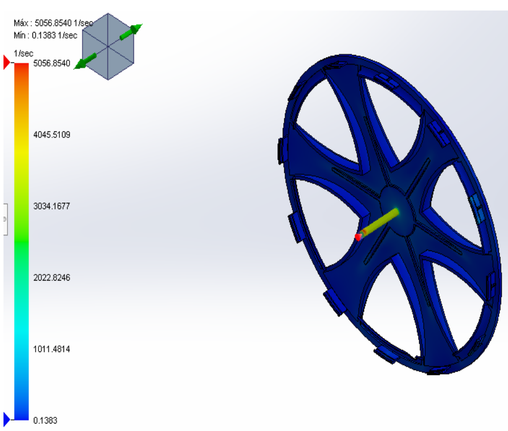
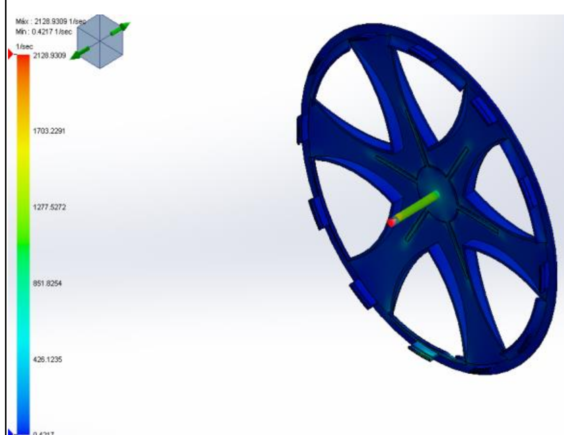
2.2. SHEAR STRESSES AT THE END OF FILLING

In the injection molding process, the polymer material undergoes shear heating during the filling stage. This increase in temperature is due to high shear rates, which can increase the temperature of the material in the cavity above the set material temperature.

SHEAR STRESSES To the END OF FILLING	
RONFALIN FF50 (ABS) I	*RONFALIN FF50 (ABS) II*
	
***Max**: 6.77 (Mpa)* ***Min**: 0.00 (Mpa)* ***Average**: 4.6 (Mpa)*	***Max:** 11.99 (Mpa)* ***Min:** 0.00 (Mpa)* ***Average:** 2.42 (Mpa)*
NOTE: Maximum stress has increase but the average is lower.	

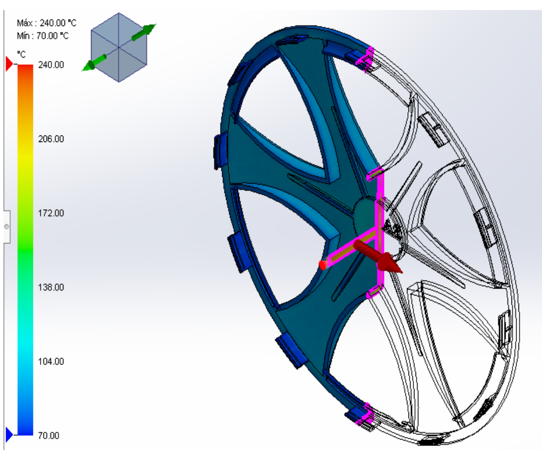
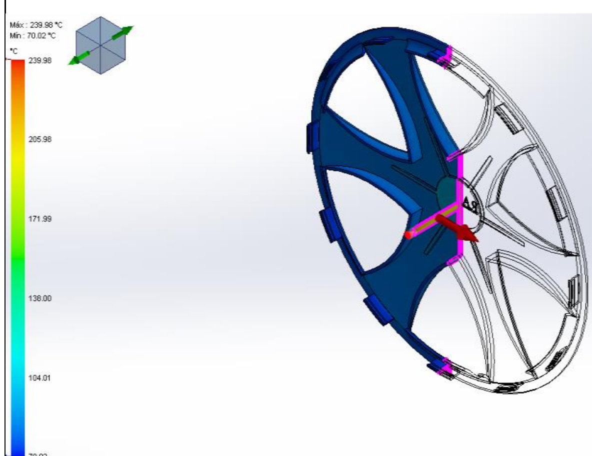
2.3. SHEAR RATE AT THE END OF PACKAGING

The shear rate measures the velocity of one layer of fluid as it passes over another layer moving at a different speed. The solidified plastic material in contact with the cavity wall does not move relative to the wall, which causes a shear rate of zero value (0.0 1/s).

<table>
<tr><th colspan="2">SHEAR RATE
TO THE
END OF FILLING</th></tr>
<tr><td>RONFALIN FF50 (ABS) I</td><td>RONFALIN FF50 (ABS) II</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Max: 5056.86 (1/s)
Min: 0.14 (1/s)
Average: 500.68 (1/s)</td><td>Max: 2128.93 (1/s)
Min: 0.42 (1/s)
Average: 627.32 (1/s)</td></tr>
<tr><td colspan="2"><u>NOTE:</u> No changes affecting the final result.</td></tr>
</table>

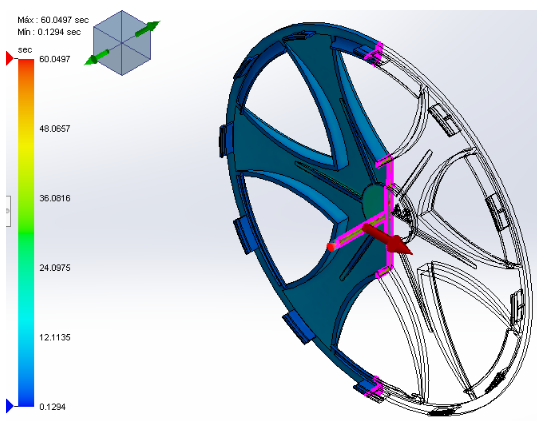
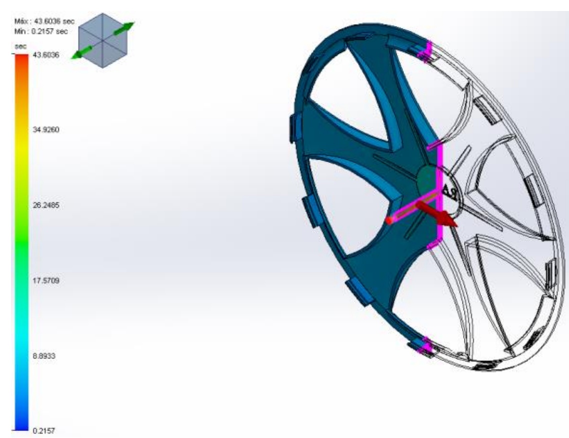
2.4. TEMPERATURE AT THE END OF PACKAGING

At the end of the packaging stage, the surface of the part has cooled to the mold temperature and the part appears blue. The internal volume of the part could still be molten, close to the crystalline transition of the material (T_g) or the temperature of the material (T_m).

TEMPERATURE AT THE END PACKAGING	
RONFALIN FF50 (ABS) I	*RONFALIN FF50 (ABS) II*
	
***Max**: 240.00 (C°)* ***Min**: 70.00 (C°)* ***Average**: 172.00 (C°)*	***Max:** 239.98 (C°)* ***Min:** 70.02 (C°)* ***Average:** 98.32 (C°)*
<u>NOTE:</u> Considerable improvement in temperature decrease.	

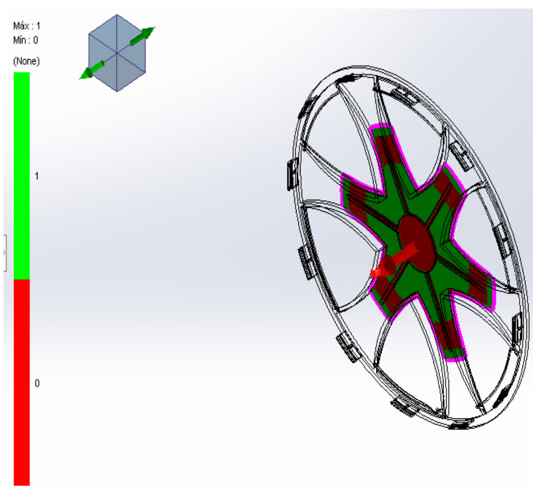
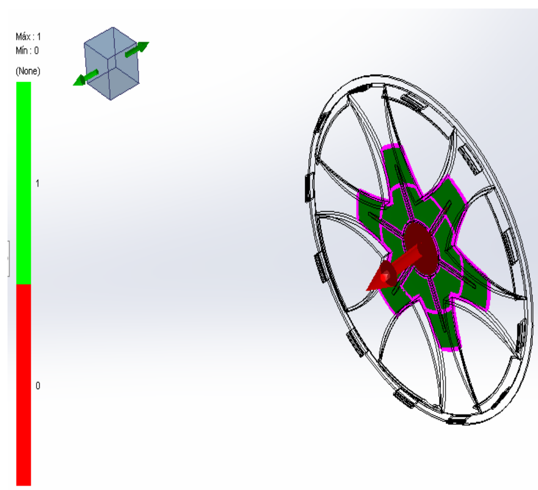
2.5. SOLIDIFICATION TIME AT THE END OF PACKAGING

The scale used for the solidification time at the end of post-filling indicates the time needed for the molten plastic material to cool to crystalline transition temperature. The time needed to reduce a molten material to crystalline transition temperature is not the time needed to cool the part to its ejection temperature.

<table>
<tr><th colspan="2">SOLIDIFICATION TIME</th></tr>
<tr><td>RONFALIN FF50 (ABS) I</td><td>RONFALIN FF50 (ABS) II</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Max: 60.0 4(s)
Min: 60.04 (s)
Average: 60.04 (s)</td><td>Max: 43.60 (s)
Min: 43.60 (s)
Average: 43.60 (s)</td></tr>
<tr><td colspan="2"><u>NOTE:</u> Considerable improvement.</td></tr>
</table>

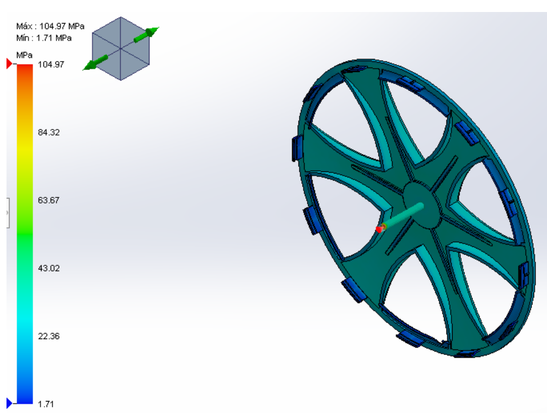
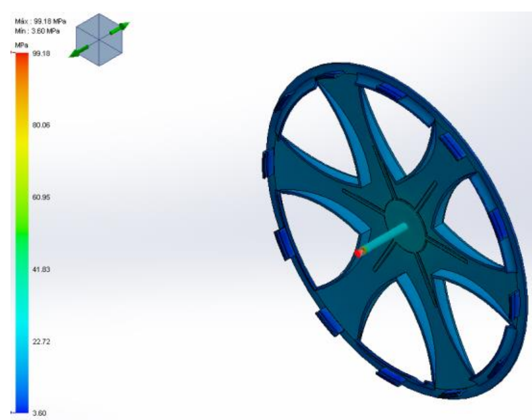
2.6. SOLIDIFIED REGION AT THE END OF PACKAGING

The tracing of the solidified region at the end of post-filling indicates the parts of the material that have reached the crystalline transition temperature (green, value = 1). Red areas (value = 0) indicate that the material is above crystalline transition temperature.

REGION SOLIDIFIED AT THE END OF PACKAGING	
RONFALIN FF50 (ABS) I	*RONFALIN FF50 (ABS) II*
	
***Max**: 1 (OK)* ***Min**: 0 (NOK)* ***Medium**: -*	***Max:** 1 (OK)* ***Min:** 0 (NOK)* ***Stocking:-***
NOTE: Considerable decrease of the unsolidified region.	

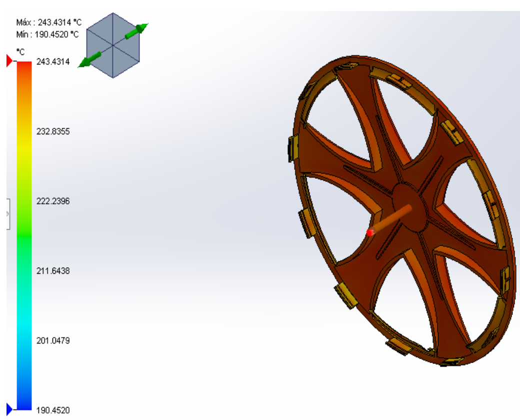
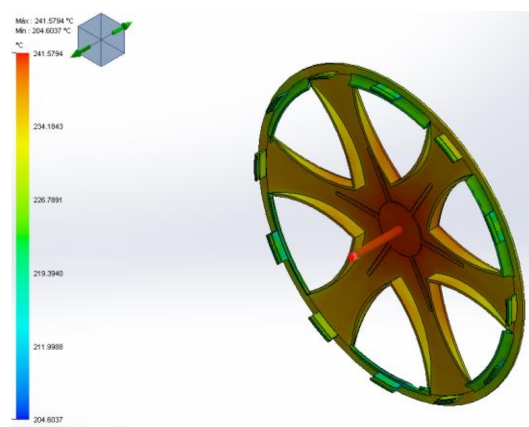
2.7. RESIDUAL STRESSES AT THE END OF PACKAGING

During the injection molding process, the polymer is exposed to thermal and physical stresses. Residual stresses are forces trapped within the polymer as it cools from the melted state to the crystalline transition temperature. Residual stresses are the result of non-uniform variations in cooling and pressure that take place in the viscoelastic polymer material during molding.

RESIDUAL STRESSES AT THE END OF THE POST FILLING	
RONFALIN FF50 (ABS) I	*RONFALIN FF50 (ABS) II*
	
***Max**: 104.97 (Mpa)* ***Min**: 1.17 (Mpa)* ***Average**: 43.02 (Mpa)*	***Max:** 99.18 (Mpa)* ***Min:** 3.60 (Mpa)* ***Average:** 22.72 (Mpa)*
<u>NOTE:</u> Better overall sized.	

2.8. FLOW FRONT TEMPERATURE

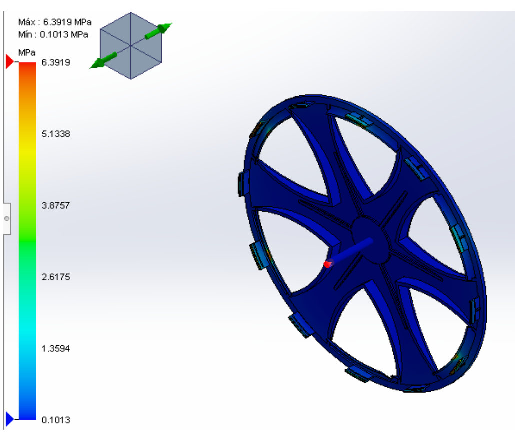
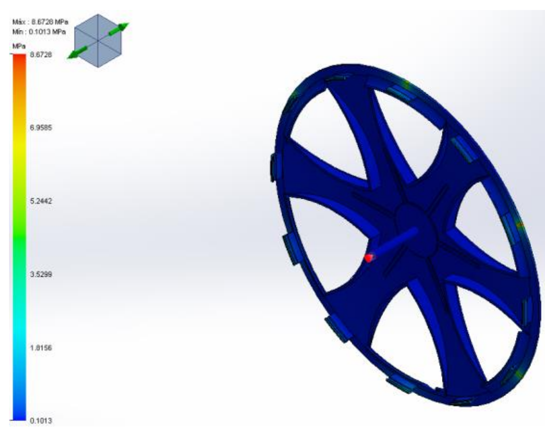
The flow front temperature during the injection molding process is the temperature of the material as it moves into the mold. This temperature may vary depending on shear or cooling stresses.

<table>
<tr><th colspan="2">FRONT TEMPERATURE
FLOW</th></tr>
<tr><td>RONFALIN FF50 (ABS) I</td><td>RONFALIN FF50 (ABS) II</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Max: 243.93 (C°)
Min: 190.45 (C°)
Average: 240.12 (C°)</td><td>Max: 241.58 (C°)
Min: 204.60 (C°)
Average: 232.59 (C°)</td></tr>
<tr><td colspan="2"><u>NOTE:</u> There is an improvement on the difference between the maximum and minimum temperatures.</td></tr>
</table>

3. COMMON AND TERTIARY RESULTS OF ANALYSIS.

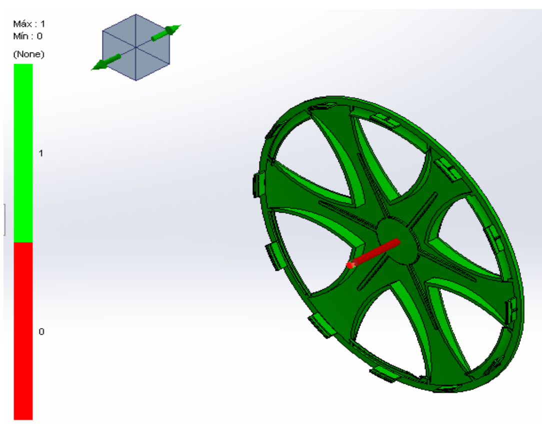
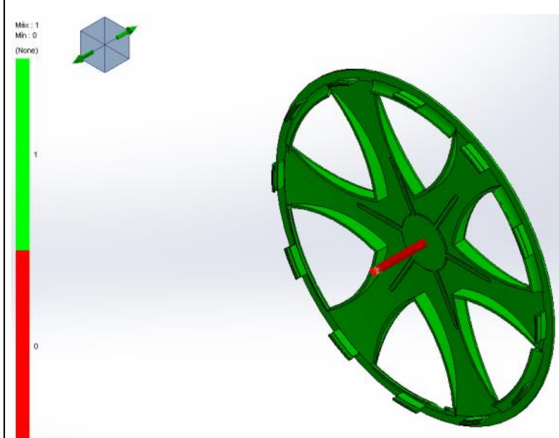
3.1. VENTILATION PRESSURE

As the piece fills, air from the cavity tries to escape. If it does not succeed, it will cause brown, gray or black discolorations on the surface of the piece due to burns or desertification. This occurs because gases and volatiles are trapped in the mold, causing the gases to compress and heat up in the first injection (filling) stage. It is possible to release the gases through vents and thus avoid these discolorations.

<table>
<tr><th colspan="2">VENTILATION PRESSURE</th></tr>
<tr><td>RONFALIN FF50 (ABS) I</td><td>RONFALIN FF50 (ABS) II</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Max: 6.39 (Mpa)
Min: 0.10 (Mpa)
Average: 1.36 (Mpa)</td><td>Max: 8.67 (Mpa)
Min: 0.10 (Mpa)
Average: 1.82 (Mpa)</td></tr>
<tr><td colspan="2"><u>NOTE:</u> There are no significant changes.</td></tr>
</table>

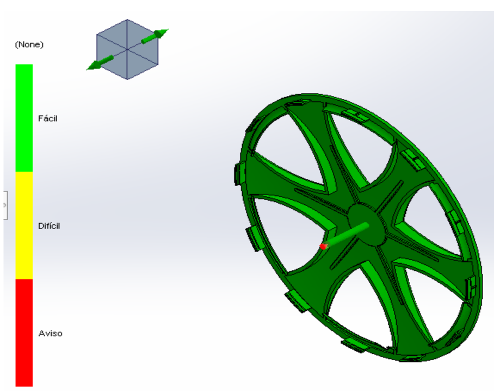
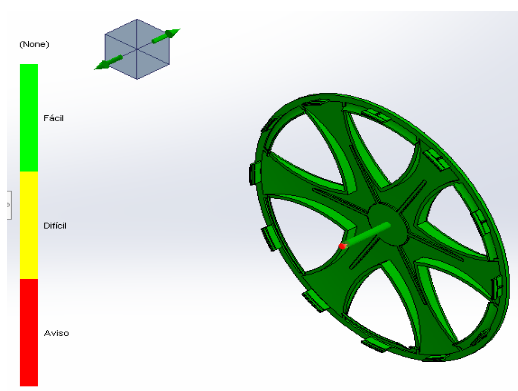
3.2. CONTRIBUTION TO THE FILLING OF INJECTION SITES

When only one injection site is used, the cavity is filled through it. When several injection sites are used, the cavity is partially filled with the material that is introduced through each of the points.

CONTRIBUTION TO FILLING OF THE INJECTION SITE	
RONFALIN FF50 (ABS) I	*RONFALIN FF50 (ABS) II*
	
***Max**: 1 (OK)* ***Min**: 0 (NOK)* ***Medium**: -*	***Max**: 1 (OK)* ***Min:** 0 (NOK)* ***Medium: -***
<u>NOTE:</u> Ease of filling is maintained.	

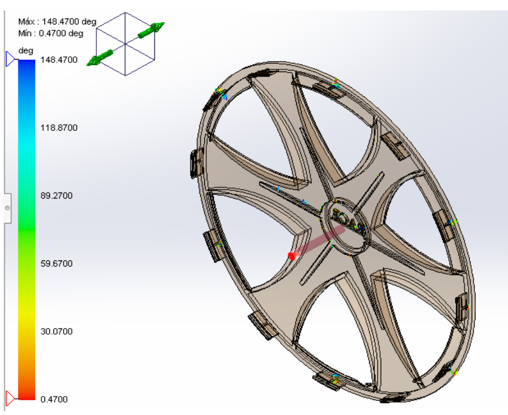
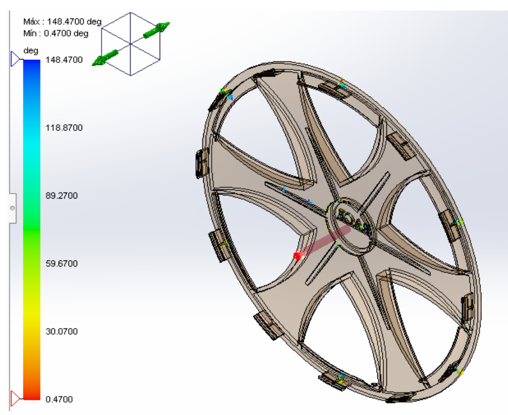
3.3 FACILITY OF FILLING

Green zones indicate areas that can be filled with normal injection pressures. Yellow zones indicate areas where the injection pressure exceeds 70 percent of the machine's maximum injection pressure. The red zones indicate areas where the injection pressure exceeds 85 percent of the machine's maximum injection pressure.

FACILITY OF FILLING	
RONFALIN FF50 (ABS) I	*RONFALIN FF50 (ABS) II*
	
***Max**: EASY* ***Min**: NOTICE* ***Medium**: -*	***Max:** EASY* ***Min:** NOTICE* ***Medium: -***
<u>NOTE:</u> Ease of filling is maintained.	

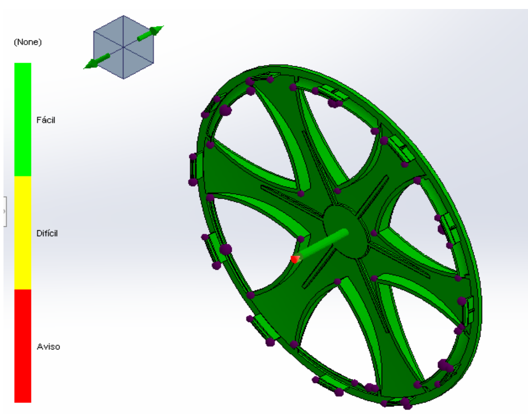
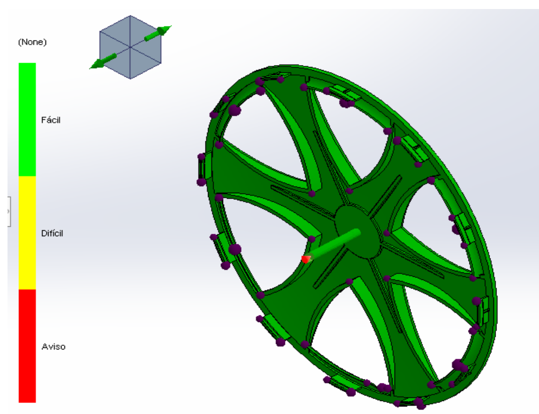
3.4. WELDING LINES

Welding lines are formed when two or more flow fronts of the molten plastic converge. Among the possible causes for its formation are the closing surfaces of the mold, the characteristics of the mold core, the existence of several injection points or variations in the thickness of the walls that cause an increase in speed or a stagnation of the flow front. Welding lines are generally weaker than areas without weld lines and usually cause visual defects. They can also act as stress concentrators in the molded part.

WELDING LINES	
RONFALIN FF50 (ABS) I	*RONFALIN FF50 (ABS) II*
	
***Max**: 148.47 (deg)* ***Min**: 0.47 (deg)* ***Medium**: -*	***Max:** 148.47 (deg)* ***Min:** 0.47 (deg)* ***Medium:** -*
NOTE: No significant changes.	

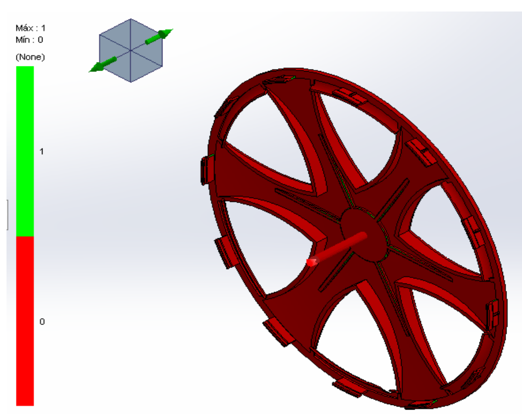
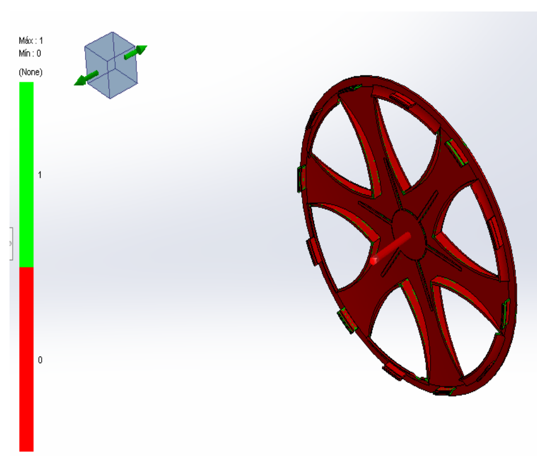
3.5. AIR ENTRAPMENTS

If the air from the mold cavity cannot be expelled into the atmosphere during the filling stage, the trapped air can cause the plastic material not to fill the volume where the air is trapped. This can result in an incomplete filling and packaging process at the location of the trapped air or even a hole in the part caused by trapped air.

AIR ENTRAPMENTS	
RONFALIN FF50 (ABS) I	*RONFALIN FF50 (ABS) II*
	
Max: - ***Min***: - ***Medium***: -	***Max: -*** ***Min: -*** ***Medium: -***
NOTE: No significant changes.	

3.6. SOLIDIFIED REGION AT THE END OF FILLING

The tracing of the solidified region at the end of the filling indicates the areas of the part that have reached the crystalline transition temperature of the material. Green areas (value 1) indicate that the material has reached the crystalline transition temperature of the material. Red areas (value 0) indicate that the material still exceeds the crystalline transition temperature. The solidified region at the end of filling indicates the thickness of the solidified layer that increases during the source flow.

SOLIDIFIED REGION AT THE END OF FILLING	
RONFALIN FF50 (ABS) I	*RONFALIN FF50 (ABS) II*
	
***Max**: 1 (OK)* ***Min**: 0 (NOK)* ***Medium**: -*	***Max:** 1 (OK)* ***Min:** 0 (NOK)* ***Medium: -***
NOTE: No significant changes.	

ANEXED III – MATERIALS PROPERTIES

INDEX

FIGURE INDEX

1. SOLIDWORKS DATABASE MATERIAL PROPERTIES

1.1. RONFALLIN FF-50 (ABS)

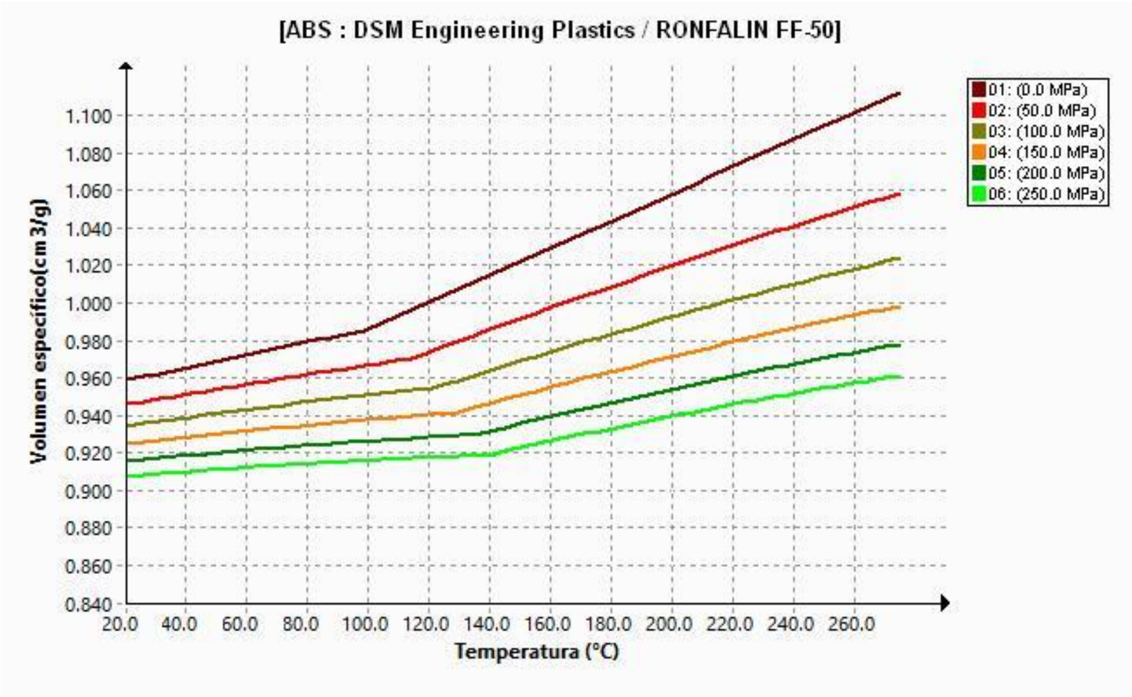


Figure 1 Specific volume and Temperature for RONFALIN FF-50

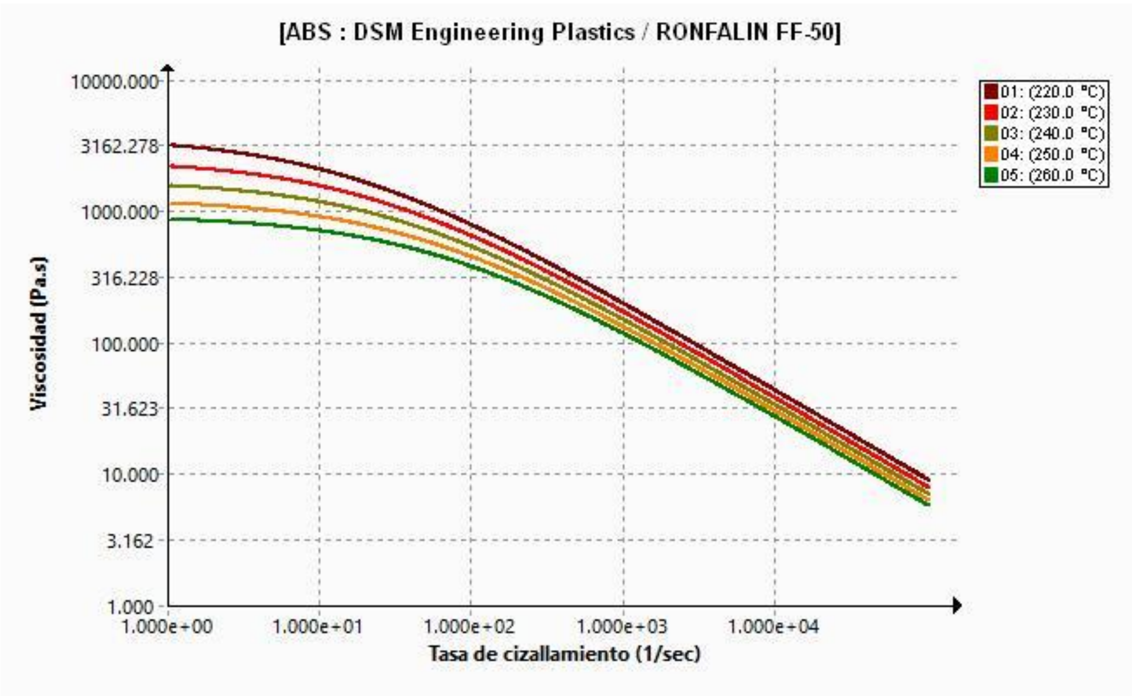


Figure 2 Viscosity and Share stress rate for RONFALIN FF-50

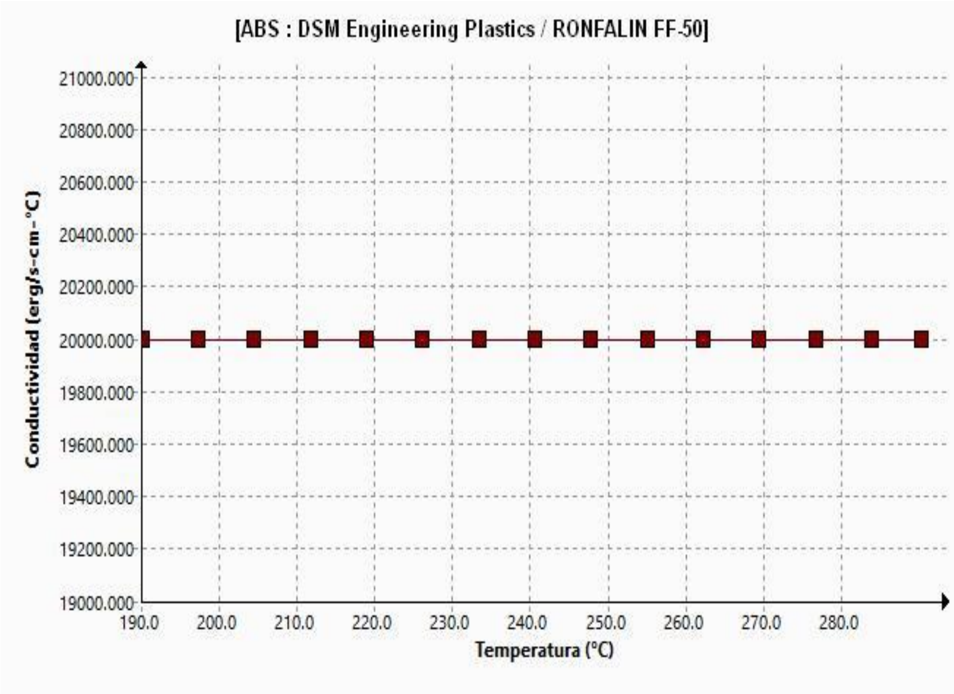


Figure 3 Conductivity and Tempreature for RONFALIN FF-50

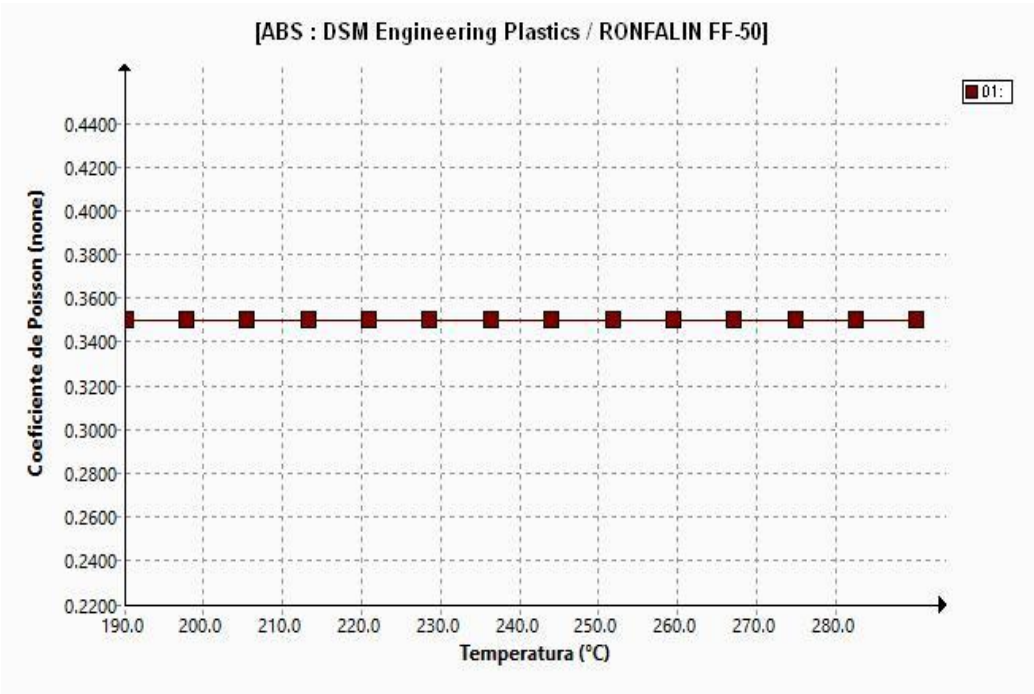


Figure 4 Poisson ratio and Temperature for RONFALIN FF-50

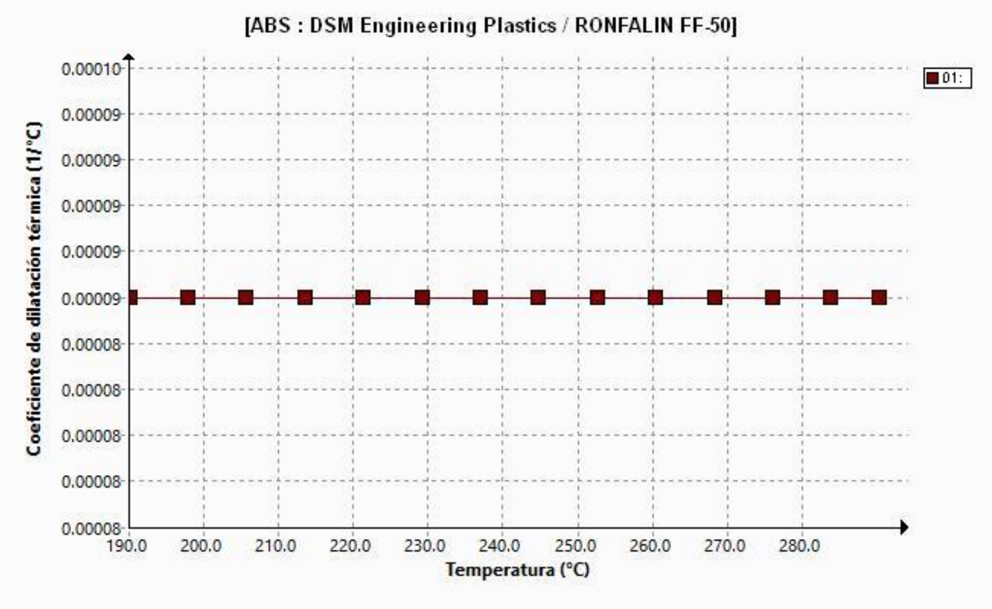


Figure 5 Thermic dilatation coefficient and Temperature for RONFALIN FF-50

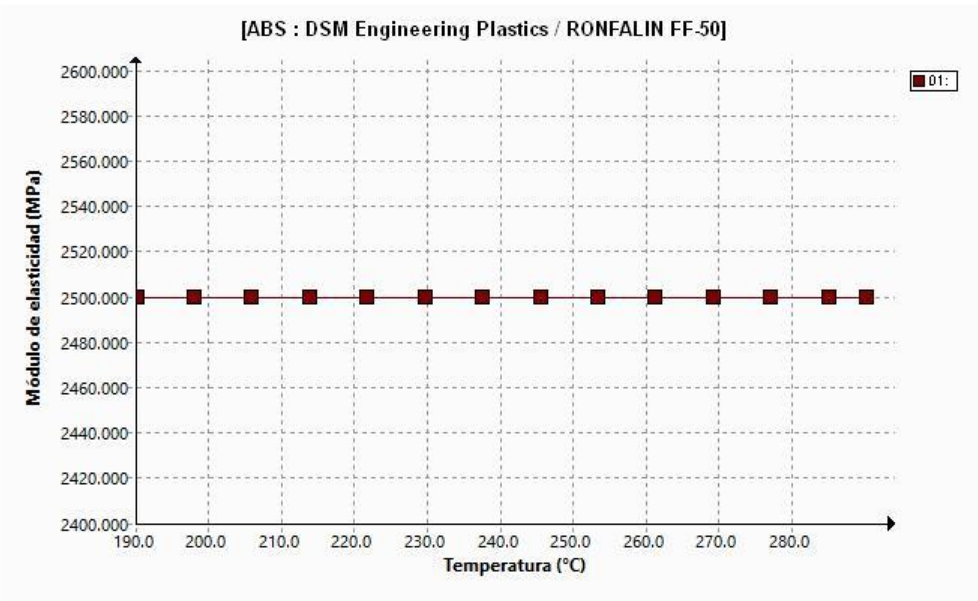


Figure 6 Modulus of elasticity and Temperature for RONFALIN FF-50

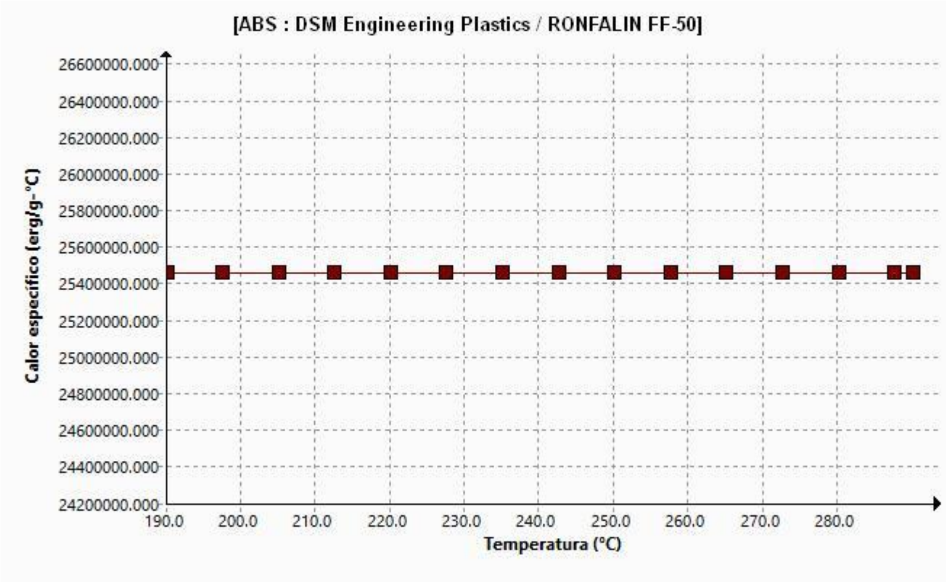


Figure 7 Specific heat coefficient and Temperature for RONFALIN FF-50

1.2. PP 412 MN 40 (PP)

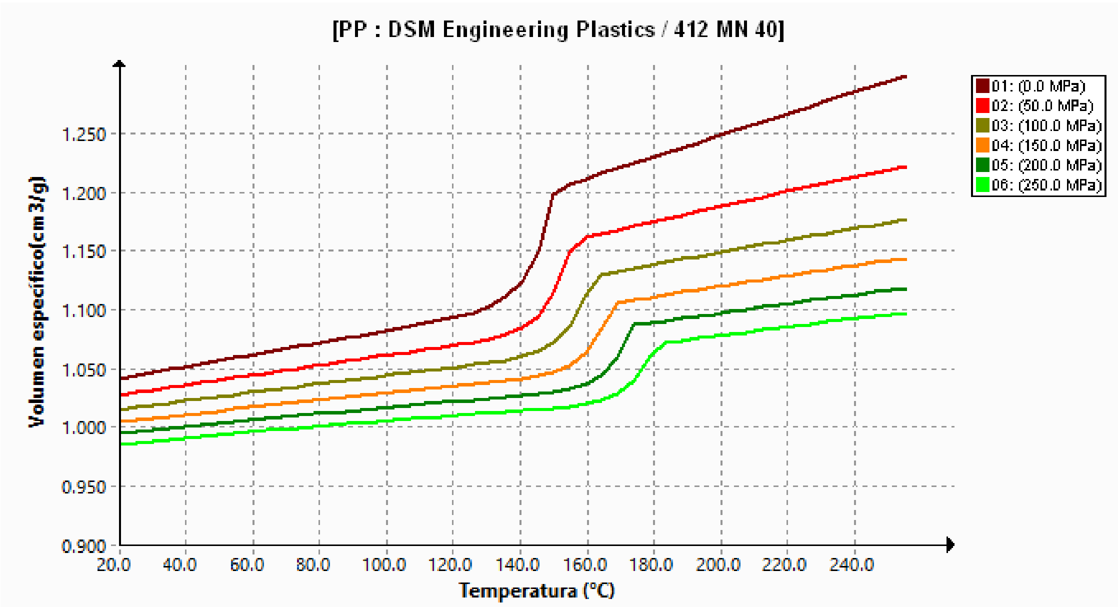


Figure 8 Specific Volume and Temperature for PP 412MN 40

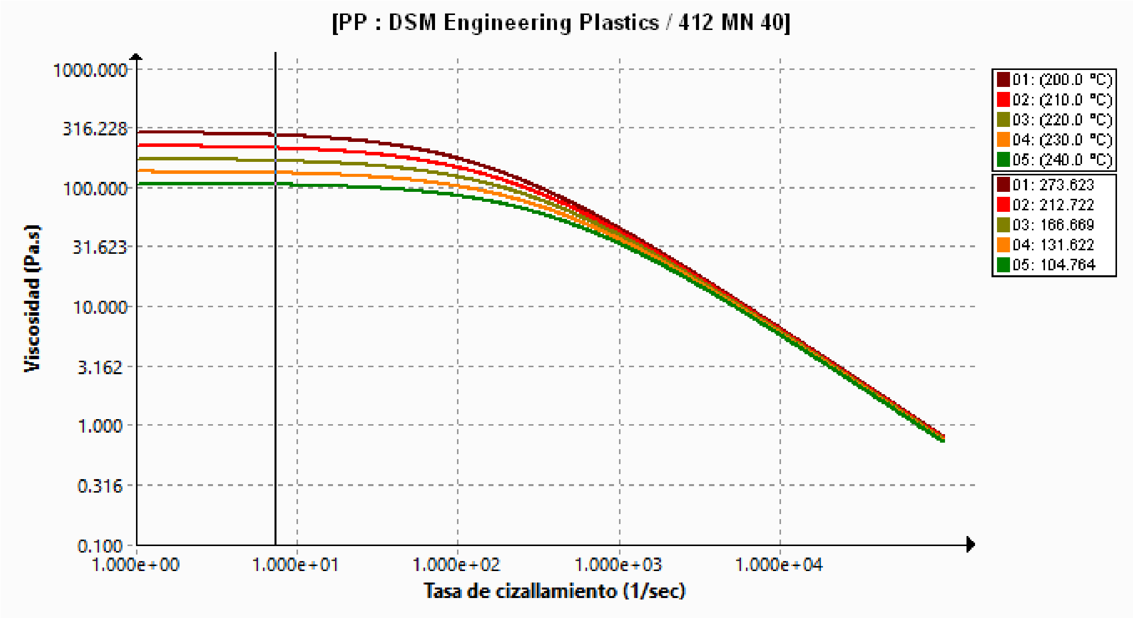


Figure 9 Viscosity and Share stress rate and Temperature for PP 412MN 40

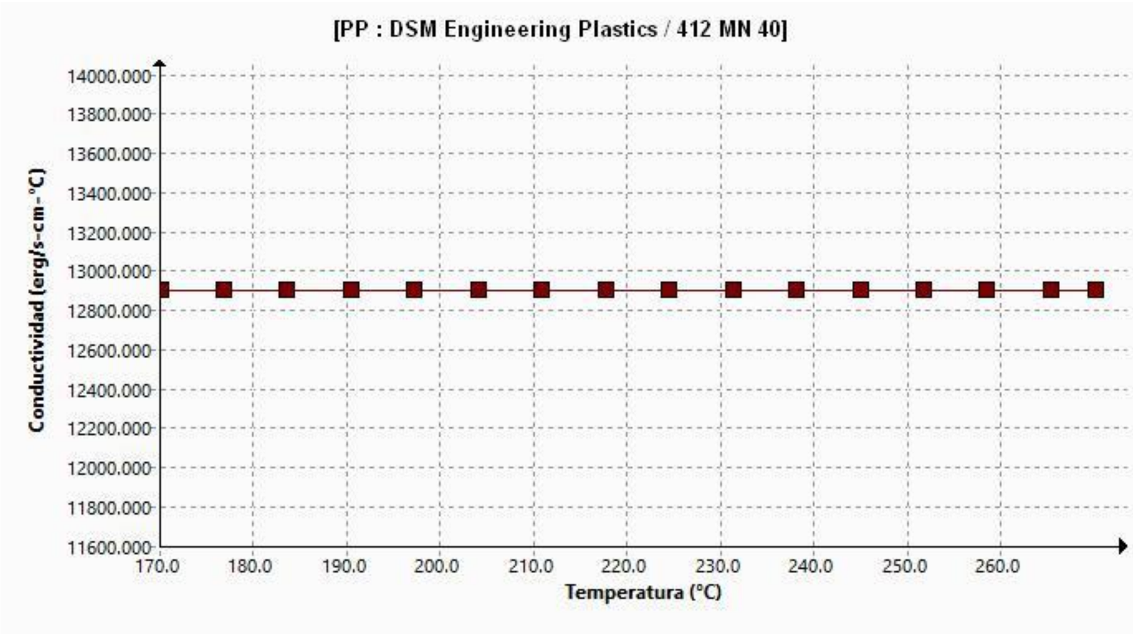


Figure 10 Conductivity and Temperature for PP 412MN 40

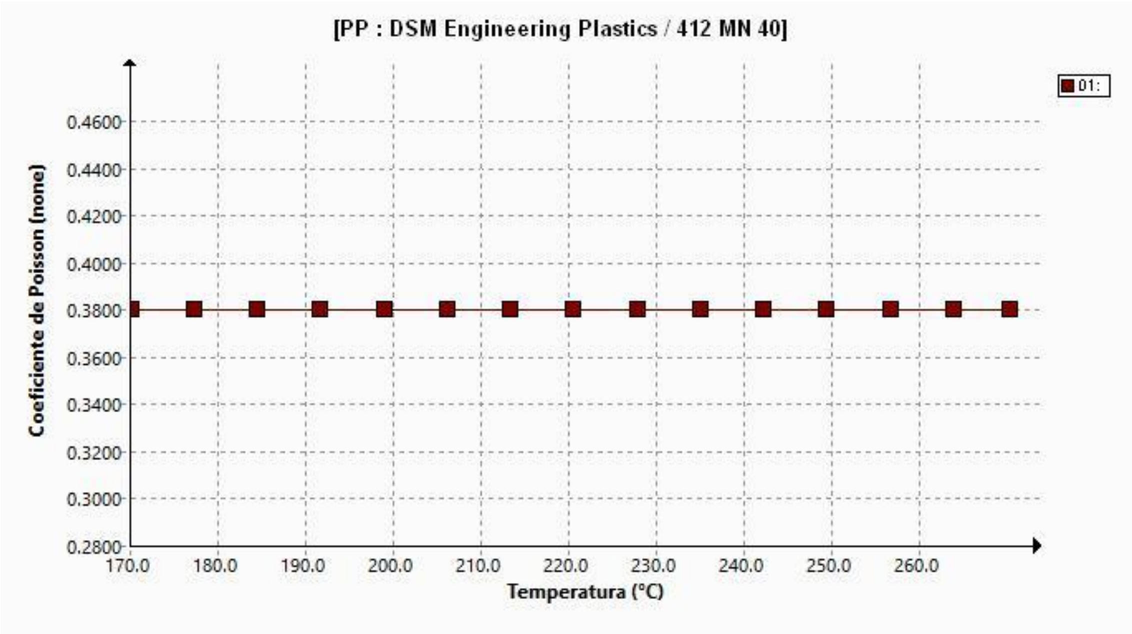


Figure 11 Poisson´s ratio and Temperature for PP 412MN 40

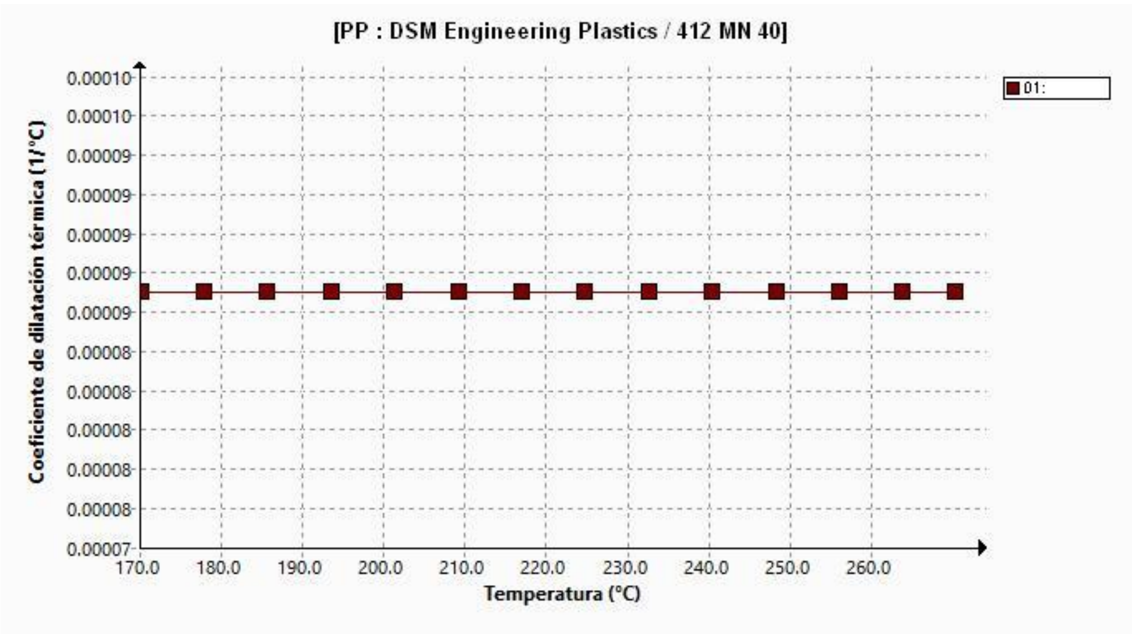


Figure 12 Thermic dilatation coefficient and Temperature for PP 412MN 40

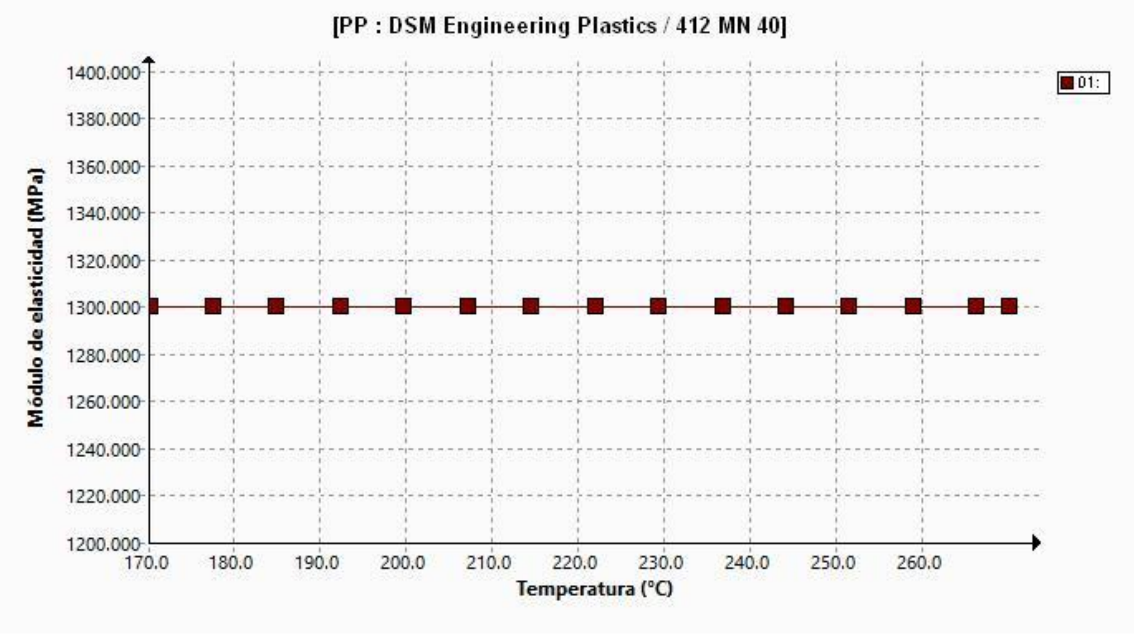


Figure 13 Elasticity Modulus and Temperature for PP 412MN 40

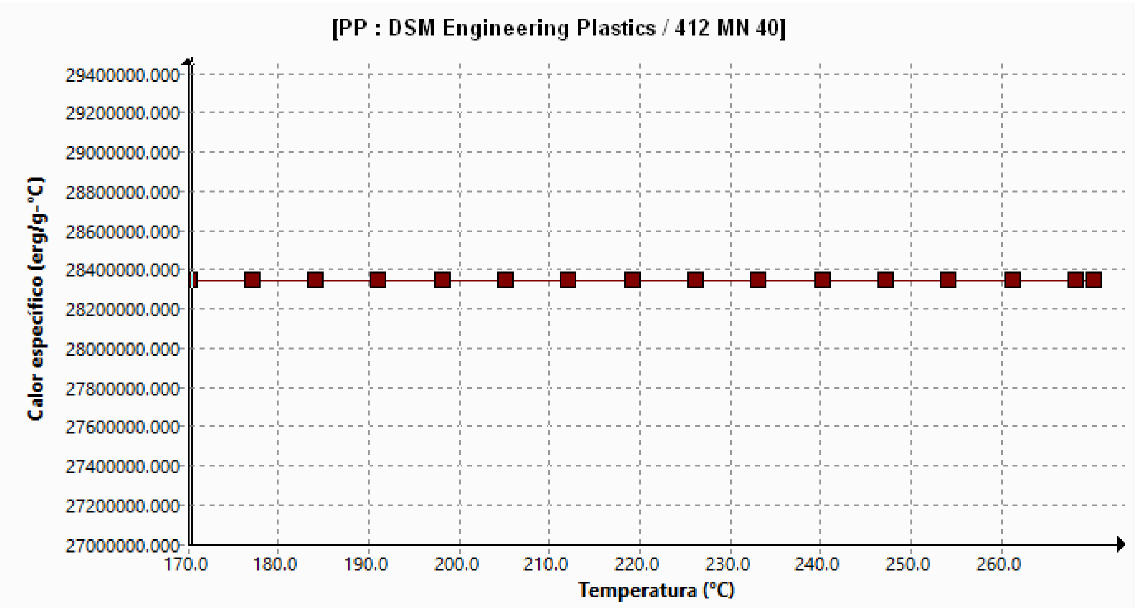


Figure 14 Specific heat rate and Temperature for PP 412MN 40

1.3. XANTAR 18 R (PC)

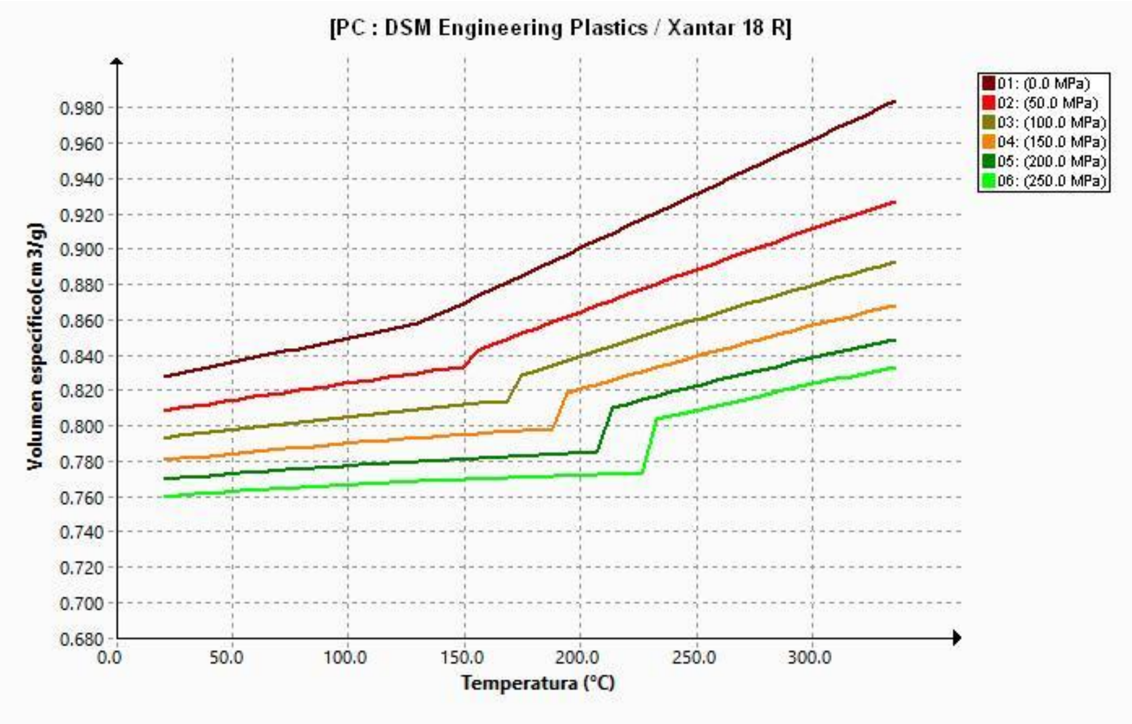


Figure 15 Specific Volume and Temperature for XANTAR 18R

Figure 16 Viscosity and Share stress rate and Temperature for XANTAR 18R

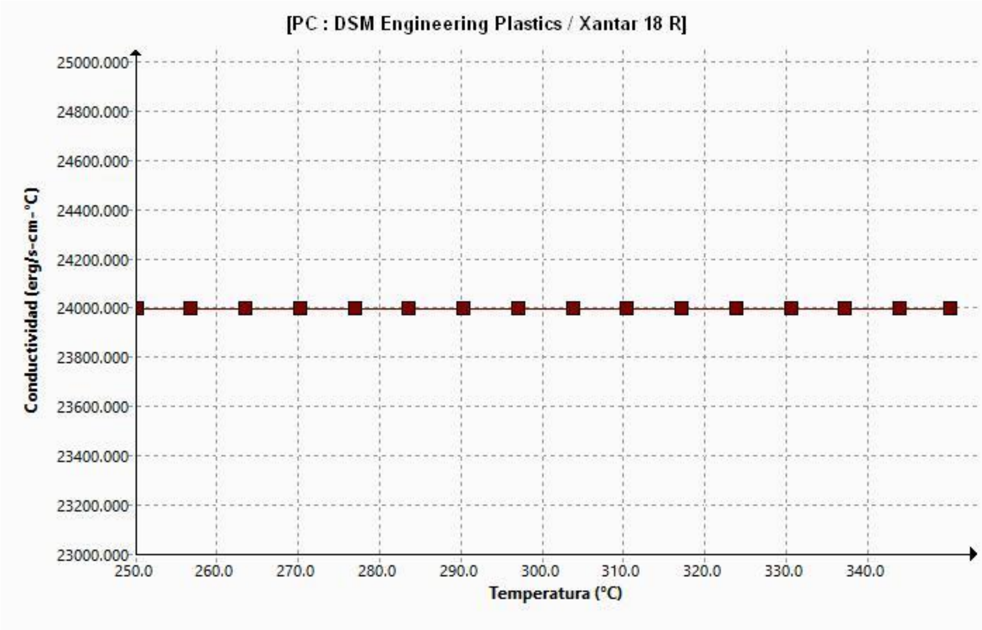


Figure 17 Conductivity and Temperature for XANTAR 18R

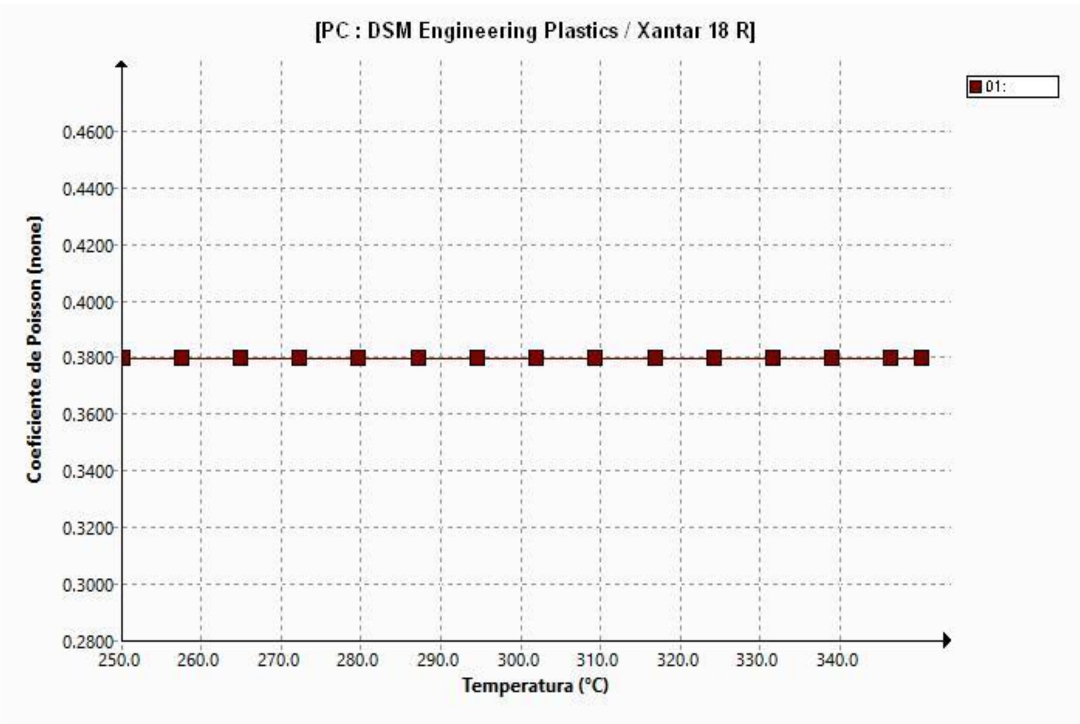


Figure 18 Poisson´s ratio and Temperature for XANTAR 18R

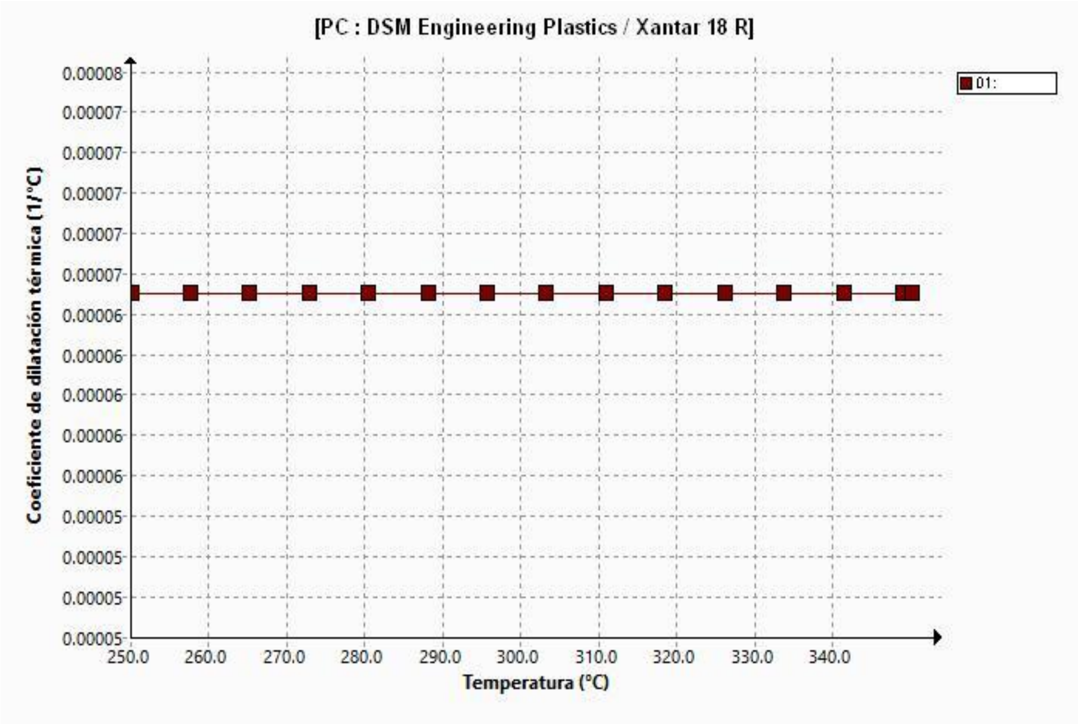


Figure 19 Thermic dilatation coefficient and Temperature for XANTAR 18R

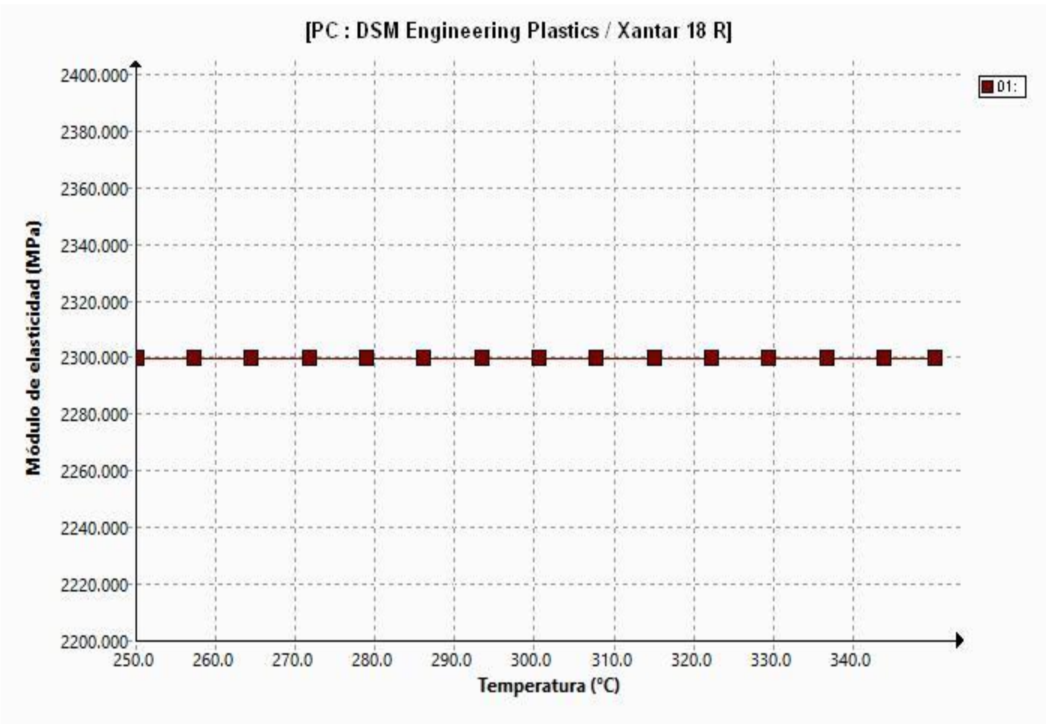


Figure 20 Elasticity Modulus and Temperature for XANTAR 18R

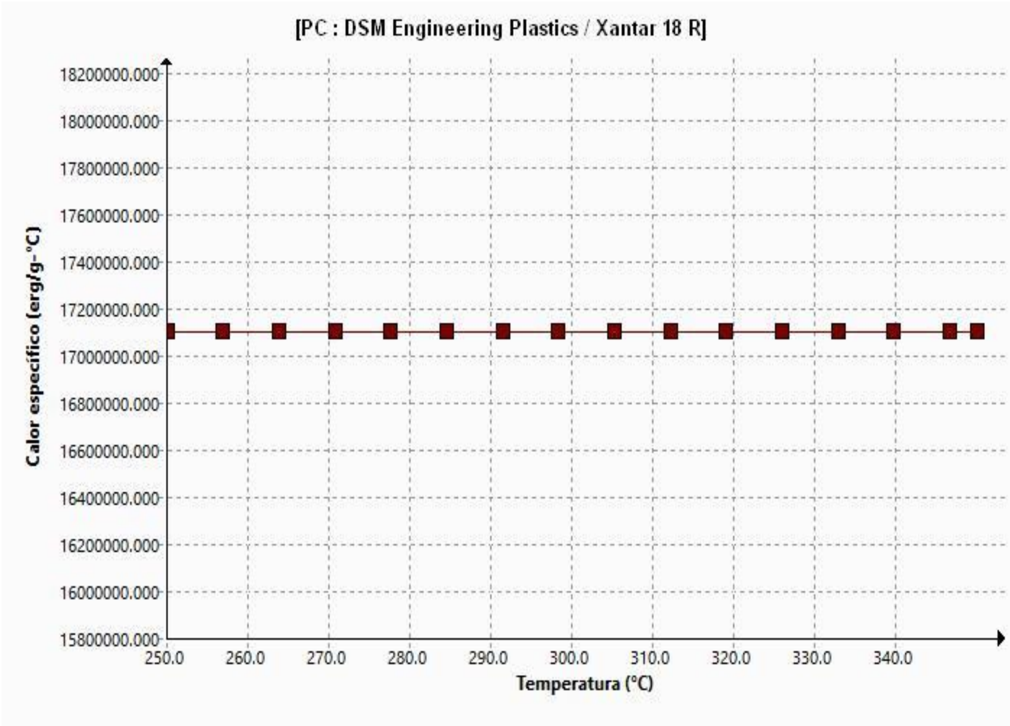


Figure 21 Specific heat rate and Temperature for XANTAR 18R

2. MANUFACTURER TECHNICAL SHEET.

lyondellbasell

Ronfalin ABS 1443 LE

Acrylonitrile Butadiene Styrene
LyondellBasell Industries
Engineering Plastics

Product Description

Low Emission ABS compound with increased heat distortion temperature and impact strength. Available with and without UV-stabilization. (Former name: POLYMAN ABS M/HI W LE UV)

General

Material Status	• Commercial: Active
Availability	• Africa & Middle East • Asia Pacific • Europe • Latin America
Features	• Good Flow
Processing Method	• Injection Molding
Resin ID (ISO 1043)	• ABS

Physical	Nominal Value (English)	Nominal Value (SI)	Test Method
Density	1.05 g/cm³	1.05 g/cm³	ISO 1183/A
Melt Volume-Flow Rate (MVR) (220°c/10.0 Kg)	17 cm³/10min	17 cm³/10min	ISO 1133
VOC Content	< 50.0µgC/g	< 50.0µgC/g	VDA 277
Mechanical	**Nominal Value (English)**	**Nominal Value (SI)**	**Test Method**
Tensile Modulus	334000 psi	2300 MPa	ISO 527-1/1A/1
Tensile Stress			ISO 527-2/1A/50
Yield	6240 psi	43.0 MPa	
Break	5220 psi	36.0 MPa	
Tensile Strain (Yield)	2.9 %	2.9 %	ISO 527-2/1A/50
Nominal Tensile Strain at Break	12 %	12 %	ISO 527-2/1A/50
Flexural Modulus [1]	377000 psi	2600 MPa	ISO 178
Flexural Stress [1] (4.6% Strain)	10700 psi	74.0 MPa	ISO 178
Impact	**Nominal Value (English)**	**Nominal Value (SI)**	**Test Method**
Charpy Notched Impact Strength			ISO 179/1eA
-22°f (-30°c)	3.8 ft·lb/in²	8.0 kJ/m²	
73°f (23°c)	10 ft·lb/in²	22 kJ/m²	
Charpy Unnotched Impact Strength			ISO 179/1eU
-22°f (-30°c)	No Break	No Break	
73°f (23°c)	No Break	No Break	
Hardness	**Nominal Value (English)**	**Nominal Value (SI)**	**Test Method**
Ball Indentation Hardness (H 358/30)	15100 psi	104 MPa	ISO 2039-1
Thermal	**Nominal Value (English)**	**Nominal Value (SI)**	**Test Method**
Deflection Temperature Under Load			
66 Psi (0.45 Mpa), Unannealed	198 °F	92.0 °C	ISO 75-2/Bf
264 Psi (1.8 Mpa), Unannealed	183 °F	84.0 °C	ISO 75-2/Af
Vicat Softening Temperature			
--	216 °F	102 °C	ISO 306/B50
--	234 °F	112 °C	ISO 306/A50
Electrical	**Nominal Value (English)**	**Nominal Value (SI)**	**Test Method**
Surface Resistivity	> 1.0E+15 ohms	> 1.0E+15 ohms	IEC 60093
Volume Resistivity	> 1.0E+13 ohms·m	> 1.0E+13 ohms·m	IEC 62631-3-1
Comparative Tracking Index (Solution A)	600 V	600 V	IEC 60112

Ronfalin ABS 1443 LE

Acrylonitrile Butadiene Styrene
LyondellBasell Industries
Engineering Plastics

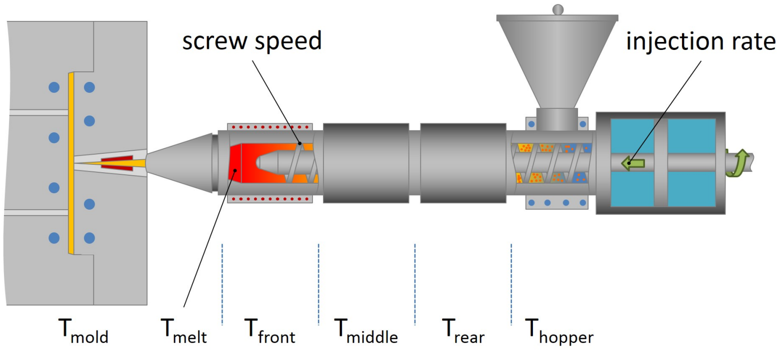
Flammability	Nominal Value (English)	Nominal Value (SI)	Test Method
Burning Rate			
0.0787 In (2.00 Mm)	< 3.9 in/min	< 100 mm/min	ISO 3795
0.0787 In (2.00 Mm)	< 3.9 in/min	< 100 mm/min	FMVSS 302
Flammability Classification			IEC 60695-11-10, -20
0.06 In (1.5 Mm)	HB	HB	
0.12 In (3.0 Mm)	HB	HB	
Glow Wire Ignition Temperature			IEC 60695-2-13
0.06 In (1.5 Mm)	1290 °F	700 °C	
0.12 In (3.0 Mm)	1290 °F	700 °C	

Additional Information

1.) Not for use in food contact applications
2.) Not for use in medical or pharmaceutical applications

Ronfalin ABS 1443 LE

Acrylonitrile Butadiene Styrene
LyondellBasell Industries
Engineering Plastics



Injection	Nominal Value (English)	Nominal Value (SI)
Drying Temperature	176 °F	80 °C
Drying Time	2.0 to 4.0 hr	2.0 to 4.0 hr
Processing (Melt) Temp	446 to 482 °F	230 to 250 °C
Mold Temperature	104 to 176 °F	40 to 80 °C

Ronfalin ABS 1443 LE

Acrylonitrile Butadiene Styrene
LyondellBasell Industries
Engineering Plastics

Notes

[1] 0.079 in/min (2.0 mm/min)

Notes

These are typical property values not to be construed as specification limits.

Processing Techniques

Specific recommendations for resin type and processing conditions can only be made when the end use, required properties and fabrication equipment are known.

Product Storage and Handling

- Product should be stored in dry conditions at temperatures below 50°C and protected from UV-light
- Improper storage may bring damage to the packaging and can negatively affects on the quality of this product
- Keep material completely dry for good processing

SABIC® PP 412MN40

Polypropylene Impact Copolymer

SABIC

PROSPECTOR®
www.ulprospector.com

Technical Data

Product Description

SABIC® PP 412MN40 is a multi-purpose grade with good flow properties, combining stiffness and good balance in impact strength. The material has a very low tendency for warpage and is typically used for the production of thin wall packaging articles. Cycle times can be very short. It is formulated with a combined processing and antistatic additive package. This grade is widely applied in thin wall technical injection moulded articles and thin-walled containers, in particular where dimensional stability is important.

Health, Safety and Food Contact regulations:
Material Safety Data Sheets (MSDS) and Product Safety declarations are available on our Internet site http://www.SABIC.com

The product mentioned herein is in particular not tested and therefore not validated for use in pharmaceutical/ medical applications.

This grade material is UL registered under File E111275 (www.ul.com) / IMDS 80775790

General

Material Status	• Commercial: Active		
UL Yellow Card [1]	• E111275-219027		
Search for UL Yellow Card	• SABIC • SABIC® PP		
Availability	• Africa & Middle East • Asia Pacific	• Europe • Latin America	• North America
Additive	• Antistatic	• Nucleating Agent: No	
Features	• Antistatic		

Physical	Nominal Value	Unit	Test Method
Density	0.905	g/cm³	ASTM D1505
Melt Mass-Flow Rate (MFR) (230°C/2.16 kg)	37	g/10 min	ISO 1133
Mechanical	**Nominal Value**	**Unit**	**Test Method**
Tensile Modulus	1300	MPa	ISO 527-1/1A/1
Tensile Stress (Yield)	25.0	MPa	ISO 527-2/1A
Tensile Strain (Yield)	5.0	%	ISO 527-2/1A/50
Impact	**Nominal Value**	**Unit**	**Test Method**
Charpy Notched Impact Strength			ISO 179/1eA
-20°C	5.0	kJ/m²	
0°C	7.0	kJ/m²	
23°C	11	kJ/m²	
Notched Izod Impact Strength			ISO 180/1A
-20°C	5.0	kJ/m²	
0°C	6.5	kJ/m²	
23°C	8.0	kJ/m²	
Hardness	**Nominal Value**	**Unit**	**Test Method**
Shore Hardness (Shore D)	63		ISO 868
Thermal	**Nominal Value**	**Unit**	**Test Method**
Deflection Temperature Under Load [3]			
0.45 MPa, Unannealed, 4.00 mm	85.0	°C	ISO 75-2/Bf
1.8 MPa, Unannealed, 4.00 mm	55.0	°C	ISO 75-2/Af
Vicat Softening Temperature			
--	75.0	°C	ISO 306/B120
--	150	°C	ISO 306/A120

Notes

[1] A UL Yellow Card contains UL-verified flammability and electrical characteristics. UL Prospector continually works to link Yellow Cards to individual plastic materials in Prospector, however this list may not include all of the appropriate links. It is important that you verify the association between these Yellow Cards and the plastic material found in Prospector. For a complete listing of Yellow Cards, visit the UL Yellow Card Search.

[2] Typical properties: these are not to be construed as specifications.

[3] 80*10*4mm

Form No. TDS-70707-en

Document Created: Monday, October 31, 2022
Added to Prospector: October 2003
Last Updated: 9/22/2022

Where to Buy

Supplier

SABIC
Web: http://www.sabic.com/

Distributor

AECTRA
Telephone: +33-4-72-54-36-42
Web: https://www.aectra.fr/
Availability: France

AGI-Augusto Guimarães & Irmão
Telephone: +351-22753-7400
Web: https://www.agi.pt/en/
Availability: Portugal

Distrupol Ltd
Distrupol Ltd is a Pan European distribution company. Contact Distrupol Ltd for availability of individual products by country.
Telephone: 08452003040
Web: http://www.distrupol.com/
Availability: Denmark, Finland, Norway, Sweden

Guangzhou Hua Xiu Plastics Co. Ltd
Telephone: +86-20-82582555
Web: http://www.va-so.cn/
Availability: Asia Pacific

Guzmán Polymers
Telephone: +34-963-992-400
Web: https://www.guzmanglobal.com/en/productos/plastics/
Availability: Italy, Spain, Turkey

Plastoplan
Telephone: +43-1-25040-0
Web: https://www.plastoplan.com/
Availability: Czech Republic, Poland, Slovakia

POLYMIX
POLYMIX is a Pan European distribution company. Contact POLYMIX for availability of individual products by country.
Telephone: +33-3-8920-1380
Web: http://www.polymix.eu/
Availability: France

RESINEX Group
RESINEX is a Pan European distribution company. Contact RESINEX for availability of individual products by country.
Telephone: +32-14-672511
Web: http://www.resinex.com/
Availability: Europe

Document Created: Monday, October 31, 2022
Added to Prospector: October 2003
Last Updated: 9/22/2022

CAMPUS® Datasheet

XANTAR™ 18 R - PC
Mitsubishi Engineering-Plastics Corporation

Mitsubishi Engineering-Plastics Corporation

Product Texts

Extremely Low Viscosity, Molding Release

ISO 1043 PC

XANTAR Polycarbonate & Blends, your global partner for innovative added value

Rheological properties	Value	Unit	Test Standard
Melt volume-flow rate, MVR	**23**	cm³/10min	ISO 1133
Temperature	**300**	°C	ISO 1133
Load	**1.2**	kg	ISO 1133
Molding shrinkage, parallel	**0.6**	%	ISO 294-4, 2577

Mechanical properties	Value	Unit	Test Standard
Tensile modulus	**2300**	MPa	ISO 527-1/-2
Yield stress	**60**	MPa	ISO 527-1/-2
Yield strain	**6**	%	ISO 527-1/-2
Nominal strain at break	**>50**	%	ISO 527-1/-2

Thermal properties	Value	Unit	Test Standard
Temp. of deflection under load, 1.80 MPa	**130**	°C	ISO 75-1/-2
Vicat softening temperature, 50°C/h 50N	**145**	°C	ISO 306
Coeff. of linear therm. expansion, parallel	**65**	E-6/K	ISO 11359-1/-2
Burning behavior at 1.5 mm nominal thickness	**V-2**	class	IEC 60695-11-10
Thickness tested (1.5)	**1.5**	mm	IEC 60695-11-10
Yellow Card available	**Yes**	-	-
Burning behavior at thickness h	**V-2**	class	IEC 60695-11-10
Thickness tested (h)	**0.8**	mm	IEC 60695-11-10
Yellow Card available	**Yes**	-	-
Oxygen index	**26**	%	ISO 4589-1/-2

Electrical properties	Value	Unit	Test Standard
Relative permittivity, 100Hz	**3**	-	IEC 62631-2-1
Relative permittivity, 1MHz	**2.9**	-	IEC 62631-2-1
Dissipation factor, 100Hz	**6.6**	E-4	IEC 62631-2-1
Dissipation factor, 1MHz	**92**	E-4	IEC 62631-2-1
Volume resistivity	**>1E13**	Ohm*m	IEC 62631-3-1
Surface resistivity	**>1E15**	Ohm	IEC 62631-3-2
Electric strength	**29**	kV/mm	IEC 60243-1
Comparative tracking index	**225**	-	IEC 60112

Other properties	Value	Unit	Test Standard
Water absorption	**0.35**	%	Sim. to ISO 62
Density	**1200**	kg/m³	ISO 1183

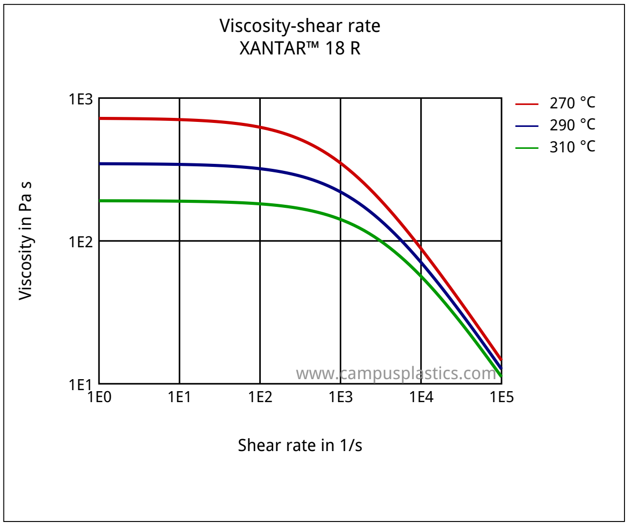
Rheological calculation properties	Value	Unit	Test Standard
Density of melt	**1010**	kg/m³	-
Thermal conductivity of melt	**0.24**	W/(m K)	-
Spec. heat capacity melt	**1710**	J/(kg K)	-
Eff. thermal diffusivity	**1.4E-7**	m²/s	-

Ejection temperature	**131**	°C	-

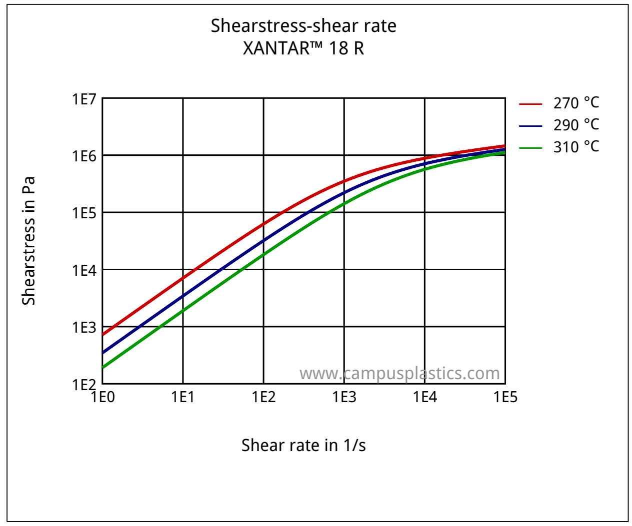
Test specimen production	Value	Unit	Test Standard
Injection molding, melt temperature	**300**	°C	ISO 294
Injection molding, mold temperature	**90**	°C	ISO 294

Diagrams

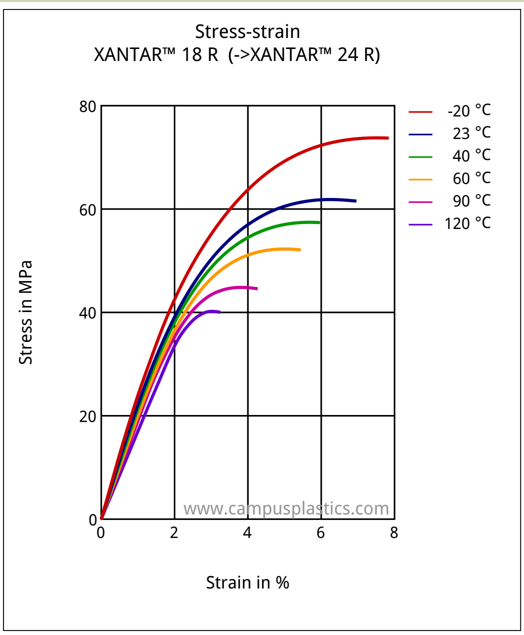
Viscosity-shear rate



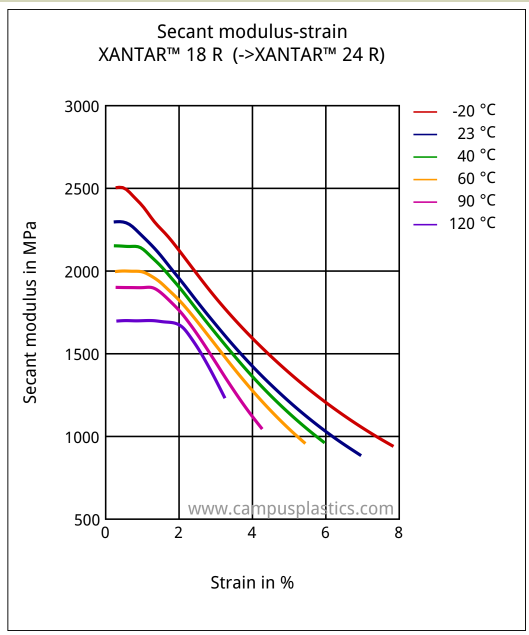
Shearstress-shear rate



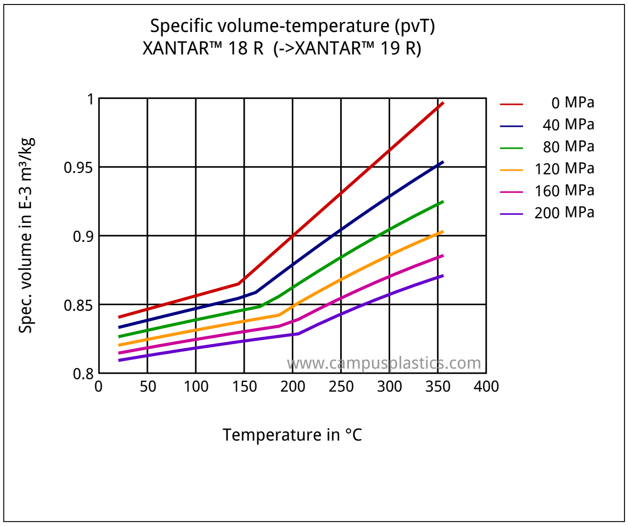
Stress-strain



Secant modulus-strain



Specific volume-temperature (pvT)



Characteristics

Processing
Injection Molding

Special Characteristics
Heat stabilized or stable to heat, Transparent

Delivery form
Pellets

Regional Availability
Europe

Additives
Release agent

Other text information

Injection molding
[Injection Molding Recommendations]

Chemical Media Resistance

Acids
- Acetic Acid (5% by mass) (23°C)
- Citric Acid solution (10% by mass) (23°C)
- Lactic Acid (10% by mass) (23°C)
- Hydrochloric Acid (36% by mass) (23°C)
- Nitric Acid (40% by mass) (23°C)
- Sulfuric Acid (38% by mass) (23°C)
- Sulfuric Acid (5% by mass) (23°C)
- Chromic Acid solution (40% by mass) (23°C)

Bases
- Sodium Hydroxide solution (35% by mass) (23°C)
- Sodium Hydroxide solution (1% by mass) (23°C)
- Ammonium Hydroxide solution (10% by mass) (23°C)

Alcohols
- Isopropyl alcohol (23°C)
- Methanol (23°C)

- Ethanol (23°C)

Hydrocarbons

- n-Hexane (23°C)
- Toluene (23°C)
- iso-Octane (23°C)

Ketones

- Acetone (23°C)

Ethers

- Diethyl ether (23°C)

Salt solutions

- Sodium Chloride solution (10% by mass) (23°C)
- Sodium Hypochlorite solution (10% by mass) (23°C)
- Sodium Carbonate solution (20% by mass) (23°C)
- Sodium Carbonate solution (2% by mass) (23°C)
- Zinc Chloride solution (50% by mass) (23°C)

Other

- Ethyl Acetate (23°C)
- Hydrogen peroxide (23°C)
- Water (23°C)
- Phenol solution (5% by mass) (23°C)