A Dissertation

On

Effect of Cooling Systems along with Thickness Variations on Injection Molding Warpage Results and CAE Correlations for Automation of Autodesk Moldflow

Submitted in partial fulfilment of requirements for the degree of

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in

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Certificate

This is to certify that the work done in the dissertation "**Effect of Cooling Systems along with Thickness Variations on Injection Molding Warpage Results and CAE correlations for Automation of Autodesk Moldflow**" submitted by Mr. Bharat Gupta in partial fulfilment of requirements for the award of Master of Engineering degree in **CAD/CAM Engineering** at **Mechanical Engineering Department** of **Thapar Institute of Engineering and Technology, Patiala** is an authentic record of work carried out under the guidance of **Dr. J.S. Saini** and **Dr. Gagandeep Bhardwaj** in the industrial organisation LG Soft, Greater Noida along with industrial guidance of **Mr. Srinivas Ganeboina**. The matter embedded in this report has not been submitted in any part or full to any other university or institute for the award of any degree.

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ABSTRACT

The injection molding process has been widely used to manufacture various plastic products featuring complex geometry. Product quality and productivity are conflicting requirements which are hard to achieve simultaneously. Some molding simulation packages are available which can accurately simulate the injection molding process based on process parameters, material data and mold configuration, and can help engineers to understand the molding process and evaluate the quality of the parts. However, due to the complexity of the molding process, producing high-quality plastic parts in less cycle time is still difficult, even with the help of advanced simulation technology. This thesis analyses the gaps between the real injection molding process and the current available technology, and proposes a methodology for optimization of warpage results along with CAE correlation.

The fundamental contrast is that thermoplastics are recyclable and can be re-fabricated after warming as the restoring procedure is totally reversible and no synthetic holding occurs. Thermoset plastics can't be re-fabricated by warmth once they have been formed in light of the fact that the thermoset relieving procedure contains a substance response which is irreversible in request to acquire an attractive mix of properties; some filler have been added to the plastic material. For instance, strengthening filaments, for example, those made of glass and carbon are added to improve the plastic material's mechanical quality; fire retardants are added to avert fire. Infusion embellishment is one of the most generally utilized strategies to make plastic parts. It is the second most normal procedure, just somewhat less famous than the expulsion, regarding the all-out plastic material utilization. Infusion trim is a modest and proficient approach to make items that have complex geometry, a high surface completion, and measurement exactness necessities. It is additionally effectively mechanized, which makes it increasingly appropriate for large scale manufacturing.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1
INTRODUCTION

1.1 Introduction

Plastic material has been broadly utilized in our everyday lives for quite a long time. Contrasted with metal, plastic has numerous focal points: it is lightweight, has high explicit quality and a low warm development rate, is anything but difficult to manufacture, and is grinding, compound, electrical-and, consumption safe. Because of its superb mechanical properties, plastic has been broadly used to supplant metal in many designing applications. It is likewise less expensive and simpler to produce contrasted with metal. Plastic factors vigorously in our day by day lives as toys, bundling, electronic gadgets, restorative devices, and so forth. Because of their particular properties and applications, the two thermoplastics and thermosets have been utilized to fabricate plastic parts. The fundamental contrast is that thermoplastics are recyclable and can be re-fabricated after warming as the restoring procedure is totally reversible and no synthetic holding occurs. Thermoset plastics can't be re-fabricated by warmth once they have been formed in light of the fact that the thermoset relieving procedure contains a substance response which is irreversible in request to acquire an attractive mix of properties; some filler have been added to the plastic material. For instance, strengthening filaments, for example, those made of glass and carbon are added to improve the plastic material's mechanical quality; fire retardants are added to avert fire. Infusion embellishment is one of the most generally utilized strategies to make plastic parts. It is the second most normal procedure, just somewhat less famous than the expulsion, regarding the all-out plastic material utilization. Infusion trim is a modest and proficient approach to make items that have complex geometry, a high surface completion, and measurement exactness necessities. It is additionally effectively mechanized, which makes it increasingly appropriate for large scale manufacturing.

In spite of the fact that the infusion embellishment procedure has been broadly used to make a wide range of plastic parts, there are still a few difficulties. Some infusion formed plastic parts need additional post-preparing, for example, painting and evacuating the nourishing framework. Additionally, plastic part measurements are increasing, which requires bigger infusion embellishment machines with a higher clipping power. Like in a car industry with an expanding number of enormous plastic parts, for example, the front and back guard, all that should be infusion formed. Besides, there is an expanding interest for plastic parts with slight thickness and excellent, which requires progressively exact control of the trim procedure parameters. Infusion trim is an intricate procedure including rheology, heat conduction, material stage progress, and so on. In this way, engineers structuring the plastic parts and forms must think about embellishment material science.

1.2 Polymer

Compound atom or Chemical molecule with its individuality is termed as monomer. At the point when numerous monomers are connected together to shape a chain, a polymer particle is framed. Connection of numerous monomers classifies the polymers as in Figure 1.1 and Figure 1.2.

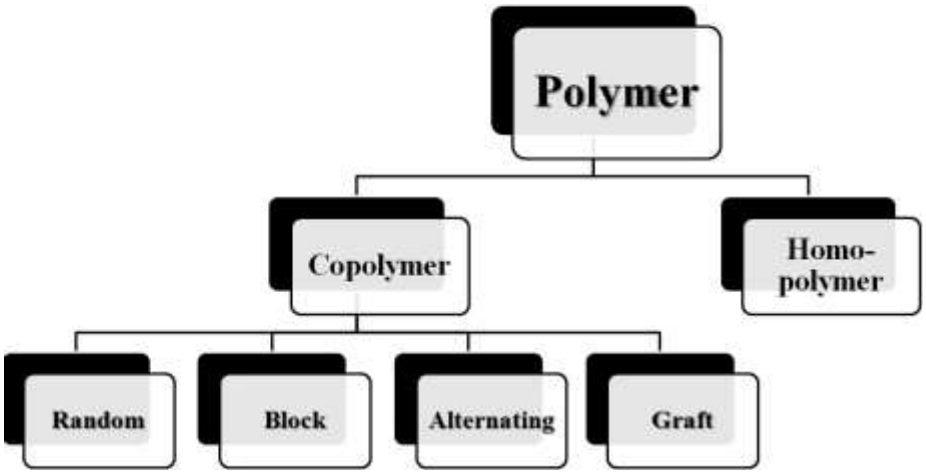


Figure 1.1: Flow Chart showing connection of monomers that classifies polymers

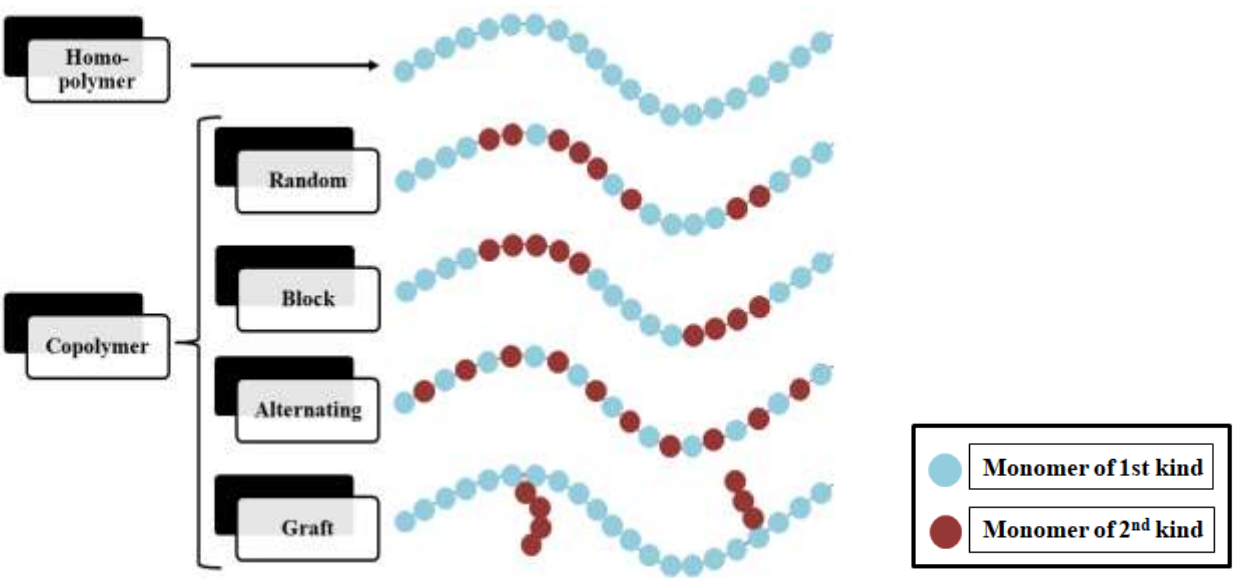


Figure 1.2: Monomers arrangement for polymerization

1.3 Plastics

Figure 1.3 shows that a plastic comprises of numerous polymer particles when consolidated together.

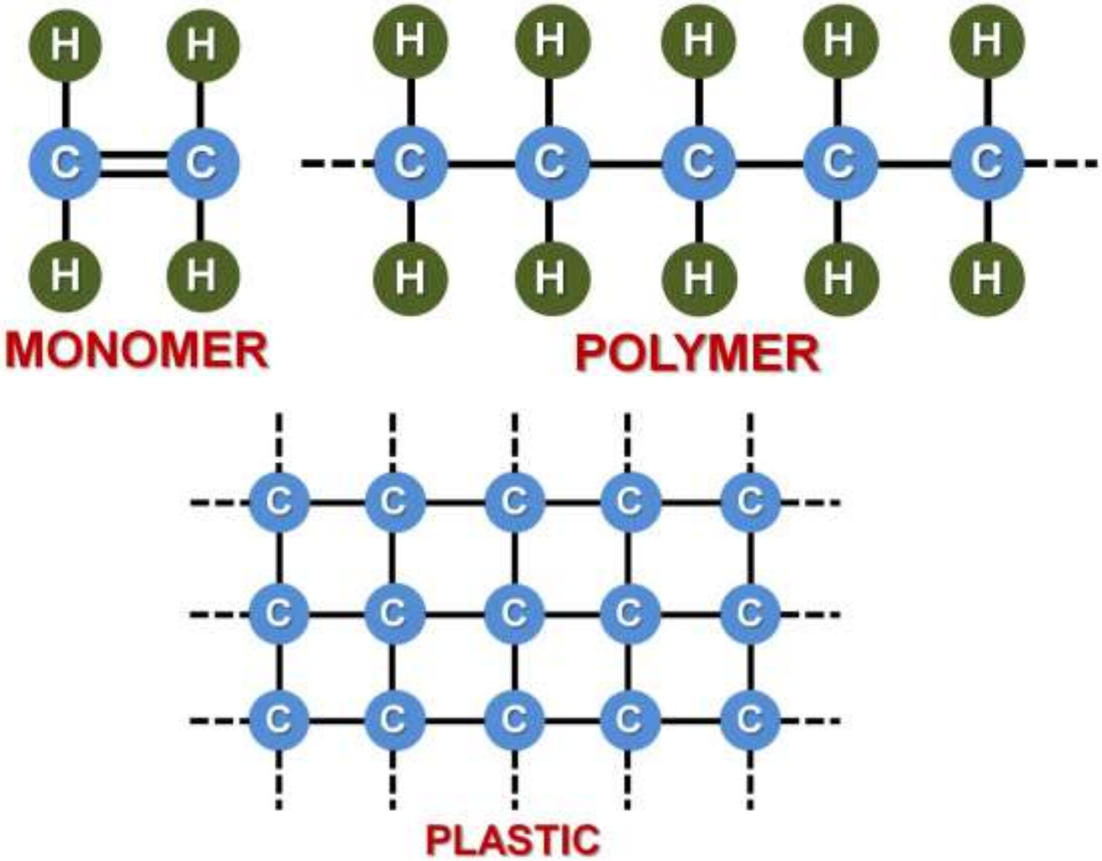


Figure 1.3: Example of Monomer, Polymer and Plastic

Organic polymers like ABS, HDPE, LDPE, Polystyrene, and so forth are utilized in wide scope to shape into plastics. These natural polymers can be shaped into shape while delicate and afterward set into an inflexible or somewhat versatile structure.

1.3.1 Plastic Material Considerations

For a Product Design Engineer, one of the prominent tasks is to see that what are the requirements of plastic material and also corresponding to that what are the various factors and application tests that must be considered while choosing the apt material for different process [1]. Some of the factors corresponding to considerations of plastic material as shown in Figure 1.4 are as follows:

- **Aesthetic property**
- **Geometrical property**
- **Mechanical property**
- **Material property**
- **Operations to be performed**
- **Environmental conditions**
- **Processing Technique**
- **Cost Effectiveness**

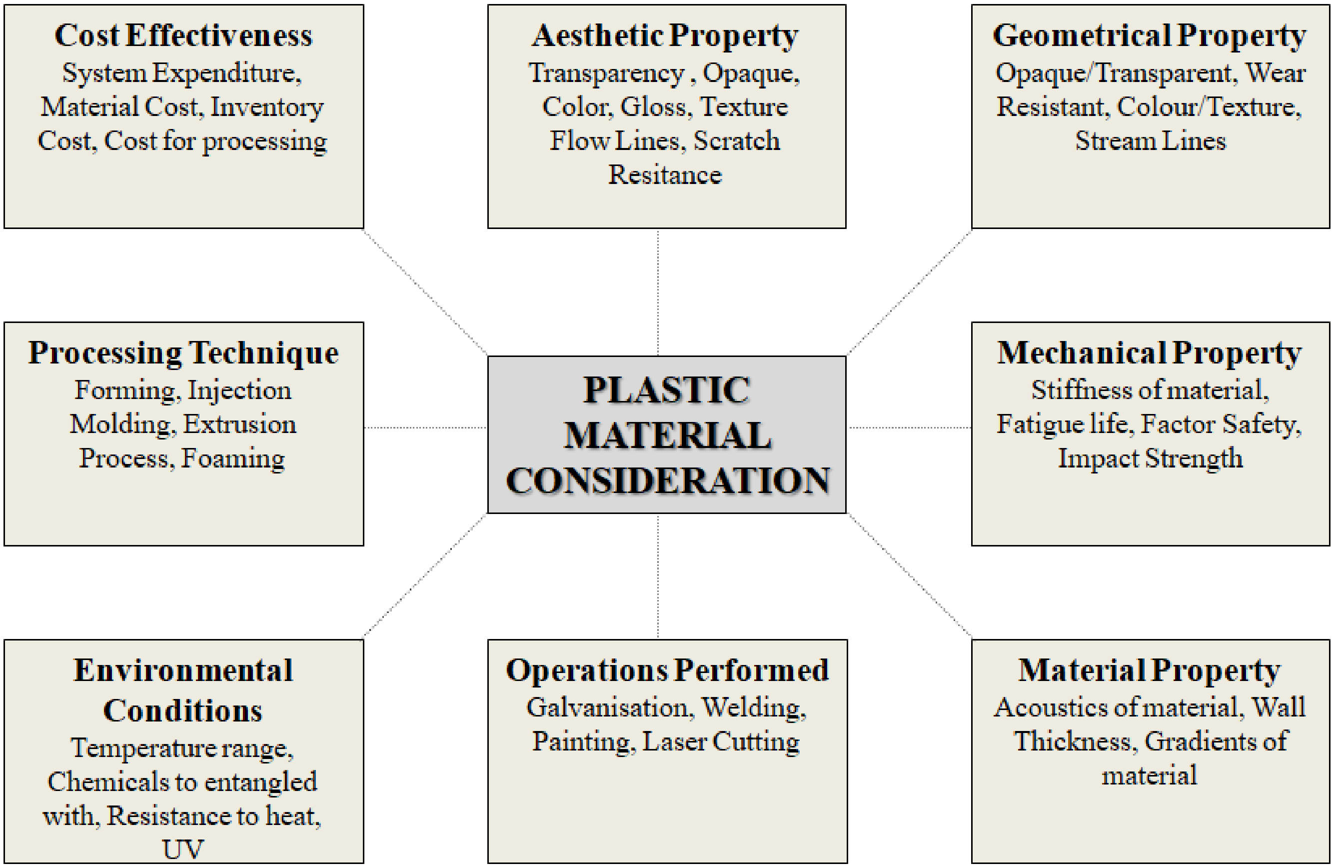


Figure 1.4: Factors for Plastic Material Consideration

The decision of thermoplastic embellishment material is a key component in a section being appropriate for its expected application. We can offer help drawing without anyone else specialized information and handling background banding together with our confided in crude material providers. Due thought must be given to the mechanical attributes, shaping procedure, cost per kilo and material accessibility.

Over determination of materials is best maintained a strategic distance from as it could bargain generation costs, lead times and device steel choice making the task more intricate and included than might be essential. The decision of thermoplastic embellishment material is a key component in a section being appropriate for its planned application [2,3]. We can offer help drawing without anyone else specialized learning and handling knowledge collaborating with our confided in crude material providers. Due thought must be given to the mechanical attributes, shaping procedure, cost per kilo and material accessibility. Over particular of materials is best kept away from as it could bargain generation costs, lead times and device steel determination making the venture more perplexing and included than might be vital. Structuring a plastic part for manufacturability includes numerous significant variables that touch on all zones of part configuration, tooling, material determination and creation. To begin with, it is basic to assemble parts around useful needs by remembering structure expectation or the end use. Consider weight decreases, the end of creation and gathering steps, improving auxiliary parts, lessening costs and getting items to advertise faster.

1.4 Injection Molding

Injection molding is an assembling procedure for creating parts by infusing liquid material into a form. It tends to be performed with a large group of materials fundamentally including glasses, elastomers, sugary treats, metals and most normally thermoplastic and thermosetting polymers. Material for the part is encouraged into a warmed barrel, blended into a helical formed screw and infused into a shape cavity, where it cools and solidifies to the setup of the hole [4]. After an item is structured, more often than not by a mechanical fashioner or an architect, molds are made by a shape creator (or toolmaker) from metal, for the most part either steel or aluminium, and accuracy machined to frame the highlights of the ideal part. It is broadly utilized for assembling an assortment of parts, from the littlest segments to whole body boards of vehicles. Advances in 3D printing innovation, utilizing photopolymers which don't liquefy during the infusion trim of some lower temperature thermoplastics, can be utilized for some basic infusion molds.

Infusion embellishment is the most generally utilized assembling process for the creation of plastic parts. It is utilized to make wide assortment of items, which change incredibly in their size, intricacy, and application. The plastic is softened in the infusion embellishment machine and after that infused into the shape, where it cools and cements into the last part as in Figure 1.5. Infusion embellishment is utilized to create slight walled plastic parts for a wide assortment of utilizations, a standout amongst the most well-known being plastic lodgings. Plastic lodging is a flimsy walled fenced in area, regularly requiring numerous ribs and managers on the inside. These lodgings are utilized in an assortment of items including family unit machines, customer hardware, control instruments, and as car dashboards. Other normal slender walled items incorporate various sorts of open compartments, for example, basins. Infusion trim is likewise used to deliver a few ordinary things, for example, toothbrushes or little plastic toys. Numerous therapeutic gadgets which include syringe can be produced with the utilization of Injection Molding.

The prominent units in Injection molding machine are portrayed in more detail in the following section.

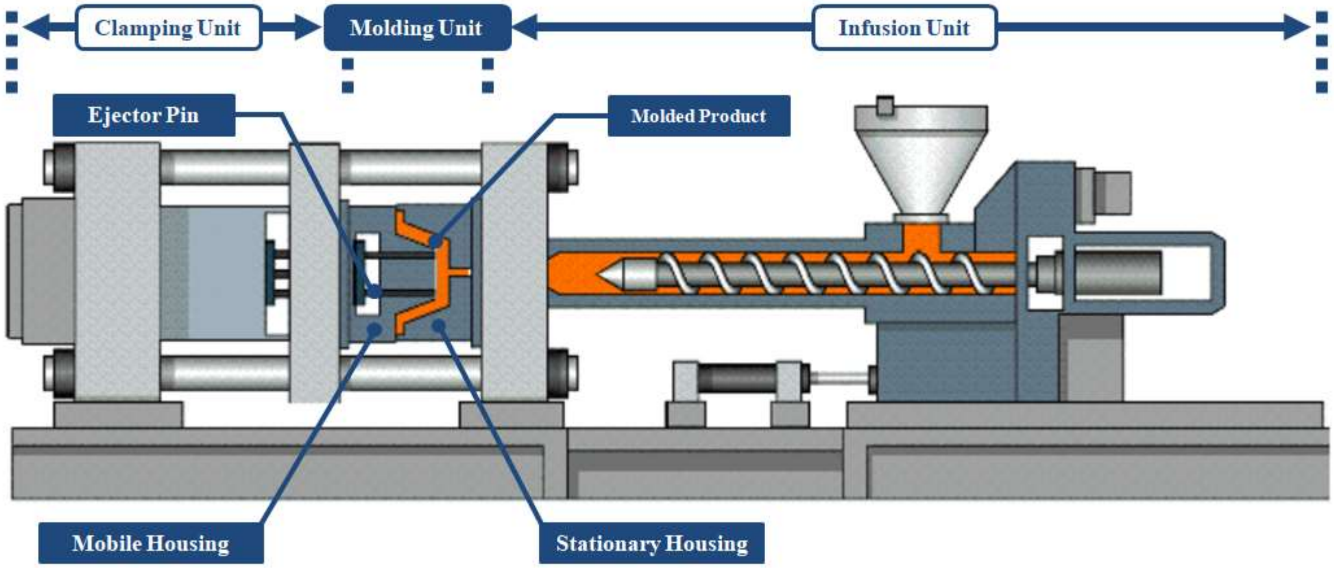


Figure 1.5: Units of Injection Molding Machine [W1]

Injection molding machine is divided into 3 main units which comprises of:

- **Infusion Unit**
- **Molding Unit / Ejecting Unit**
- **Clamping Unit**

1.4.1 Infusion Unit

The infusion unit is in charge of both warming and infusing the material and then fed into the cavity formed in a mold. The initial segment of this unit is the container, an enormous holder into which the crude plastic is poured usually known as hopper. It has an open base, which enables the material to bolster into the barrel with ease. It contains the instrument which acts as heating pad for warming and infusing the material into the shape. This component is normally a smash injector or a responding screw. A slam injector powers the material forward through a warmed area with a smash or plunger that is generally using pressurized water fuelled. Today, the more typical strategy is the utilization of a responding screw. A responding screw pushes the material ahead by both pivoting and sliding pivotally, being controlled by either a pressure driven or electric engine as in Figure 1.6. The material enters the notches of the screw from the container and is progressed towards the form as the screw pivots. While it is propelled, the material is liquefied by weight, rubbing, and extra warmers that encompass the responding screw. The liquid plastic is then infused in all respects rapidly into the form through the spout toward the finish of the barrel by the development of weight and the forward activity of the screw. This expanding weight enables the material to be pressed and coercively held in the form. When the material has hardened inside the shape, the screw can withdraw and load up with increasingly material for the upcoming plunged shot.

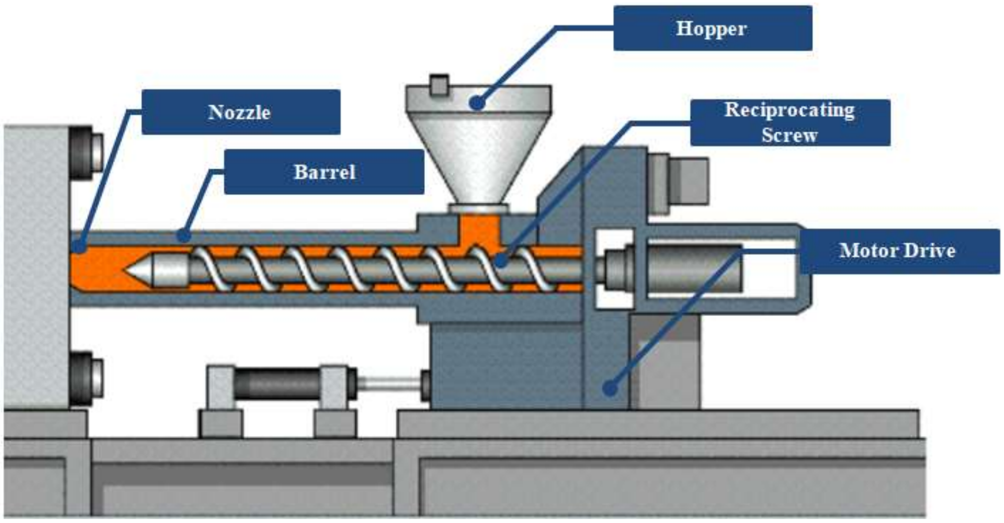


Figure 1.6: Infusion Unit [W1]

1.4.2 Molding Unit / Ejecting Unit

In injection molding, molds of different materials are used for the purpose of tooling. The form has numerous parts, however can be parted into two parts. Inside machine, one half of mold are appended inside the machine and the back half is permitted to guide so the form can be opened and shut along the shape's separating line commonly known as parting line. There are 2 prior parts of a mold i.e. the form centre which is known as core and the form depression which is known as cavity. Further Part cavity is usually framed with the space between the form centre and the form cavity at the point when the mold is shut. Further to get desired shaped part, the cavity will be loaded up with plastic that is being intended through nozzle and solidification by the prior of cooling. To get two shape parts structure with indistinguishable part depressions, molds with multiple cavity can be utilised. The form centre and shape depression are each mounted to the form base, which is then fixed to the platens inside the infusion embellishment machine. The front portion of the form base incorporates a help plate, to which the shape hole is appended, the sprue bushing, into which the material will spill out of the spout, and a finding ring, so as to adjust the form base with the spout. The back portion of the form base incorporates the launch framework, to which the shape centre is connected, and a help plate. At the point when the clipping unit isolates the shape parts, the ejector bar activates the launch framework. The ejector bar pushes the ejector plate forward inside the ejector box, which thus pushes the ejector pins into the shaped part. The ejector pins drive the hardened part out of the open shape cavity. In request for the liquid plastic to stream into the form cavities, a few channels are incorporated into the shape structure. To begin with, the liquid plastic enters the form through the sprue. Extra channels, called sprinters, convey the liquid plastic from the sprue to the majority of the depressions that must be filled. Toward the finish of every sprinter, the liquid plastic enters the depression through an entryway which coordinates the stream as in Figure 1.7.

The liquid plastic that hardens inside these sprinters is appended to the part and should be isolated after the part has been shot out from the form. Be that as it may, at times hot sprinter frameworks are utilized which autonomously heat the channels, enabling the contained material to be dissolved and segregated from the part. Another kind of channel that is incorporated with the form is cooling channels. These channels enable water to course through the form dividers, adjoining the hole, and cool the liquid plastic. In expansion to sprinters and entry ways, there are numerous other plan issues that must be considered in the structure of the molds. Right off the bat, the form must enable the liquid plastic to stream effectively into the majority of the pits. Similarly significant is the expulsion of the cemented part from the form, so a draft point must be connected to the shape dividers. The plan of the form should likewise oblige any unpredictable highlights on the part, for example, undermines or strings, which will require extra shape pieces. A large portion of these gadgets slide into the part hole through the side of the shape, and are in this manner known as slides, or side-activities. The most well-known kind of side-activity is a side-centre which empowers an outer undercut to be formed. Different gadgets enter through the finish of the shape along the separating course, for example, inside centre lifters, which can frame an interior undercut. To shape strings into the section, an unscrewing gadget is required, which can pivot out of the form after the strings have been framed.

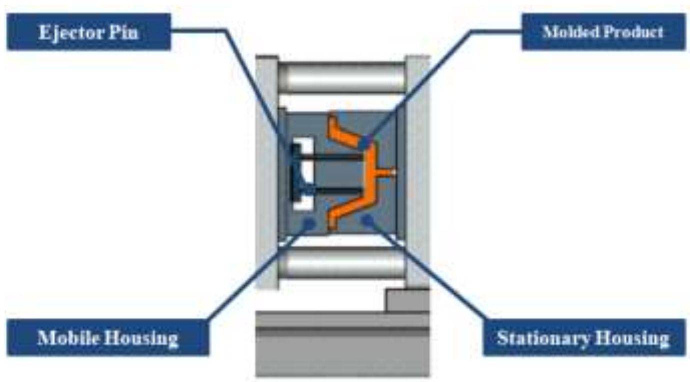


Figure 1.7: Molding Unit / Ejecting Unit [W1]

1.4.3 Clamping Unit

It is the capacity of the clasp framework to close the form with moving platen which takes half of the shape, and hold it shut under strain during shot and cooling, and after that opens the form so that the wok piece can be knock ousted from the shape. As shown in Figure 1.8, there are four clasping frameworks in infusion trim machine: pressure driven clipping framework, mechanical cinching framework, hydro mechanical bracing framework and electric clasping framework. Before the infusion of the liquid plastic into the shape, the two parts of the form should initially be safely shut by the clasping unit. At the point when the shape is connected to the infusion embellishment machine, every half is fixed to a huge plate, called a platen.

The front portion of the shape, called the form depression, is mounted to a stationary platen and lines up with the spout of the infusion unit. The back portion of the shape, called the form center, is mounted to a mobile platen, which slides along the tie bars. The powerfully controlled clipping engine activates cinching bars that push the moveable platen towards the stationary platen and apply adequate power to keep the form safely shut while the material is infused and along these lines cools. After the required cooling time, the shape is then opened by the clipping engine. A discharge framework, which is appended to the back portion of the form, is incited by the ejector bar and drives the cemented part out of the open pit.

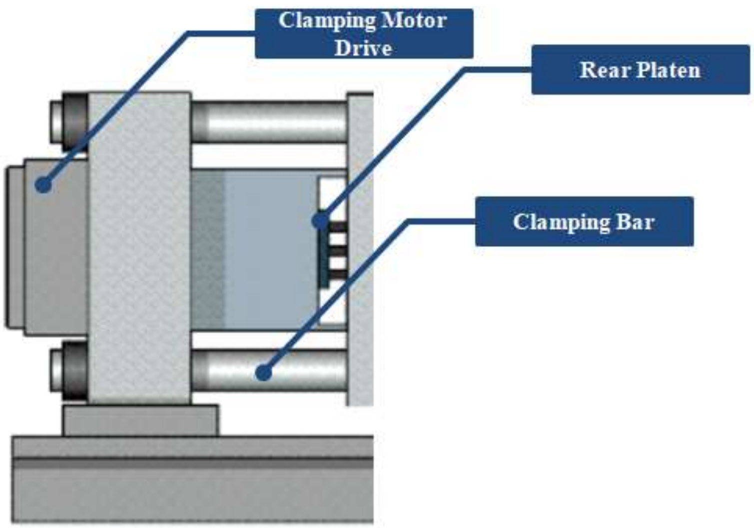


Figure 1.8: Clamping Unit [W1]

1.4.4 Infusion Embellishment Cycle

The grouping of occasions during the infusion shape of a plastic part is known as the infusion trim cycle. The cycle starts when the form closes, trailed by the infusion of the polymer into the shape depression. When the hole is filled, a holding weight is kept up to make up for material shrinkage [5,6]. In the subsequent stage, the screw turns, encouraging the following shot to the front screw. This makes the screw withdraw as the following shot is readied. When the part is adequately cool, the shape opens and the part is launched out as shown in Figure 1.9.

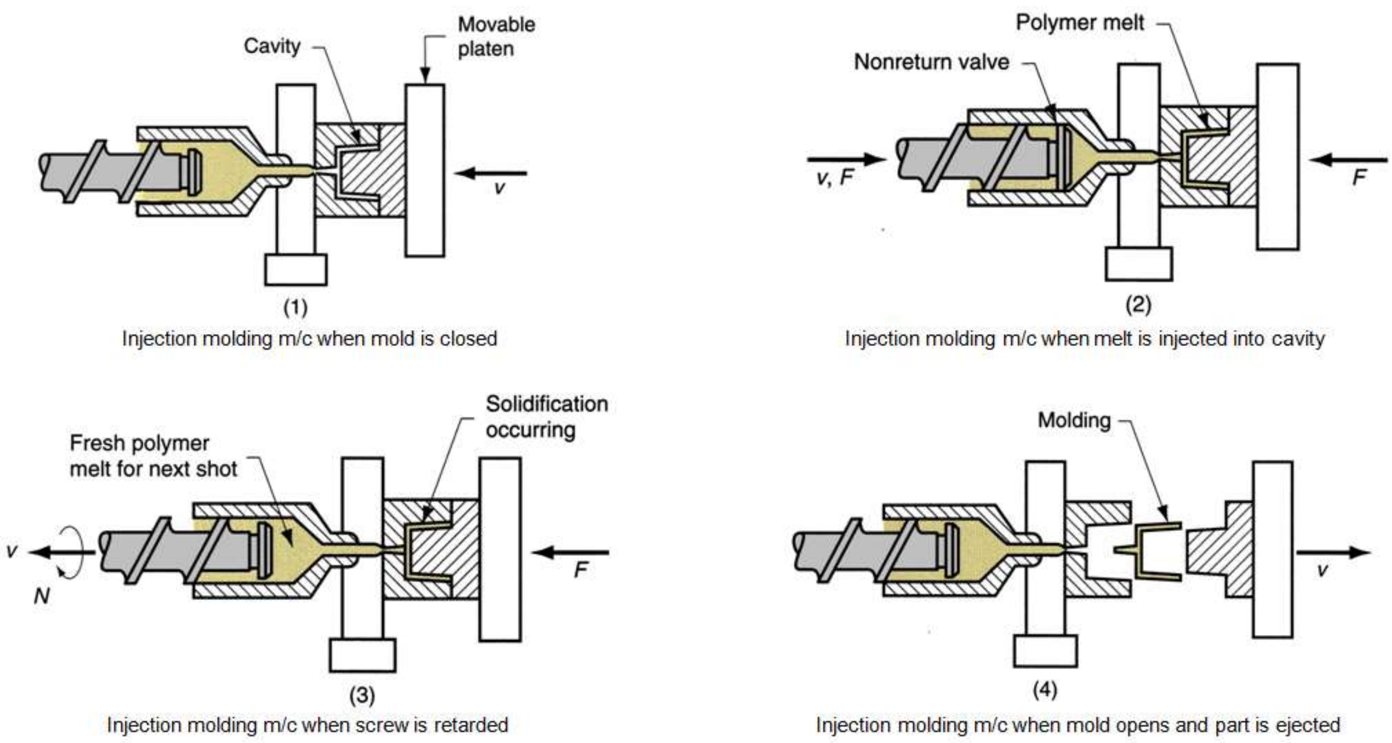


Figure 1.9: Infusion Embellishment Cycle [W2]

1.5 Computer Aided Engineering

CAE is amazing asset with the help of computer that is utilized to tackle a wide scope of designing and engineering problems. CAE is a term used to portray the method of the whole item building procedure, from structure and virtual testing with refined investigative calculations for assembling. Practically, PC supported basic building of engineering applications is standard in any industry that uses a type of structure programming to create items. CAE is the following stage in structuring an item, yet in addition supporting the building procedure, as it permits to perform tests and reproductions of the item's physical properties without requiring a physical model.

With regards to CAE, the most ordinarily utilized re-enactment investigation types incorporate Meshing Analysis, Extended Finite Element Methods, Multi-body Elements with Enhancements and Dynamics related to Stress and Fluid. By utilizing the upsides of building re-enactment, particularly when joined with the power and the speed of elite distributed computing, the expense and time of each structure emphasis cycle just as the general advancement procedure can be significantly diminished [7]. The standard CAE work process is to initially produce an underlying structure and afterward recreate the computer aided design geometry. The re-enactment results are then assessed and used to improve the structure. Figure 1.10 corresponds to methodology for CAE.

The procedure is rehashed until all the item's necessities are met and for all intents and purposes affirmed. If there should arise an occurrence of any shaky areas or zones where the computerized model's presentation doesn't coordinate the desires, specialists and architects can improve the computer aided design model and check the impacts of their change by testing the refreshed structure in another reproduction. This procedure underpins quicker item advancement as there is no requirement for structure physical models in early improvement stages. Re-enacting with CAE techniques will just take a couple of hours all things considered, in contrast with days or likely weeks that building a physical model would require. Everybody acquainted with the item improvement procedure realizes that it is unavoidable to construct a physical model before beginning with the sequential creation of an item. However reproduction can lessen the measure of those models.

When intending to incorporate recreation methods into the item improvement process, it is imperative to think about nature that the item will be presented to. Realizing these conditions is urgent to appropriately set up a recreation. The prescient estimation of any recreation must be the exactness of the limit conditions made. As of not long ago, other than foreseeing the natural factors and conditions, designing reproduction was a perplexing and troublesome undertaking without anyone else, for the most part saved for experienced specialists and re-enactment specialists.

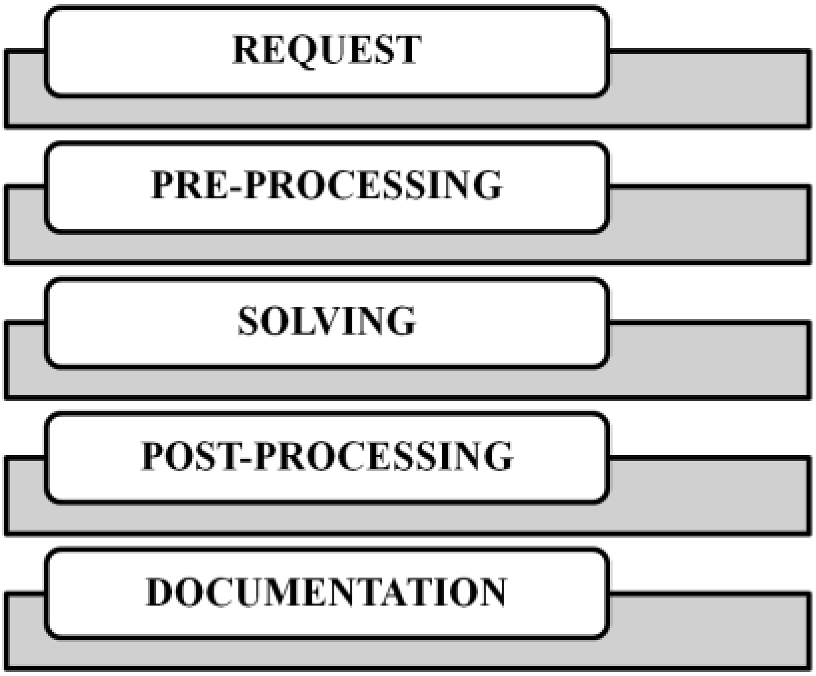


Figure 1.10: Methodology for CAE

Novices needed to battle with a lofty expectation to absorb information. Present day CAE recreation instruments, for example, Sims-scale, attempt to separate these obstructions, permitting even unpractised clients without profound learning of the physical procedures and extraordinary solver qualities to create quick re-enactment results [8]. Reproducing complex geometries is troublesome, notwithstanding for current PCs. This is the reason a great deal of figuring force is expected to perform practical re-enactment results. Huge organizations with advanced IT foundation can utilize their very own servers to host and run reproductions.

The ascent of HPC distributed computing currently likewise gives littler organizations, which more often than not can't stand to purchase and keep up the essential equipment, access to a similar re-enactment devices and capacities that already were saved uniquely for a chosen few.

This disturbance in the market for recreation items makes it now workable for everybody to mimic the items they structure. CAE is the utilized for recreate execution so as to:

- **Improve item structures**
- **Proactively aid related to designing issues as well as for engineering active issues**
- **Incorporates reproduction, approval with advancement of items, procedures and assembling apparatuses.**

1.5.1 Computer Aided Engineering Correlation with Process

These days, the push to plan, create and analyse a model has been expanding quickly and improvements times have been cut so as to put more items into market in less time. One of the prominent and useful answer for this issue is to build the CAE assets around the work. The CAE Correlation with procedure can be comprehended by the Figure 1.11.

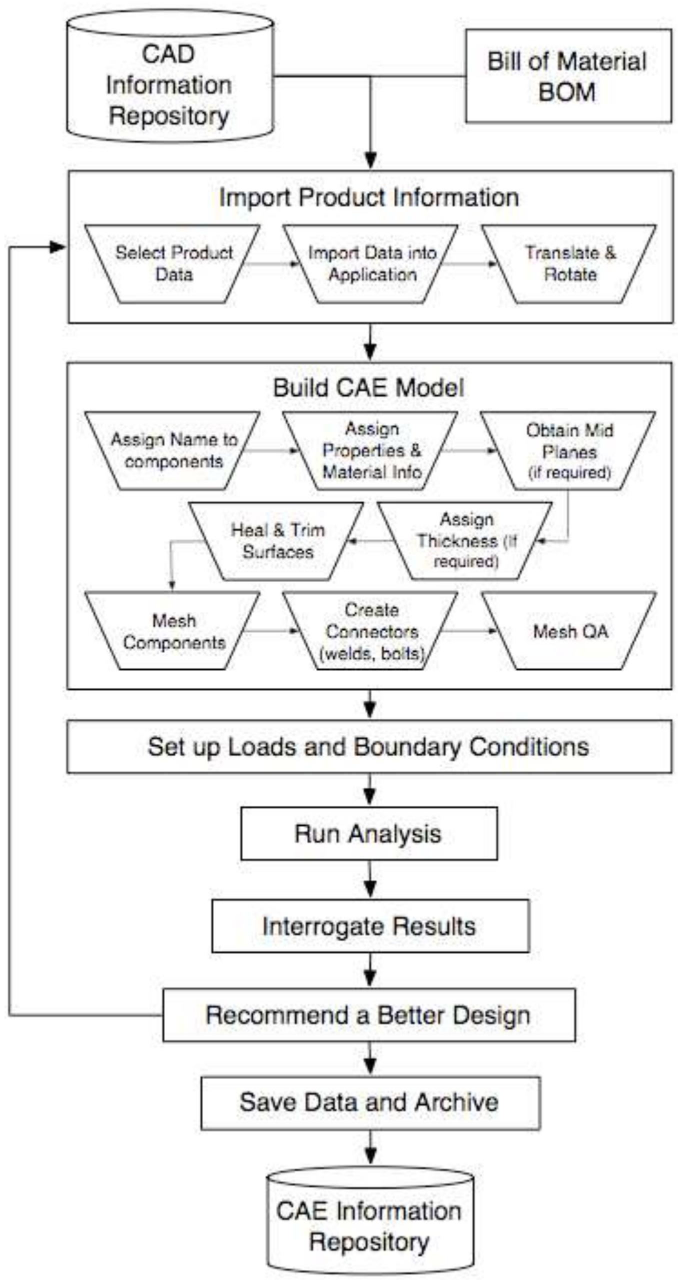


Figure 1.11: Flowchart showing CAE Correlation with Process [W3]

1.6 Moldflow

Moldflow is software to assist the designer for analysing the plastic infusion into the mold. Immense collection of information, acts as reference for materials to be utilised for production and this helps designers for accrediting. Analysis arrangements with elucidation of results indicates that how a variation in cooling system, process conditions, property of materials, influencing conditions and sort of gate implanted influences production.

This software gives plastic recreation instruments to specialists and investigators to guarantee shaped part quality and its production. Its Knowledge recreates the most developed trim procedures to keep away from creation delays [9,10,11]. To enhance the structure and quality of molded parts as well as for infusion molds various active keys of instruments are provided by this software which is a prominent assistance. By precisely foreseeing the embellishment procedure, potential deformities can be abstained from, empowering great plastic items to be produced effectively first time.

The modified strategy for Moldflow is as per the Figure 1.12.

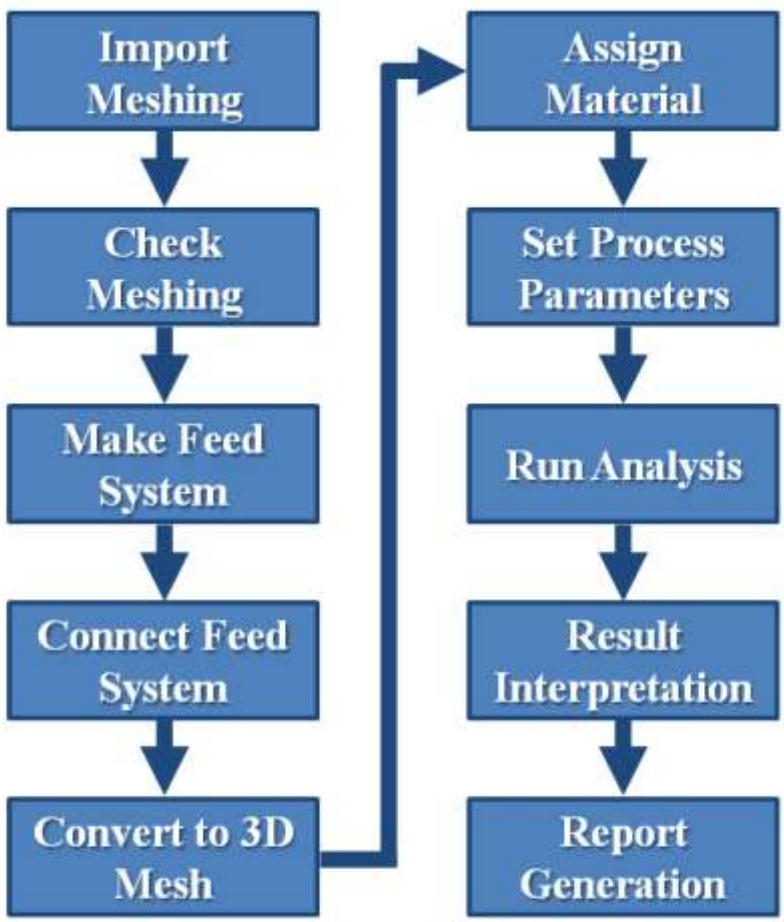


Figure 1.12: Procedure for Moldflow Synergy

1.7 Visual Basics for Applications

Microsoft Company inherits us with a programming language which is occasion oriented and this language is currently utilized prevalently with other applications of the company. It leads the geeks to manufacture altered applications along with answers for improvement in the abilities of those applications. The prominent benefit of this sort of language is that we don't require having this language based software to be in the computer; be that as it may, introducing Office will verifiably help in accomplishing the reason.

Visual Basics Application on Excel is the most well known among the rest of applications as shown in Figure 1.13. We can construct extremely useful assets in Excel with the utilizing of direct programming; this is the upside of inheriting VBA. VBA turns to be the most evident arrangement when Excel given fundamental capacities which are keenly inbuilt capacities, won't be adequate to perform complex geometry problems.

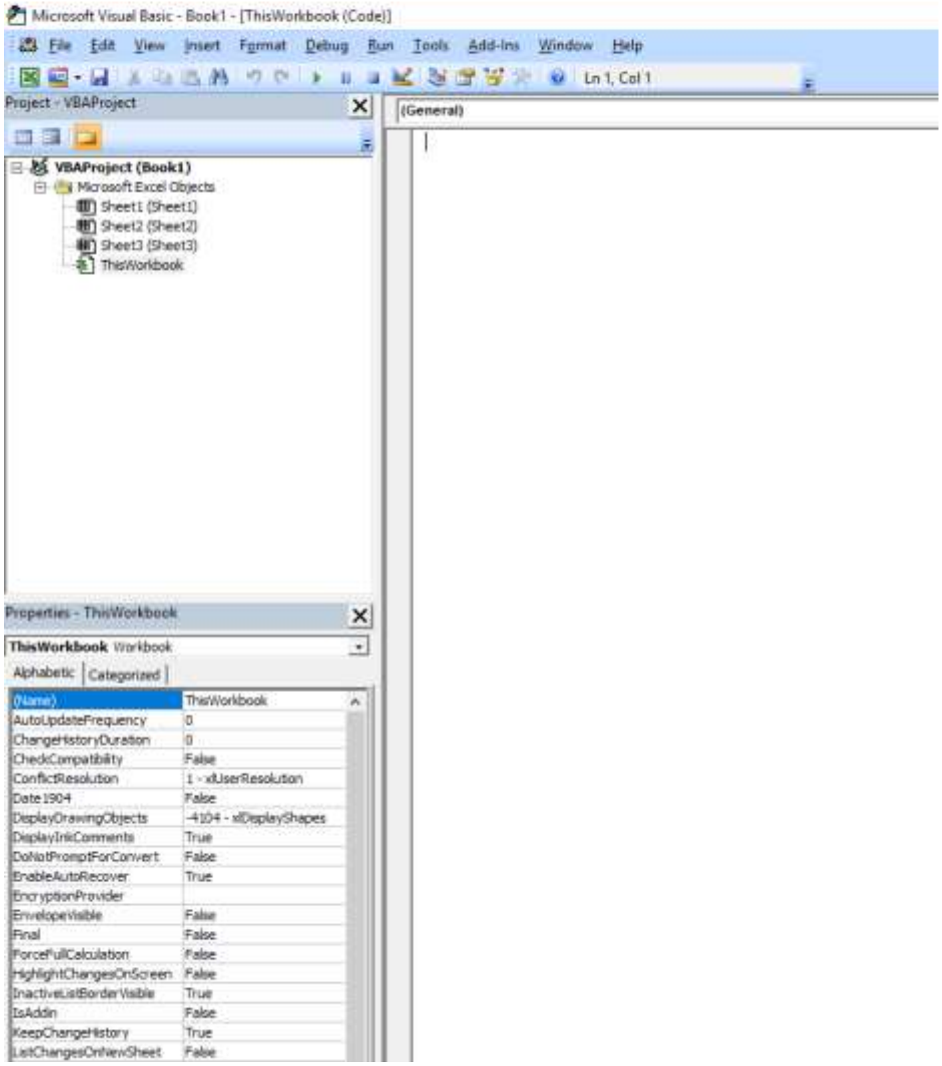


Figure 1.13: Interface of Excel based Visual Basic Application

1.8 Literature Review

Burden with infusion embellishment process is that the form will in general be over the top with higher cost and adjustments of the shape along with the plan of the component that are to be formed is normal and price-devouring. Fundamental apparatus with the assistance of PC along with innovation corresponding to engineering performs convergent analysis of the infusion embellishment procedure. Its legitimate utilization is going to limit the measure of up gradation and adaptation. By utilizing approximation systems, the procedure is recreated in a situation numerically along with shape adjustments and procedure inputs can be tried over and over before the real generation of the product.

Experimentation have demonstrated that expenses up to half can be trimmed for form alterations and near about fifteen percent for process duration when utilizing approximate procedure recreation methodology. Infusion embellishment process analysis becomes an important method for analysts in the last decade. The main business virtual products could anticipate all sort of streams in slender locales in light of one-dimensional stream with different geometrical segments. Two decades back, purported Two and a half dimensional stream examination was created in which two-dimensional stream investigation was connected to a three-dimension hollow prototype.

Afterward materials corresponding to fiber were presented and now regardless of whether it is utilized in this theory or not, it is additionally conceivable to anticipate every one of the means from stream to shrinkage in muddled projects where for instance inactivity and acceleration impacts are incorporated. The infusion embellishment procedure is a retro issue with a displacing performs, where dual warmth movement is available. This is a sort of hypothetical concept. Most exertion is to be indulging in the advancement of approximate re-enactments to demonstrate these material sciences. This section will depict the basic thought along with its way of the approximate examination which can be completed so as to recreate the various strides from the infusion of the material to the launch of the formed product.

1.7.1 Examination of Fill during Infusion

Filling of a slender boundary component which is possessing the property to get stiff by the virtue of heat is quite tedious procedure. Further, to have the option to simulate the procedure it tends to be streamlined by a summed-up methodology of creeping flow which is isochoric and summed up under provided inputs [12,13]. Methodology corresponding to creep flow alludes to stream through dual components which are placed near one another. Along with that, consequently breadth of the distance between them is thought to be a lot littler than different elements of the stream and these sorts of approximations along with presumption yields that the stream with reference to a predefined location is for the most affected by the neighbor locations as can be seen in Figure 1.14.

Hence, free film theory can be related as the speed insight along the distance between them. Creep flow is analyzed with the usage of following:

Continuity Equation:

$$\frac{\partial \aleph}{\partial \underline{T}} + \frac{\partial(\aleph\alpha)}{\partial \underline{P}} + \frac{\partial(\aleph\beta)}{\partial \underline{Q}} + \frac{\partial(\aleph\gamma)}{\partial \underline{R}} = 0 \tag{1}$$

Momentum Equations:

$$\frac{\partial \wp}{\partial \underline{P}} = \frac{\partial}{\partial \underline{R}}\left(\gimel \frac{\partial \alpha}{\partial \underline{R}}\right) \tag{2}$$

$$\frac{\partial \wp}{\partial \underline{Q}} = \frac{\partial}{\partial \underline{R}}\left(\gimel \frac{\partial \beta}{\partial \underline{R}}\right) \tag{3}$$

Energy Equation:

$$\aleph_{\acute{M}} \underline{S}_{\acute{M}} \left(\frac{\partial \varphi}{\partial \overline{\overline{T}}} + \alpha \frac{\partial \varphi}{\partial \underline{P}} + \beta \frac{\partial \varphi}{\partial \underline{Q}}\right) = \gimel \dot{C}^2 + \kappa_{\acute{M}} \frac{\partial^2 \varphi}{\partial \underline{R}^2} \tag{4}$$

In which, $(\underline{P}, \underline{Q}, \underline{R})$ – Cartesian Coordinate

(α, β, γ) – Velocity Component

φ – Temperature

$\wp$ – Pressure

$\aleph_{\acute{M}}$ – Density of material

$\underline{S}_{\acute{M}}$ – Specific heat of material

$\kappa_{\acute{M}}$ – Thermal conductivity of material

$\gimel$ – Viscosity

$\dot{C}$ – Shear rate

Shear rate can be inferred using:

$$\dot{C} = \left(\left(\frac{\partial \alpha}{\partial \underline{R}} \right)^2 + \left(\frac{\partial \beta}{\partial \underline{R}} \right)^2 \right)^{\frac{1}{2}} \quad (5)$$

The methodology conditions depend on the accompanying assumptions:

- The stream doesn't possess property of extensibility.
- The wellspring stream marvels, all the external energies are ignored
- Ordinary anxieties are dismissed
- Convection in the hole savvy heading and conduction in the stream course are ignored.

So, the limits are as follows:

$$At\ \underline{R} = b, \alpha = \beta = 0, \varphi = \varphi_{WT} \quad (6)$$

$$At\ \underline{R} = 0, \frac{\partial \alpha}{\partial \underline{R}} = \frac{\partial \beta}{\partial \underline{R}} = \frac{\partial \varphi}{\partial \underline{R}} = 0 \quad (7)$$

$$\wp = 0 \quad (8)$$

In which, φ_{WT} – Uniform temperature corresponding to wall

2b – Distance between walls

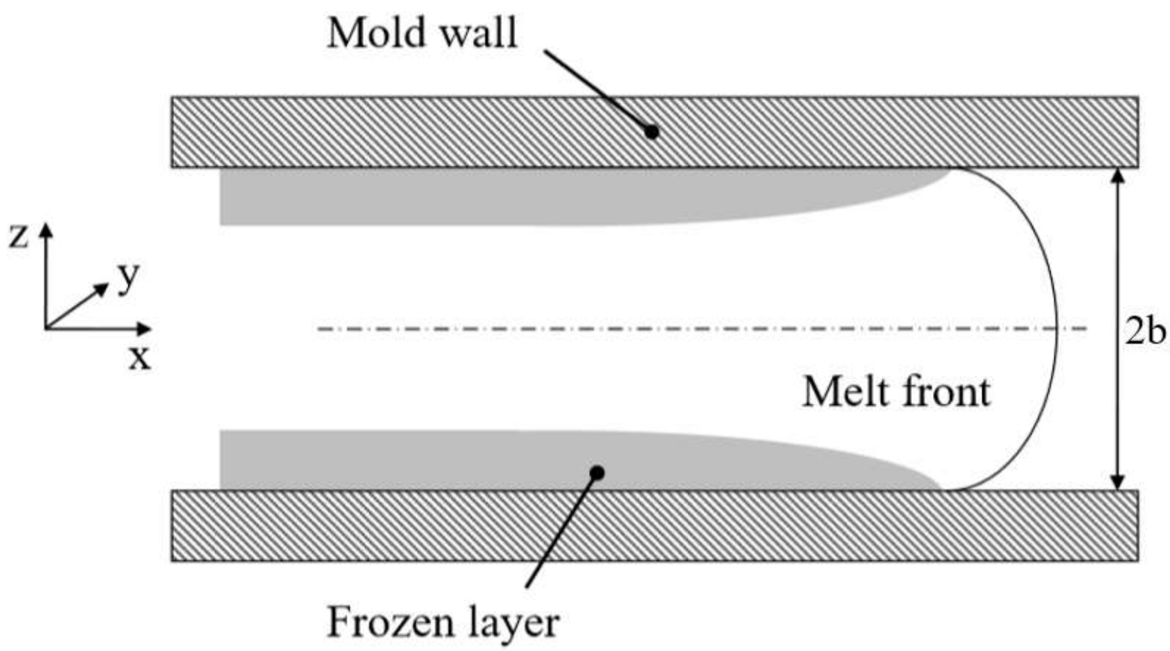


Figure 1.14: View corresponds to stream [W4]

Integration of Eq.2 and Eq.3 making use of Eq.8 results in:

$$\gimel \frac{\partial \alpha}{\partial \underline{R}} = \frac{\partial \wp}{\partial \underline{P}} \underline{R}$$
$$\gimel \frac{\partial \beta}{\partial \underline{R}} = \frac{\partial \wp}{\partial \underline{Q}} \underline{R} \tag{9}$$

Integrating once more together with Eq.6 results in:

$$\alpha = -\frac{\partial \wp}{\partial \underline{P}} \int_{\underline{R}}^{b} \frac{\underline{R}\, d\underline{R}}{\gimel} \tag{10}$$

$$\beta = -\frac{\partial \wp}{\partial \underline{Q}} \int_{\underline{R}}^{b} \frac{\underline{R}\, d\underline{R}}{\gimel} \tag{11}$$

Combining Eq.5 with Eq.10 and Eq.11 yields:

$$\dot{C} = \frac{\underline{R}}{\gimel} \left(\left(\frac{\partial \wp}{\partial \underline{P}} \right)^2 + \left(\frac{\partial \wp}{\partial \underline{Q}} \right)^2 \right)^{\frac{1}{2}} \tag{12}$$

Further, the gap-wise averaged velocities are obtained by integration of Eq.10 and Eq.11:

$$\overline{\alpha} = \frac{-(\partial\wp/\partial\underline{P})}{b} C_F \tag{13}$$

$$\overline{\beta} = \frac{-(\partial\wp/\partial\underline{Q})}{b} C_F \tag{14}$$

In which, C_F – Stream Conductance

$$C_F = \int_0^b \frac{\underline{R}^2}{ƛ} d\underline{R} \tag{15}$$

Substituting Eq.13 and Eq.14 into Eq.1 gives:

$$\frac{\partial}{\partial\underline{P}}\left(C_F \frac{\partial\wp}{\partial\underline{P}}\right) + \frac{\partial}{\partial\underline{Q}}\left(C_F \frac{\partial\wp}{\partial\underline{Q}}\right) = 0 \tag{16}$$

The viscosity can be described with different material models.

The Newtonian models

$$ƛ = ƛ_o \tag{17}$$

The power law models

$$ƛ = \rho\dot{C}^{k-1} \tag{18}$$

The Cross models

$$ƛ = ƛ_{IF} + \frac{ƛ_o - ƛ_{IF}}{(\theta\dot{C})^j + 1} \tag{19}$$

In which, $ƛ_o$ – Nil shear resistance

ρ – Uniformity constant

k – Behavior index

λ_{IF} – Extreme shear resistance

j – Coefficient for consistency

θ – Fixed value corresponding to polymer

1.7.2 Examination of Holding/Packing during Infusion

During holding/packing stage, the form is topped off by material dissolve. Dissolve is constrained into the shape in large extent so as to make up for the warpage and that's why a constrained plan is required to display this conduct [14,15,16,17]. The administering conditions for this stage are equivalent to for the filling stage and thought is being made to the constringent of the dissolve by utilizing a reliance of the particular volume as can be seen in Figure 1.15. For the recreations in this postulation, a model with various parameters is utilized.

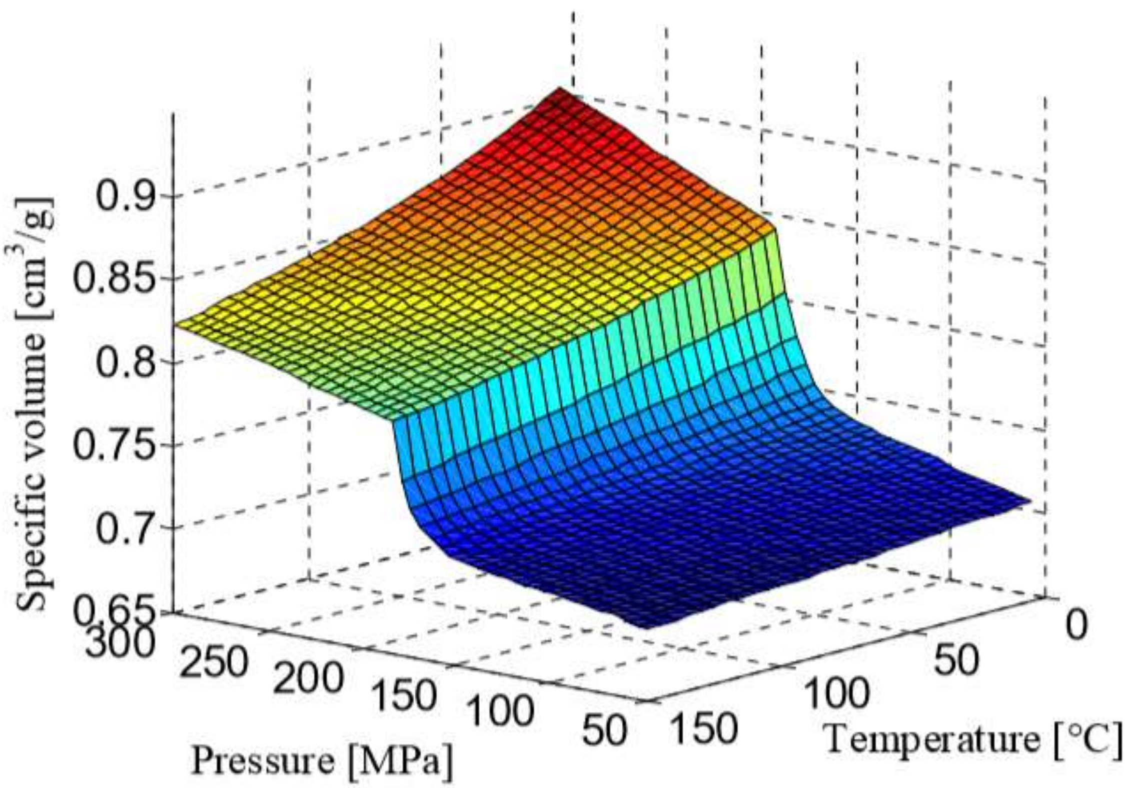


Figure 1.15: Correlation of Material parameters [W4]

$$\hat{\vartheta} = \hat{\vartheta}_T + \hat{\vartheta}_o[-Kln(1 + \wp/J) + 1] \quad (20)$$

$$\hat{\vartheta}_o = \begin{cases} j_{aR} + j_{bR}\overline{X}\,, X \le X_T\ (Freezing) \\ j_{aH} + j_{bH}\overline{X}\,, X > X_T\ (Boiling) \end{cases} \tag{21}$$

$$J = \begin{cases} j_{cR}\exp(-j_{dR}\overline{X})\,, X \le X_T\ (Freezing) \\ j_{cH}\exp(-j_{dH}\overline{X})\,, X > X_T\ (Boiling) \end{cases} \tag{22}$$

$$\hat{\vartheta}_T = \begin{cases} j_g \exp(j_h\overline{X} - j_i\wp)\,, X \le X_T\ (Freezing) \\ 0 \qquad\qquad\qquad\quad , X > X_T\ (Boiling) \end{cases} \tag{23}$$

$$\overline{X} = X - j_e \tag{24}$$

$$X_T = j_f - j_e\wp \tag{25}$$

$$K = 8.9 * 10^{-2} \tag{26}$$

In which, $\hat{\vartheta}$ – Specific Volume

K – Common Index

j_{a-i} – Polymer condition inputs

X_T – Transition temperature

1.7.3 Examination of Cooling During Infusion

The target of the form cooling examination is to comprehend the profile corresponds to heat variation utilizing limit states of material liquefy during the previous two investigations. At the point when the infusion embellishment procedure is in enduring phase, the shape temperature will vary occasionally after some duration with the procedure because of the connection of the dissolve with the form [18] as shown in Figure 1.16. So as to decrease the calculation for this intermediate procedure, a middle value of temperature is presented for the form.

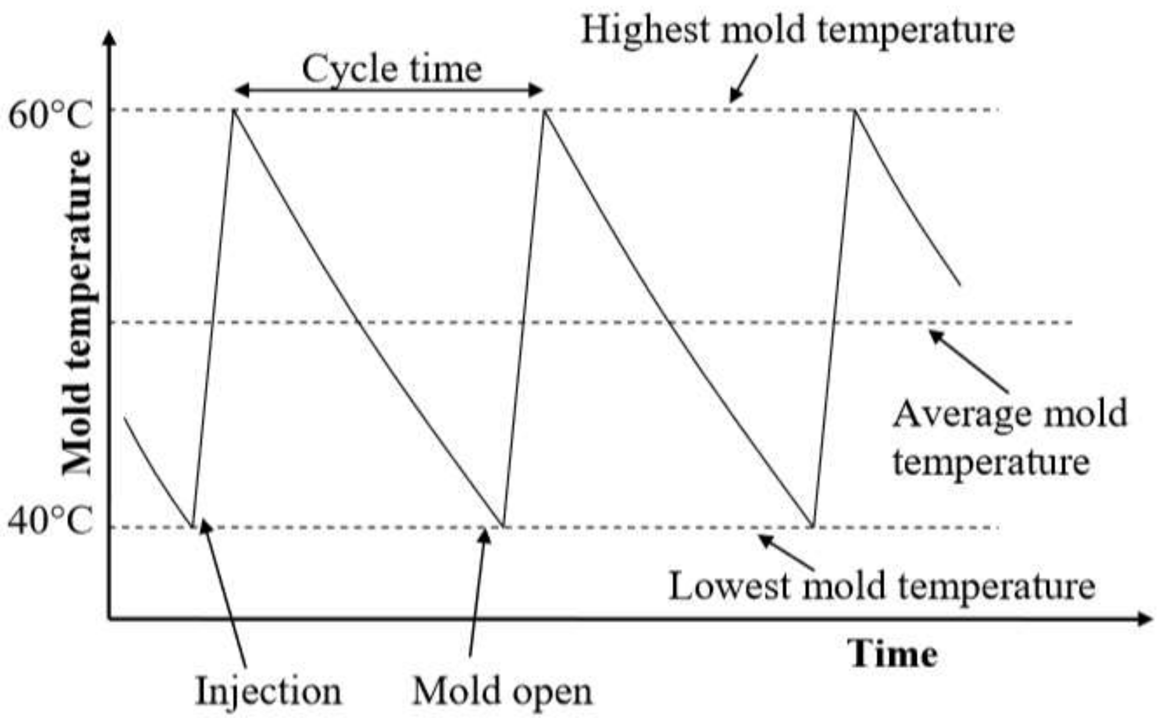


Figure 1.16: Fluctuations corresponding to form temperature [W4]

The overall heat conduction phenomenon is governed by the Fourier equation:

$$\emptyset_p S_p \frac{\partial \varphi}{\partial \overline{T}} = \epsilon_p \left(\frac{\partial^2 \overline{\varphi}}{\partial \underline{P}^2} + \frac{\partial^2 \overline{\varphi}}{\partial \underline{Q}^2} + \frac{\partial^2 \overline{\varphi}}{\partial \underline{R}^2} \right) \tag{27}$$

In which, $\emptyset_p$ – Form density

S_p – Form specific heat

ϵ_p – Diffusivity corresponding to form

The cooling phase of the process is described by solving a steady state Laplace equation for the cycle-averaged temperature distribution throughout the mold:

$$\epsilon_p \left(\frac{\partial^2 \overline{\varphi}}{\partial \underline{P}^2} + \frac{\partial^2 \overline{\varphi}}{\partial \underline{Q}^2} + \frac{\partial^2 \overline{\varphi}}{\partial \underline{R}^2} \right) = 0 \tag{28}$$

In which, $\overline{\varphi}$ – Overall mean temperature

Chapter-2

DESIGN FOR EXPERIMENTATION

2.1 Methodology

When the superficial of the acclimated part don't pursue the expected state of the plan is stated as Shrinkage. The inside burdens which are the cause of stresses leads to the Shrinkage brought about by Warpage of constituent in shaped product. The product won't disfigure or twist, when by off chance the Warpage all through the part is symmetrical. Rather than disfiguring, it just moves toward becoming shorter [19,20].

In any case, accomplishing less and symmetrical Warpage is an entangled undertaking because of the nearness and communication of numerous components, for example, sub-atomic directions, thickness optimisation, form cooling, systems and plans for form and conditions corresponding to procedure. For Infusion formed items, the typical quality related issue is that of shrinkage. All the Infusion embellishment stages have prominent effect on Shrinkage [21,22,23]. Because of its intricacy and various affecting criteria, shrinkage is factors, Warpage is amazingly hard to be maintained a strategic distance from with just judgment as per designers' involvement; it isn't exceptional that Warpage issues happen after form being made.

These days, the headway of the PC innovation makes it conceivable to re-enact the infusion trim procedure with certainty. With the sensible forecast of trim impact at the various stages, architects could increase valuable knowledge to get it how the plastic dissolve streams into the shape and why a shrinkage issue happens. In actuality, then again, organizations still face the difficulties of fixing shrinkage issues adequately, and all the more fundamentally so after the form has been made. Contrasted with the conventional method for experimentation form fixing strategy, With the aiding of technology and PC with the Engineering, innovation has the incredible potential to prompt specialists on why the issues happen and how to fix such issues immediately and bringing about something over the top shape fixing cost. This section proposes a lot of valuable strategies to address the above mentioned mechanical difficulties by utilizing the progressed innovation. Due to constrained cooling accessible, part areas which are having relatively high thickness will gradually cools than their more slender or better cooled partners. Similar mechanism to fin, edges, material, and pressure corresponds to hold, and so forth. All add to varieties in rate of cooling. Variable genre corresponds to temperature profile got build up in a section related to mold. At the point when the product is shot out, the thicker segments are as yet attaining temperature higher than there last cooled temperature while more slender areas may have achieved their last temperature. Product after ejection are not limited so the product with superficial of the higher thickness tends to conceive which is the reason for shrinkage.

Corresponding reasons are:

- Unsymmetrical temperature of form is the likewise reason for the shrinkage.
- Part shape with unsymmetrical hold and pressure.
- Thickness variation along the superficial of the acclimated part is prominent factor that affects the Warpage results.
- While shape filling stage, the orientation of strands of atomic particles along with the molecular chain is also a likewise reason that leads to shrinkage.
- Large Infusion hold or inappropriate sequence of analysis conditions.

2.2 Problem Survey

To tackle with Shrinkage issues many analysts have done inside and out analysis yet the greater deal of them concentrated on the form configuration organize with a perfect stage process to limit the odds corresponds to shrinkage, for instance beginning with product configuration, trailed by embellishment process examination to stay away from shrinkage effects and afterward settle the form plan [24,25.26]. Numerous works likewise centred around the advancement of the procedure inputs during the process of infusion embellishment so as to take care of the shrinkage issues, in the last decade.

Notwithstanding, as the infusion embellishment procedure has such a significant number of inputs and every input inherits large number of stages, the experimentation technique takes a ton of embellishment time. This is the prominent reason that practically every one of them utilized the Taguchi structure of investigation technique [27]. Likewise, utilizing the same strategy, analyst led a progression of investigations to locate the good mix of infusion time, packaging and holding pressure to make a slight superficial part component [28]. Prominent and Critical limiting factor of the procedure that is affecting the shrinkage of the slight superficial part component is pressure corresponding to packaging. Despite the fact that this strategy has been generally utilized to locate the most ideal mix of the inputs for processing, the supposed ideal parameters located might not be the ideal procedure parameters in the given rheological space. On the grounds that the preparing corrections for procedure has a restricted viable scope for shrinkage so isn't extraordinary that the trail of procedures corresponding to mold are still not fully acceptable arrangements. Then again, in light of our working knowledge, it is hard to correctly control the parameters corresponding to procedure as needed because of the constraints corresponds to handling of system. A few scientists attempted to lessen shrinkage impact by summation of extra supporting elements like ribs to fortify execution since utilizing ribs devours material to small extent than expanding or variation to the part geometry.

A unique level acclimated part with coordination to 3 different plans of various frameworks of product which contains extended part for support is being analysed for the shrinkage impacts by means of investigation including assistance of PC and Engineering technologies [29,30].

It is being examined that shrinkage diminishes fundamentally when the frameworks of product along with extended part for support are very much chosen. Be that as it may, for certain items, the look and visibility thought is as significant as the useful execution. Like many of the external acclimated parts can't possess extended part for support in light of the fact that the mark is constantly put on the level acclimated part. Undoubtedly, extended part for support will likewise confines the form progressively modern and the shape machining will be costly and more. Different analysts investigated improving the cooling framework configuration to diminish shrinkage. Time inherited during the infusion embellishment procedure is huge during the cooling and this recorded for over 79 percent of the entire infusion embellishment [31,32,33,34]. Nature of item is being impacted by framework of cooling which is ineffectual. Also it additionally impacts for low manufacturability.

Bad framework configuration for cooling, ultimately leads to unsymmetrical appropriated heat transfer thus leads to shrinkage. Along these lines utilized inclination calculation and inherited procedure to upgrade the framework plan for cooling [35]. Nonetheless, a great deal of parameters ought to be viewed as while structuring the channels for this. Like instance of this is the beams corresponds to channels might meddle to the discharging unit and the corresponding directs ought to be of sensible height for the heat distinction along the bay and vent should be under 37.4°F. Albeit diverse streamlining systems can think of some as significant limitations examined. Streamlining systems can be excessively convoluted and might lead to divergence as if numerous imperatives are thought about at once. For instance, as per the analyst's learning, there exist no streamlining systems which will assist manufacturability of frame work corresponding to cooling.

After all this, designers have immense alternatives while planning the frame structure for cooling with the improvement of cutting-edge fabricating innovation [36,37]. Likewise, Rapid prototyping is utilized for conformal framework structure conceivable by the shape supplement as superficial by superficial in a step. Generally in past, framework corresponds to cooling are erect that is linear and are quite difficult to accomplish symmetric separation from the items superficial, so the appropriation of heat transfer is more probable unsymmetrical. Conformal framework pursues the form of the shape superficial which leads to the equivalent separation by the shape superficial and framework. Therefore, the uniformly circulated temperature is bound to be accomplished. The customary beams proficiency corresponding to cooling and framework proficiency were looked by for a board lodging item for a differentiation [38,39,40]. With this, account for the temperature appropriation consistency enhanced to the half along with that the time corresponding to cool abbreviated over eight percent by utilizing processed conformal frameworks. Along these lines, shrinkage can be decreased by these frameworks. Be that as it may, as far as monetary effectiveness, Rapid Prototyping for the material like metals is moderately costly and not every organization has simple usage to this top of the line innovation. The vast majority of the past research works pursue a perfect shape structure work process to limit the shrinkage with the aid of engineering and PC, along with the re-enactment at start, then searches for the conceivable issue and after that takes care of the shrinkage issue dependent on the recreation inferences. All this is happening before the form configuration is concluded. In any case, in modern era, not every one of the organizations pursue the perfect shape structure work process and form plan work process. A ton of the organisations are as yet using the customary form configuration procedure as there is a boundary for the organisation to use the propelled PC innovation. Shrinkage deformities are generally found when the form has just been made and the manufacturing is going on at regular basis. These circumstances are typically brought about by heavy creation plans or the shy of building examination capacity in organizations. In these circumstances, the average plan methodologies inspected are never again appropriate. In this way, there is a requirement to explore successful approaches to take care of the shrinkage issue when the form has been made. With this we propose another work process and strategies to address shrinkage issues in such circumstance.

2.3 Restrictions of the Customary Strategies

The customary method to tackle shrinkage issue when the form is made is dependent to a great extent upon the information and analysis by the specialists. Normally, when the shrinkage issue is being found, the designers will alter the shape dependent on their insight and analysis that they have performed. At that point the nature of the item can't be ensured as the capacity and insight of the designers differs with one another. Much of the time, it becomes approximation and experimentation procedure as the designers don't have an unmistakable image about the causes bringing about shrinkage.

The nature of the shaped item must be assessed in the wake of experimenting phases which are important and tedious to assess that is the form change is powerful by analysing the nature of the shaped item. On the off chance that the formed items still possessing the shrinkage issue, one more cycle of shape alteration is to be done, and the examination needs to proceed until palatable items are continually delivered. The approximation and experimentation procedure for shrinkage control methodology after shape made is never again satisfactory to the latest era production [41,42,43]. The plastic items possess the property of redesign quickly for that the form organizations have the option to fabricate shape of good calibre rapidly and financially. Along these lines, rolling out any improvement when the form has just been produced must have the anticipated impact. Tragically that is difficult to be said with complete assurance. For the most part, with no use of any fixed compelling technique, the form adjustment procedure is a speculating approximation methodology in any case and it rehashes a few times till the certified item is delivered. It is additionally conceivable that if the form adjustment procedure isn't viable, the shape must be improved considerably or completely deserted in light of the fact that the shape can turn out to be increasingly convoluted but forming creation gets postponed [44]. Accordingly, a great deal of time and cash can be squandered in the shape change process and that makes the organization less focused in the outgoing world.

2.4 Process to Tackle Shrinkage Issues

The shape adjustment procedure can be significantly abbreviated with the assistance of cutting-edge forming recreation programming that make it conceivable to certainly assess the embellishment nature and procedure conduct on PCs as can be seen from Figure 2.1. Contrasted with the conventional approximation techniques, utilizing PCs to approve the nature of trim can spare a great deal of expense and processing-time. The trim recreation programming provides examination accreditations that demonstrate the conceivable nature imperfections and thus the causes bringing about these issues can be made a decision by specialists after a progression of analysis has been finished [45,46]. When the conceivable nature issues are recognized, the shape design can be altered for all intents and purposes on the PC so as to find the potential causes leading to these sorts of imperfections and to perform the recreation once more, until the reproduction desired nature is completely palatable. From that point onward, the genuine shape can be altered. In this exploration research, Synergy software has been utilized to assess 4 diverse form alteration techniques with the goal that the nature of the shaped item can be very much anticipated before the actual shape change methodology [47]. The given procedure to tackle shrinkage issue when the form is created accompanies:

- Using the meshed design proto of the project and build up the point by point shape configuration model with the encouraging framework, rheological conditions and beams of cooling.
- After that fare the coordinate elements to the embellishment recreation programming that includes assistance of PC along with innovative engineering techniques. This progression understands the exchange of configurationally data from designing phase to analysis phase.
- Simulating phase examination inputs and application of rheological data, for example, transition temperature and measured flow rate. At that point the reenactment is prepared to start.
- Performing embellishment procedure analysis along with impact investigation of heat transfer through cooling beams. In light of the reenactment, for example, percent filling appropriation, the reasons bringing about shrinkage can be dissected and recognized.
- Changing the shape plan or the procedure inputs to rectify the shrinkage reasons in like that manner.

- Again, checking all the above points so as to check whether the form changes and the latest procedure inputs can deliver well nurtured items.
- In case the outcome isn't attractive, repeat the form structure and procedure change workflow till the amazingly inherited item is delivered.
- At the time when reenacted item leads to fulfill the structure necessity, performs the plan changes to the current form.

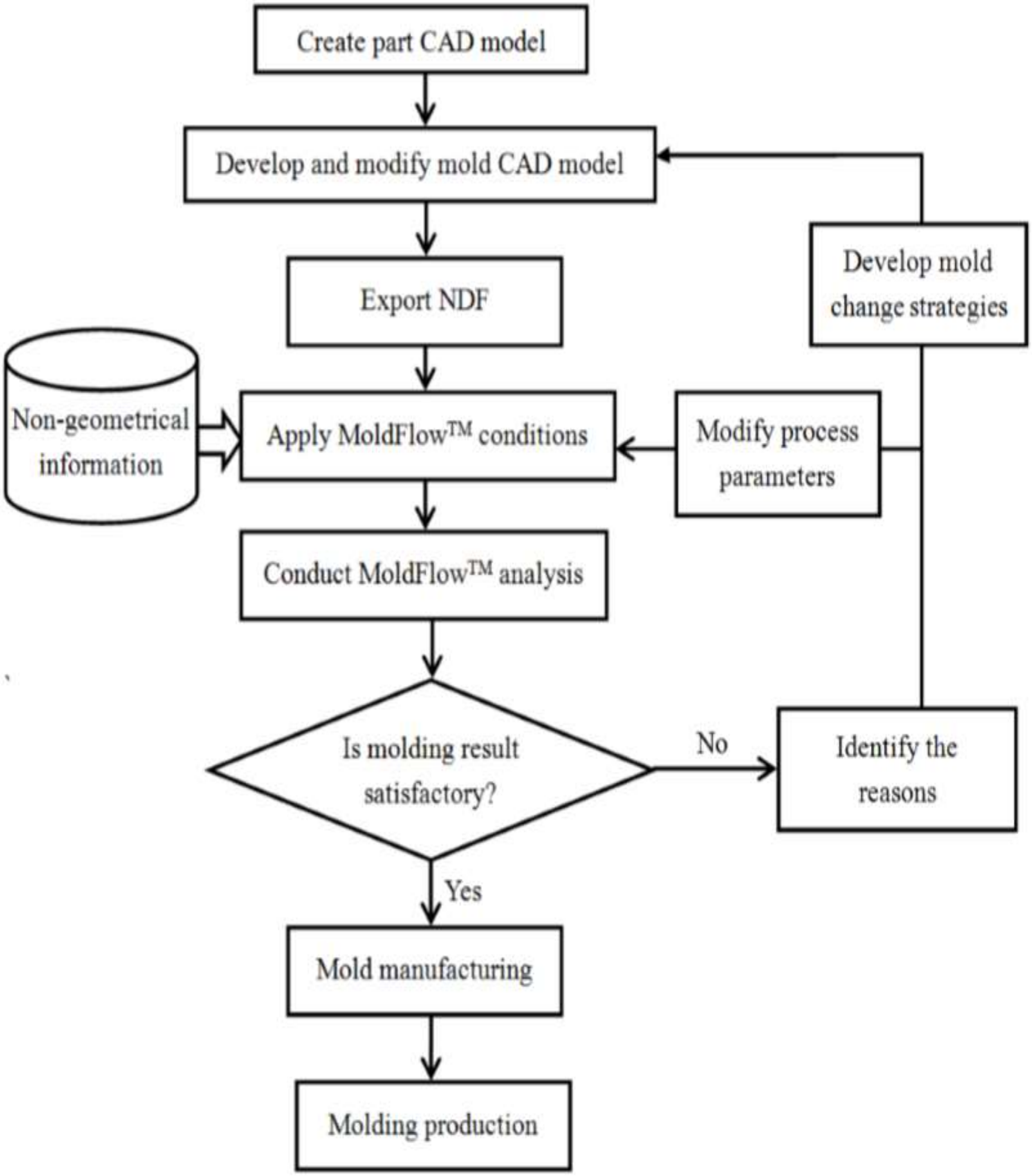


Figure 2.1: Process Cycle to tackle Shrinkage issues once the Form is manufactured [52]

Chapter-3
EXPERIMENT AND RESULT DISCUSSION

3.1 Analysis Objective

1. To study the deflection & straightness results of Titan Big - Drawer part with optimization of cooling channels.
2. To study the deflection & straightness results of Titan Big - Drawer part with optimization of thickness.

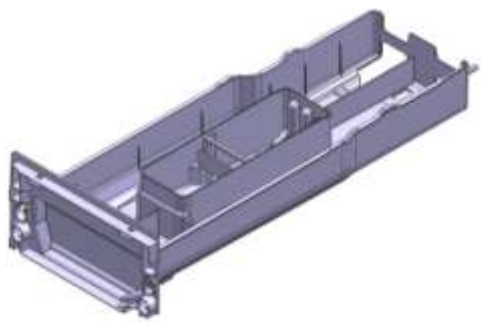


Figure 3.1: Titan Big – Drawer part

3.2 Boundary Conditions

- Melt temperature: 225°C
- Mold temperature: 60°C
- Injection time: 2.6 sec
- Packing time: 0.5sec = 35 MPa

  3.5sec = 35 MPa.
- Cooling time: 25 sec
- Cooling temperature: 16°C
- V/P Switchover at: 98%
- Material: PP TRC-2010 NP [Busung Polycom]
- Mesh type: MidPlane

3.3 Considerations of Analysis

1. Flow balance: Achieve a balanced Fill

    1) Non-Symmetric Gate Location → Fill / Unfill

    2) Symmetric gate Location → Meet 95%

    (Multi cavity analysis must meet balance in 1 Cavity and all cavities)

2. Pressure: Achieve less than 50% of machine's maximum pressure.

   (Material PP 30%, ABS 50%, PC 70%)

3. Temp deviation of part surface: $\triangle T \leq 5°C$

   (Temp deviation of mold surface: $\triangle T \leq 2°C$)

4. Temp deviation of part's cross section: $\triangle T \leq 10°C$

   (For 3D analysis to study deflection and shrinkage)

5. Deflection: Have to meet spec.

   (If material contains glass fiber, orientation analysis is necessary

6. Core shift Analysis: It is included in Moldflow.

7. Standard of analysis

    1) Cooling time must be set as the target time.

    2) Coolant flux set: Re = 10,000 and link is hose.

    3) Give the solution to improve weld line, flow mark and etc.

    4) Apply average melt temp.

    5) Apply average mold temp.

    (But we can apply min. value if it is interior item)

    6) Gate size must be set by considering the target shear rate.

3.4 Analysis Problem Definition

- To improve problems that may occur in injection process by previous mold injection CAE for new item.
  - Confirm the injection pressure and clamp force for select appropriate injection machine.
  - Confirm the exterior quality like weld line, sink mark and etc.
  - Secure the product assembly capability by confirm the deflection and improve.

3.5 Geometry Information

CASE 01- Original Case (with Existing Cooling Channels) as in Figure 3.2 and Figure 3.3

CASE 02- Modified Case (with New Cooling Channels) as in Figure 3.4

CASE 03- Modified Case (with Thickness Variation) as in Figure 3.5

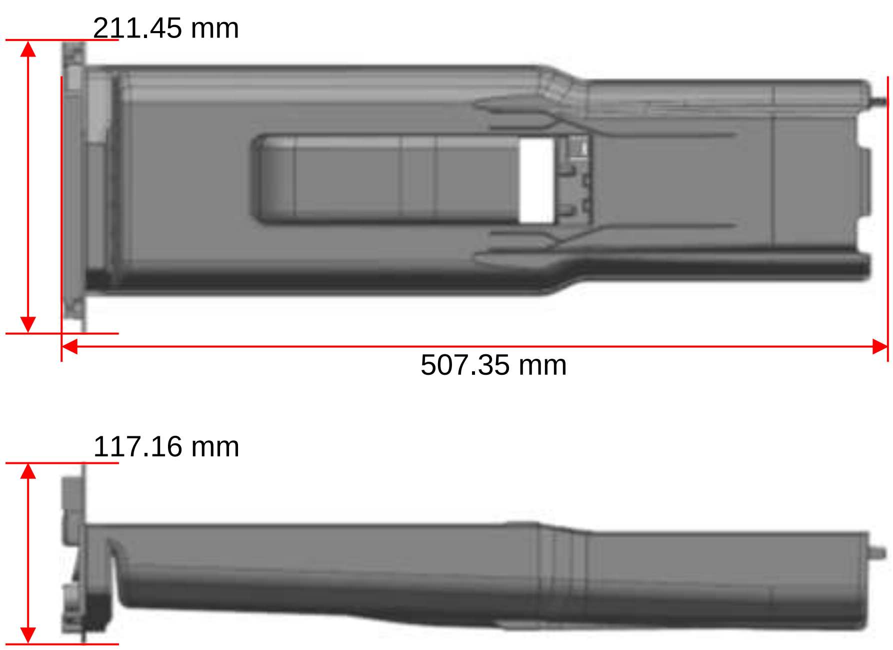


Figure 3.2: Geometrical Dimensions of Titan Big- Drawer Part

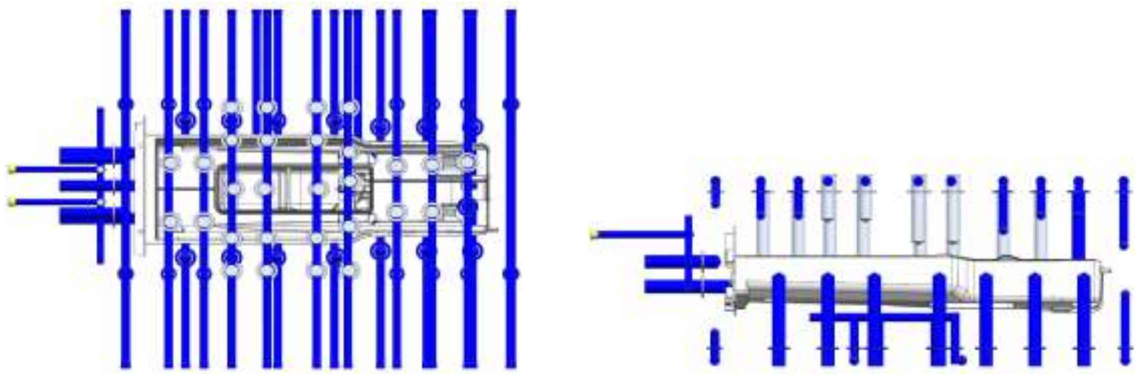


Figure 3.3: Already Existing Cooling Channels of Titan Big- Drawer Part

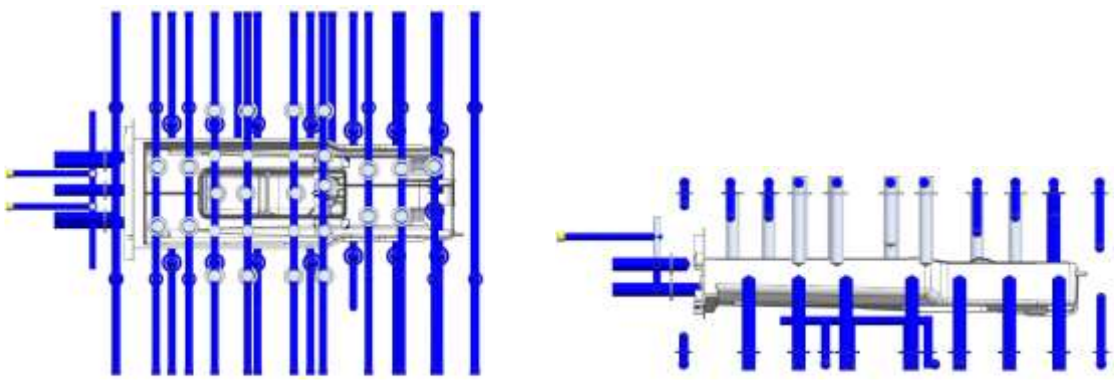


Figure 3.4: Modified Cooling Channels for Case 02

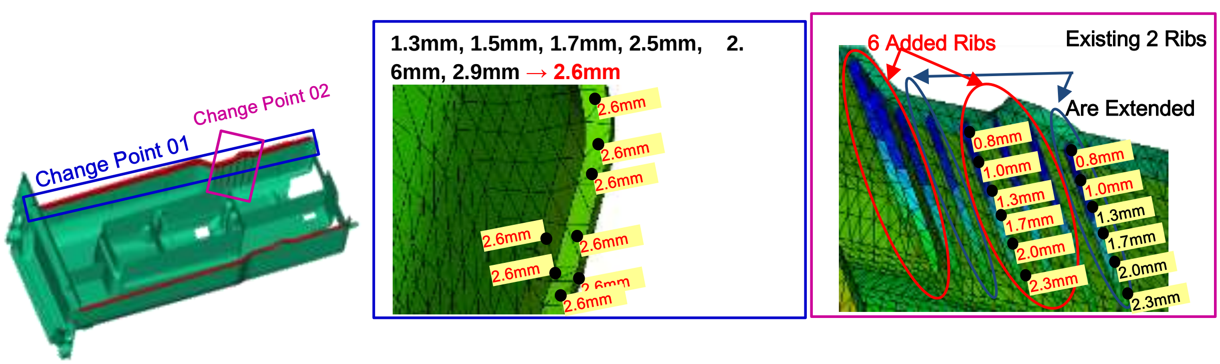


Figure 3.5: Modified Thickness for Case 03

3.6 Material Information

Material	TRC-2010 NP: Busung Polycom
Melt temp (applied temp)	220~230□ (225□)
Mold temp (applied temp)	40~80□ (60□)
Transition temp	129□
Ejection temp (Te)	117□

Table 3.1: Depicting Material Information

3.7 Fill Results

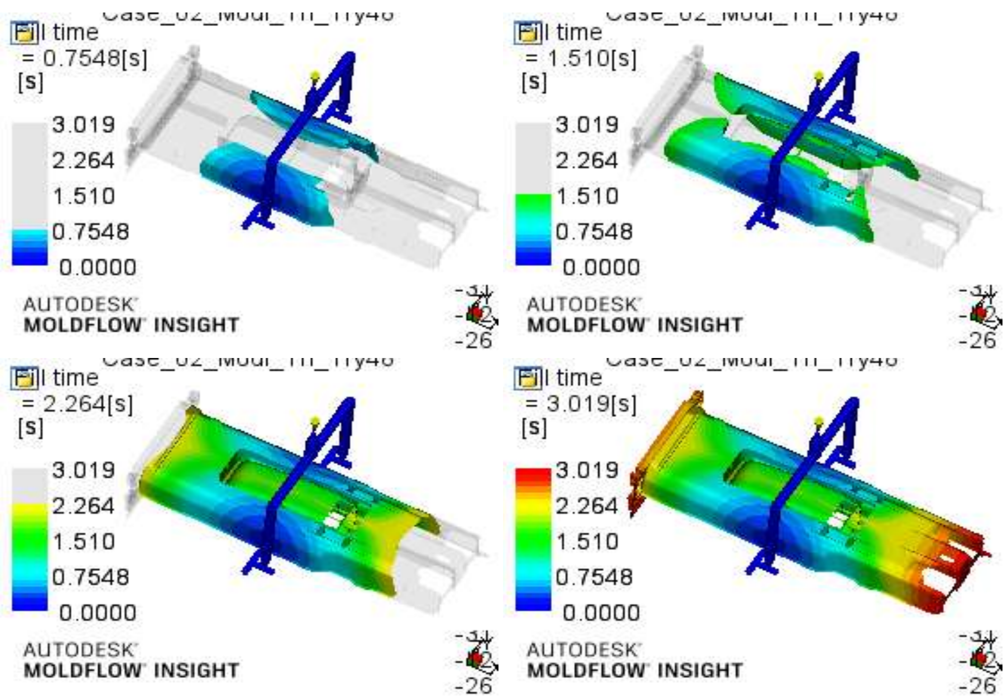


Figure 3.6: Pattern corresponds to Fill for Case 01

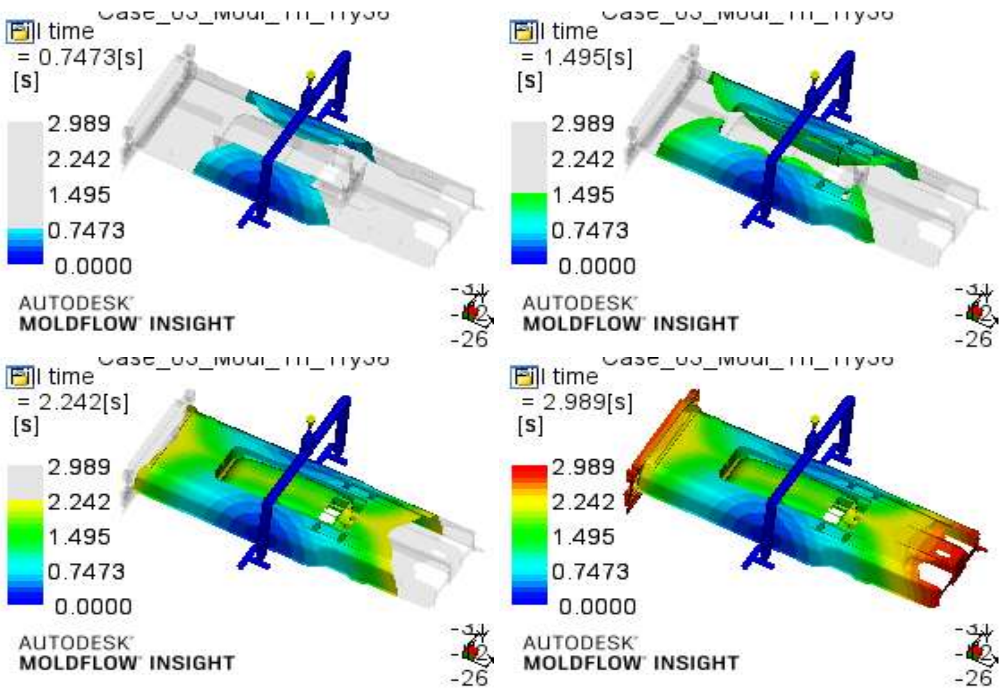


Figure 3.7: Pattern corresponds to Fill for Case 02

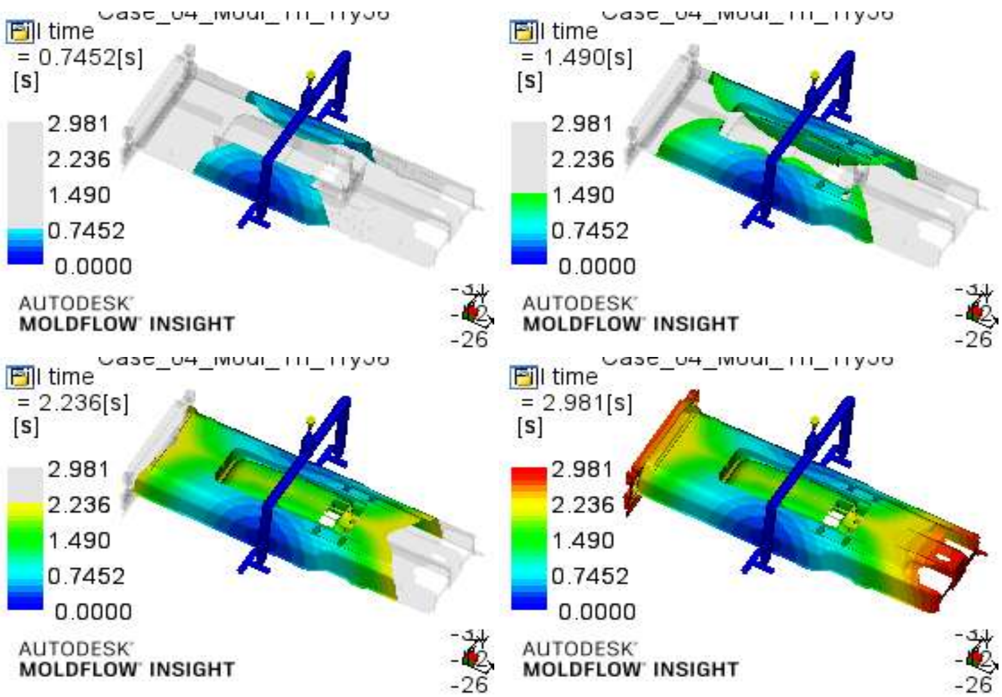


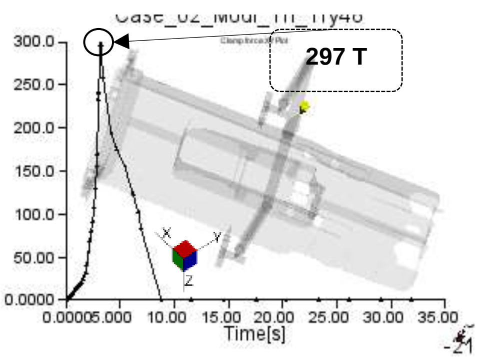
Figure 3.8: Pattern corresponds to Fill for Case 03

Figure 3.6 corresponds to the fill pattern of Titan Big-Drawer part with already existing cooling channels and with already existing thickness i.e. without any modification. Similarly, Figure 3.7 corresponds to the fill pattern of Titan Big-Drawer part with a modification in existing cooling channels and with no modification in already existing thickness of the component. Further, Figure 3.8 corresponds to the fill pattern of Titan Big-Drawer part with a modification in thickness of the component and with no modification in already existing cooling channels of the component. Fill pattern at 4 different stages are shown which is when component is 25 percent filled, 50 percent filled, 75 percent filled and when component is completely filled. It can be seen that fill pattern is balanced in all the above mentioned 3 cases. Along with that the vital information that we get is that component is completely filled in all the 3 cases i.e. there is no shot-fill in any of the case.

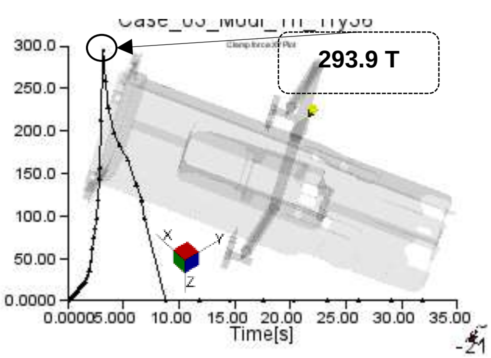
Case	25% Fill	50% Fill	75% Fill	100% Fill
Case 01	0.75 sec	1.51 sec	2.26 sec	3.02 sec
Case 02	0.74 sec	1.49 sec	2.24 sec	2.98 sec
Case 03	0.74 sec	1.49 sec	2.23 sec	2.98 sec

Table 3.2: Fill CAE results

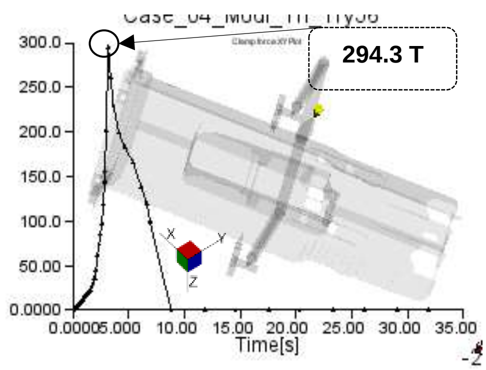
3.8 Clamp Force Results



(a)



(b)



(c)

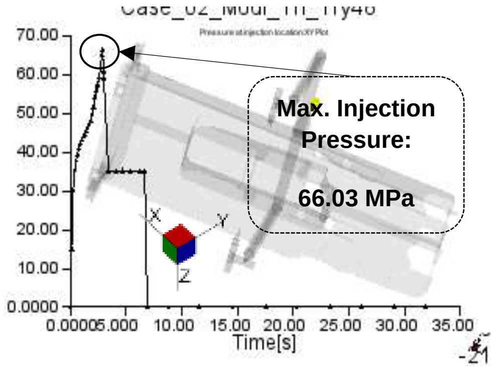
Figure 3.9: Clamp Force results

Figure 3.9 corresponds to maximum clamp force that will be exerted on the mold and a corresponding hold is to apply to tackle the clamp force while processing. Figure 3.9 (a) corresponds to clamp force of Titan Big-Drawer part with already existing cooling channels and with already existing thickness i.e. without any modification which is 297 Tonne. Similarly, Figure 3.9 (b) corresponds to the clamp force of Titan Big-Drawer part with a modification in existing cooling channels and with no modification in already existing thickness of the component and it comes out to be 293.9 Tonne. Further, Figure 3.9 (c) corresponds to the clamp force of Titan Big-Drawer part with a modification in thickness of the component and with no modification in already existing cooling channels of the component and it comes out to be 294.3 Tonne. It can be seen that there is no increase in clamp force as we optimize the cooling channels or thickness of component for warpage results and even there is a little decrement in clamp force in Case 02 and Case 03 as compared to Case 01.

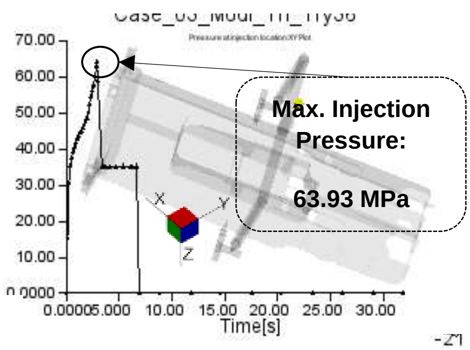
Case	Clamp Force
Case 01	297.0 T
Case 02	293.9 T
Case 03	294.3 T

Table 3.3: Clamp force CAE results

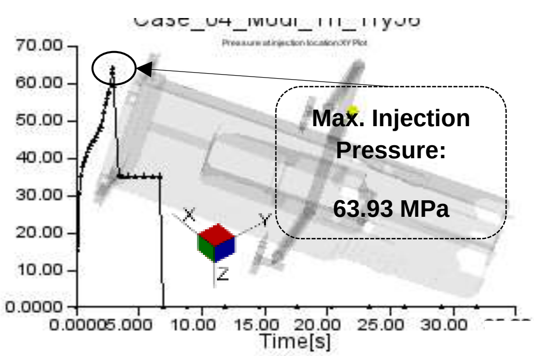
3.9 Injection Pressure Results



(a)



(b)



(c)

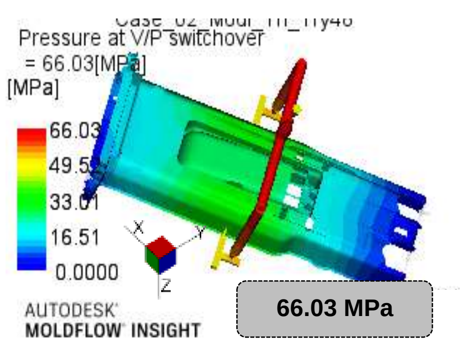
Figure 3.10: Injection Pressure results

Figure 3.10 corresponds to injection pressure that will act as driving force of the material to be injected. Figure 3.10 (a) corresponds to injection pressure of Titan Big-Drawer part with already existing cooling channels and with already existing thickness i.e. without any modification which is 66.03 MPa. Similarly, Figure 3.10 (b) corresponds to the injection pressure of Titan Big-Drawer part with a modification in existing cooling channels and with no modification in already existing thickness of the component and it comes out to be 63.93 MPa. Further, Figure 3.10 (c) corresponds to the injection pressure of Titan Big-Drawer part with a modification in thickness of the component and with no modification in already existing cooling channels of the component and it comes out to be 63.93 MPa. It can be seen that there is no increase in injection pressure as we optimize the cooling channels or thickness of component for warpage results and even there is a little decrement in injection pressure in Case 02 and Case 03 as compared to Case 01.

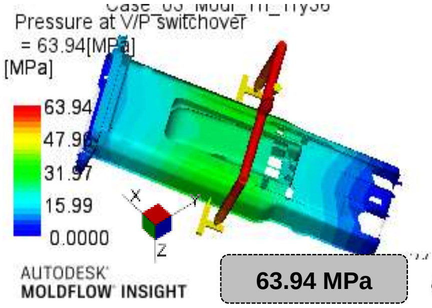
Case	Injection Pressure
Case 01	66.03 MPa
Case 02	63.93 MPa
Case 03	63.93 MPa

Table 3.4: Injection Pressure CAE results

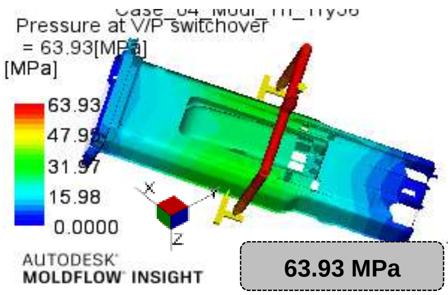
3.10 Pressure at V/P Switchover Results



(a)



(b)



(c)

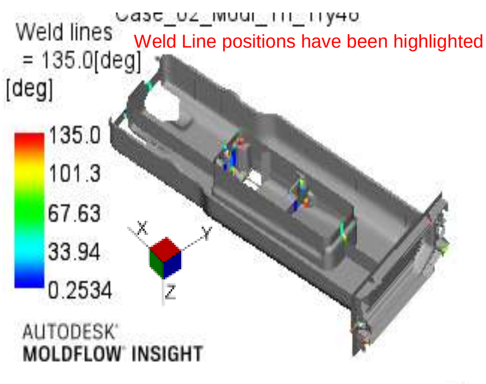
Figure 3.11: V/P switchover results

Figure 3.11 corresponds to V/P switchover pressure that is pressure at transition phase. Figure 3.11 (a) corresponds to V/P switchover pressure of Titan Big-Drawer part with already existing cooling channels and with already existing thickness i.e. without any modification which is 66.03 MPa. Similarly, Figure 3.11 (b) corresponds to the V/P switchover pressure of Titan Big-Drawer part with a modification in existing cooling channels and with no modification in already existing thickness of the component and it comes out to be 63.94 MPa. Further, Figure 3.11 (c) corresponds to the V/P switchover pressure of Titan Big-Drawer part with a modification in thickness of the component and with no modification in already existing cooling channels of the component and it comes out to be 63.93 MPa. It can be seen that there is no increase in injection pressure as we optimize the cooling channels or thickness of component for warpage results and even there is a little decrement in injection pressure in Case 02 and Case 03 as compared to Case 01.

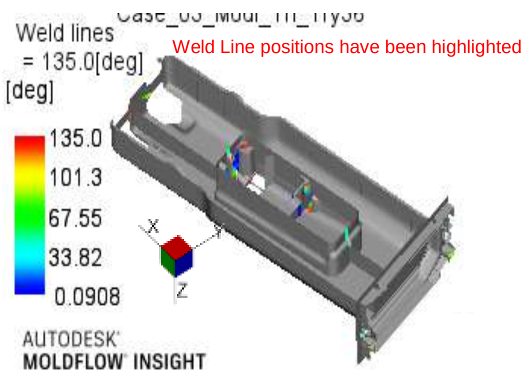
Case	V \ P Switchover Pressure
Case 01	66.03 MPa
Case 02	63.94 MPa
Case 03	63.93 MPa

Table 3.5: V/P switchover pressure CAE results

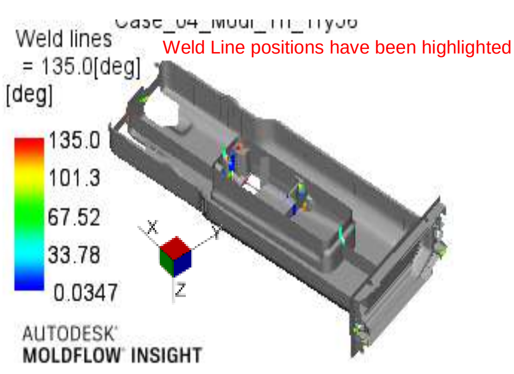
3.11 Weld Line Results



(a)



(b)

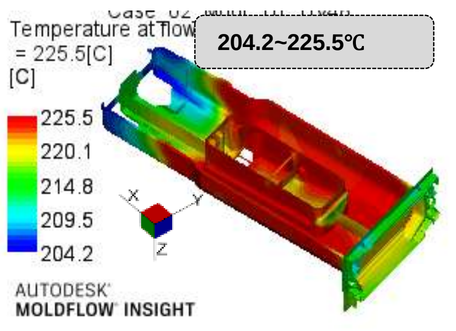


(c)

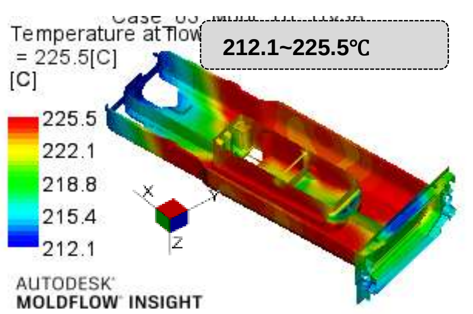
Figure 3.12: Weld Line results

Figure 3.12 (a) corresponds to Weld lines of Titan Big-Drawer part with already existing cooling channels and with already existing thickness i.e. without any modification. Similarly, Figure 3.12 (b) corresponds to the Weld lines of Titan Big-Drawer part with a modification in existing cooling channels and with no modification in already existing thickness of the component. Further, Figure 3.12 (c) corresponds to the Weld lines of Titan Big-Drawer part with a modification in thickness of the component and with no modification in already existing cooling channels of the component. Weld Line positions have been highlighted in all the cases. It can be seen that Weld Line positions are almost same in all the cases.

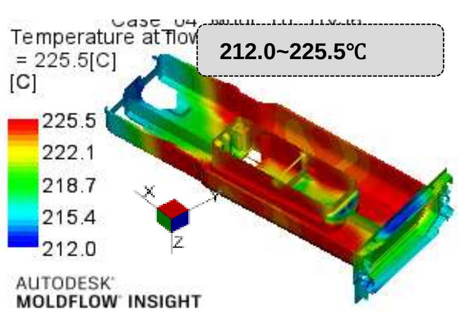
3.12 Flow Front Temperature Results



(a)



(b)



(c)

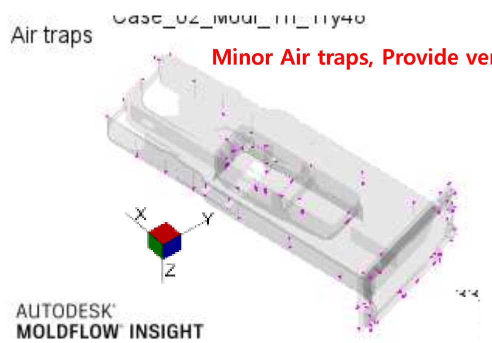
Figure 3.13: Temperature at front flow results

Figure 3.13 corresponds to Temperature at flow front. Figure 3.13 (a) corresponds to flow front t emperature of Titan Big-Drawer part with already existing cooling channels and with already exi sting thickness i.e. without any modification which ranges from 204.2□ - 225.5□. Similarly, Fig ure 3.13 (b) corresponds to the flow front temperature of Titan Big-Drawer part with a modificati on in existing cooling channels and with no modification in already existing thickness of the com ponent and it ranges from 212.1□ - 225.5□. Further, Figure 3.13 (c) corresponds to the flow fron t temperature of Titan Big-Drawer part with a modification in thickness of the component and wi th no modification in already existing cooling channels of the component and it ranges from 212. 0□ - 225.5□. It can be seen that there is no increase in range of front flow temperature as we opti mize the cooling channels or thickness of component for warpage results. Transition temperature of the material is 129℃ and front flow temperature is above the range in all the cases.

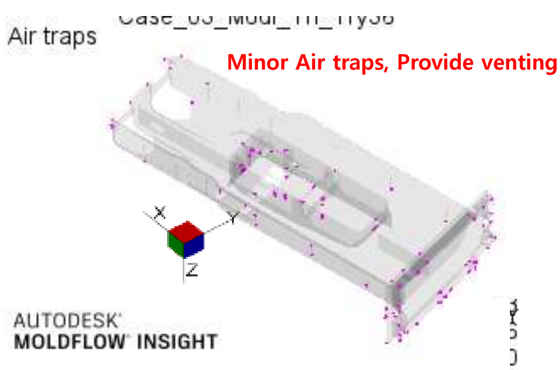
Case	Front Flow Temperature
Case 01	204.2 - 225.5 °C
Case 02	212.1 – 225.5 °C
Case 03	212.0 – 225.5 °C

Table 3.6: Front flow temperature CAE results

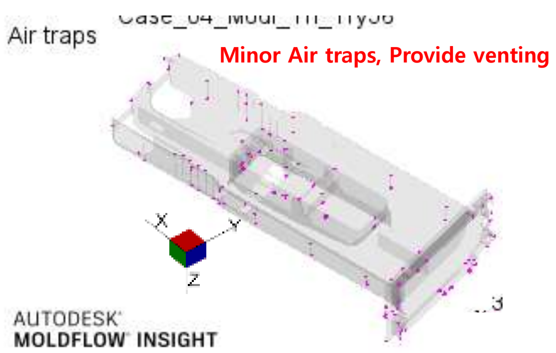
3.13 Air Trap Results



(a)



(b)



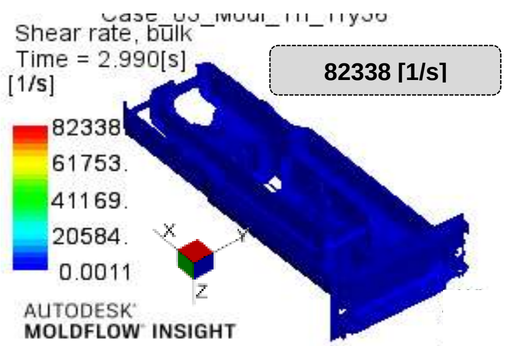
(c)

Figure 3.14: Air Trap results

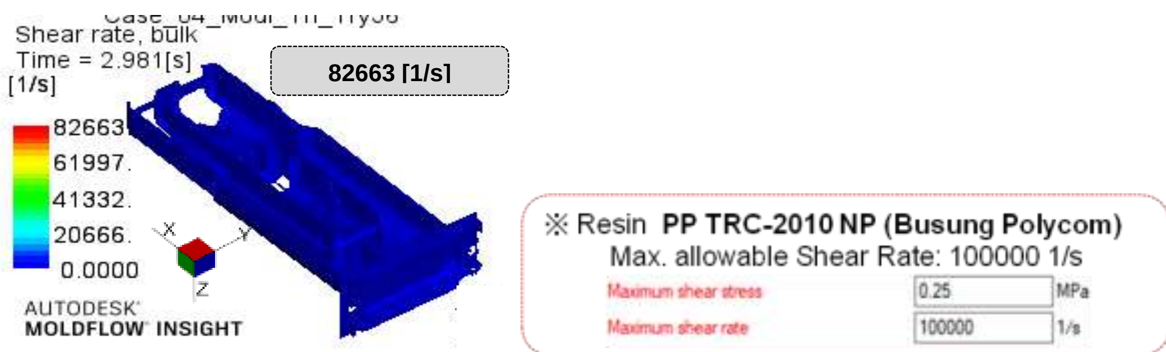
Figure 3.14 (a) corresponds to Air trap results of Titan Big-Drawer part with already existing cooling channels and with already existing thickness i.e. without any modification. Similarly, Figure 3.14 (b) corresponds to the Air trap results of Titan Big-Drawer part with a modification in existing cooling channels and with no modification in already existing thickness of the component. Further, Figure 3.14 (c) corresponds to the Air trap results of Titan Big-Drawer part with a modification in thickness of the component and with no modification in already existing cooling channels of the component. Air traps are visible in all the cases. We have to provide parting line venting in all the cases.

3.14 Shear Rate Results

(a)



(b)



(c)

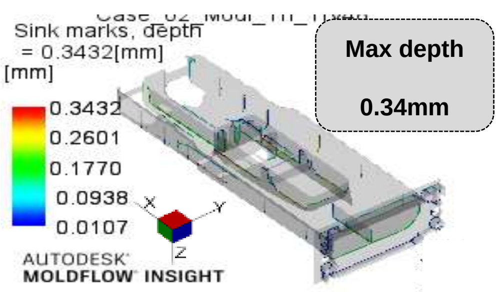
Figure 3.15: Shear rate results

Figure 3.15 corresponds to shear rate subjected to the component. Figure 3.15 (a) corresponds to shear rate of Titan Big-Drawer part with already existing cooling channels and with already existing thickness i.e. without any modification which is 81223 (1/s). Similarly, Figure 3.15 (b) corresponds to the shear rate of Titan Big-Drawer part with a modification in existing cooling channels and with no modification in already existing thickness of the component and it comes out to be 82338 (1/s). Further, Figure 3.15 (c) corresponds to the shear rate of Titan Big-Drawer part with a modification in thickness of the component and with no modification in already existing cooling channels of the component and it comes out to be 82663 (1/s). It can be seen that there is only slight increase in shear rate as we optimize the cooling channels or thickness of component for warpage results as compared to base case i.e. Case 01. The maximum shear rate measured is below the permissible Resin shear rate in all cases.

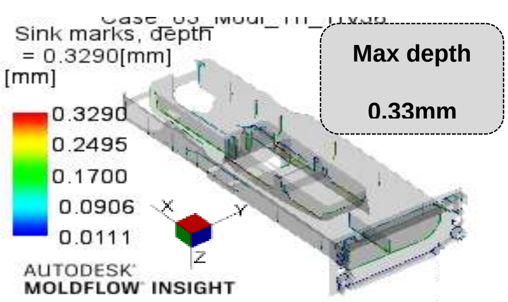
Case	Shear Rate
Case 01	81223 [1/s]
Case 02	82338 [1/s]
Case 03	82663 [1/s]

Table 3.7: Shear rate CAE results

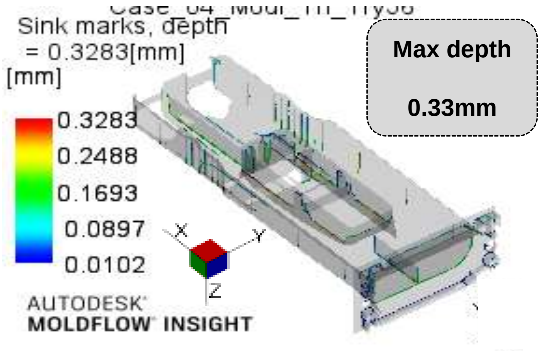
3.15 Sink Mark Results



(a)



(b)



(c)

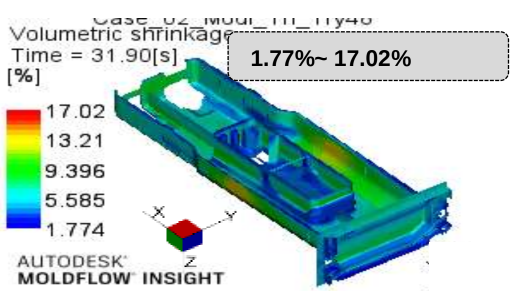
Figure 3.16: Sink mark results

Figure 3.16 corresponds to Sink mark subjected to the component. Figure 3.16 (a) corresponds to Sink mark of Titan Big-Drawer part with already existing cooling channels and with already existing thickness i.e. without any modification which is 0.34mm. Similarly, Figure 3.16 (b) corresponds to the Sink mark of Titan Big-Drawer part with a modification in existing cooling channels and with no modification in already existing thickness of the component and it comes out to be 0.33mm. Further, Figure 3.16 (c) corresponds to the Sink mark of Titan Big-Drawer part with a modification in thickness of the component and with no modification in already existing cooling channels of the component and it comes out to be 0.33mm. It can be seen that Sink mark is almost same in all cases.

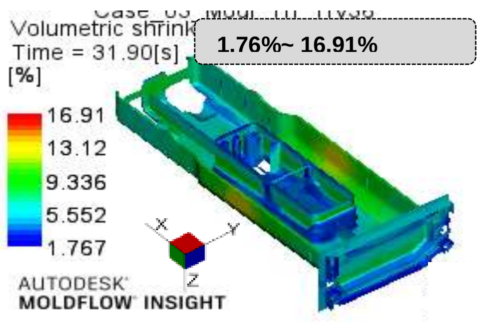
Case	Sink Mark Depth
Case 01	0.34 mm
Case 02	0.33 mm
Case 03	0.33 mm

Table 3.8: Sink Mark CAE results

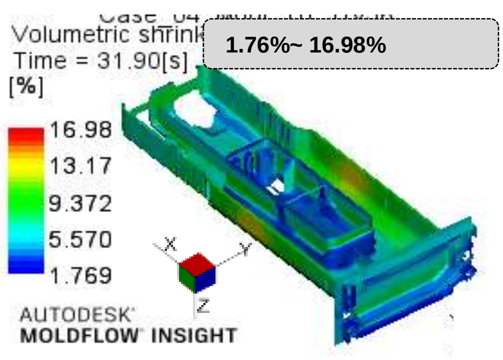
3.16 Volumetric Shrinkage Results



(a)



(b)



(c)

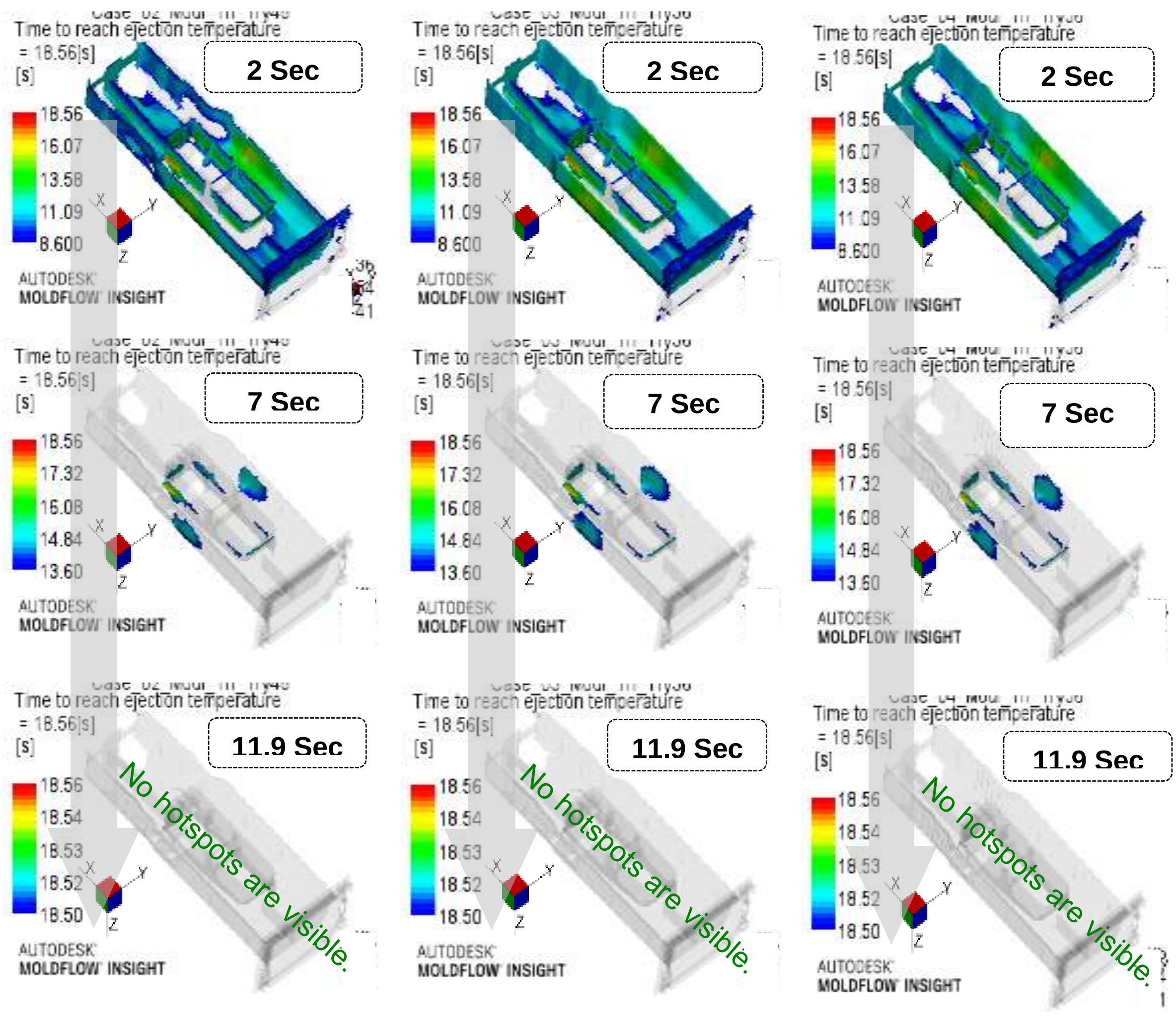
Figure 3.17: Volumetric shrinkage results

Figure 3.17 corresponds to Volumetric shrinkage results. Figure 3.17 (a) corresponds to Volumet ric shrinkage results of Titan Big-Drawer part with already existing cooling channels and with alr eady existing thickness i.e. without any modification which ranges from 1.77% - 17.02%. Similar ly, Figure 3.17 (b) corresponds to the Volumetric shrinkage of Titan Big-Drawer part with a mod ification in existing cooling channels and with no modification in already existing thickness of th e component and it ranges from 1.76% - 16.91%. Further, Figure 3.17 (c) corresponds to the Vol umetric shrinkage of Titan Big-Drawer part with a modification in thickness of the component an d with no modification in already existing cooling channels of the component and it ranges from 1.76% - 16.98%. It can be seen that Volumetric shrinkage range is almost same for all the cases.

Case	Volumetric Shrinkage
Case 01	1.77% - 17.02%
Case 02	1.76% - 16.91%
Case 03	1.76% - 16.98%

Table 3.9: Volumetric Shrinkage CAE results

3.17 Ejection Temperature Results

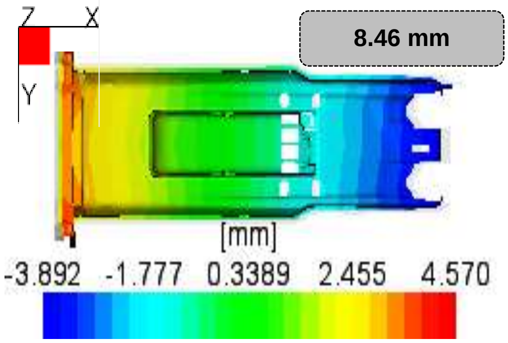


(a) (b) (c)

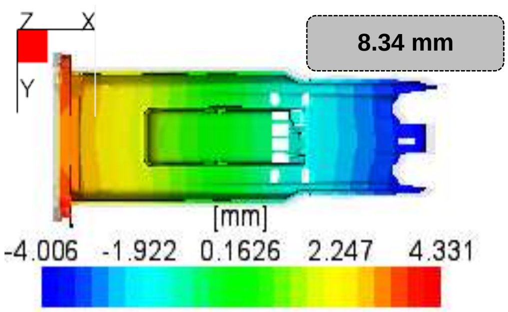
Figure 3.18: Time to reach ejection temperature results

Figure 3.18 corresponds to Time to reach ejection temperature results. Figure 3.18 (a) corresponds to Time to reach ejection temperature results of Titan Big-Drawer part with already existing cooling channels and with already existing thickness i.e. without any modification for 2 Sec, 7 Sec and 11.9 Sec cooling. Similarly, Figure 3.18 (b) corresponds to Time to reach ejection temperature results of Titan Big-Drawer part with a modification in existing cooling channels and with no modification in already existing thickness of the component for 2 Sec, 7 Sec and 11.9 Sec cooling. Further, Figure 3.18 (c) corresponds to Time to reach ejection temperature results of Titan Big-Drawer part with a modification in thickness of the component and with no modification in already existing cooling channels of the component for 2 Sec, 7 Sec and 11.9 Sec cooling. It can be seen in all the cases that no hotspots are visible at 11.9 sec cooling which is below than the maximum time to reach ejection temperature cooling (18.56 sec).

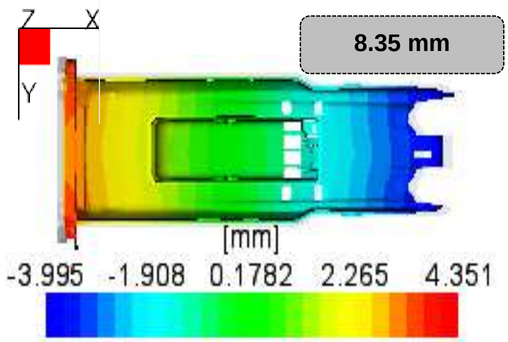
3.18 Total Deflection: X Results



(a)



(b)



(c)

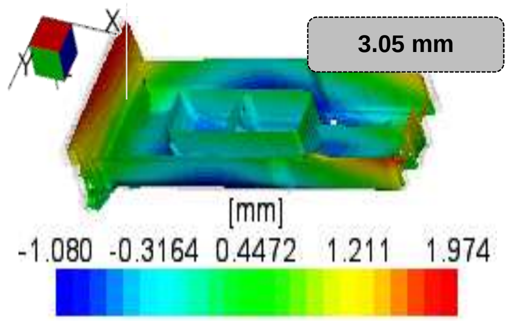
Figure 3.19: Total Deflection: X results

Figure 3.19 corresponds to total deflection for a component in x-direction. Figure 3.19 (a) corresponds to total deflection in x-direction for Titan Big-Drawer part with already existing cooling channels and with already existing thickness i.e. without any modification which is 8.46mm. Similarly, Figure 3.19 (b) corresponds to total deflection in x-direction for Titan Big-Drawer part with a modification in existing cooling channels and with no modification in already existing thickness of the component and it comes out to be 8.34mm. Further, Figure 3.19 (c) corresponds to total deflection in x-direction for Titan Big-Drawer part with a modification in thickness of the component and with no modification in already existing cooling channels of the component and it comes out to be 8.35mm. It can be seen that there is no increase in total deflection for a component in x-direction as we optimize the cooling channels or thickness of component for warpage results and even there is a little decrement in Case 02 and Case 03 as compared to Case 01.

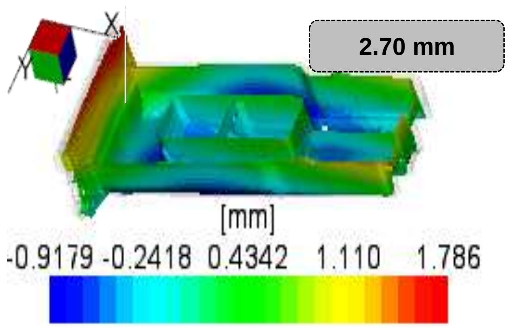
Case	Total Deflection: X
Case 01	8.46 mm
Case 02	8.34 mm
Case 03	8.35 mm

Table 3.10: Total Deflection: X CAE results

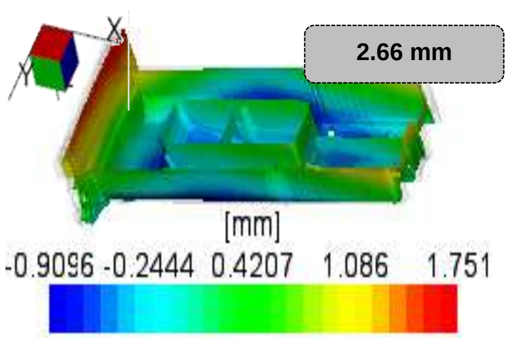
3.19 Total Deflection: Z Results



(a)



(b)



(c)

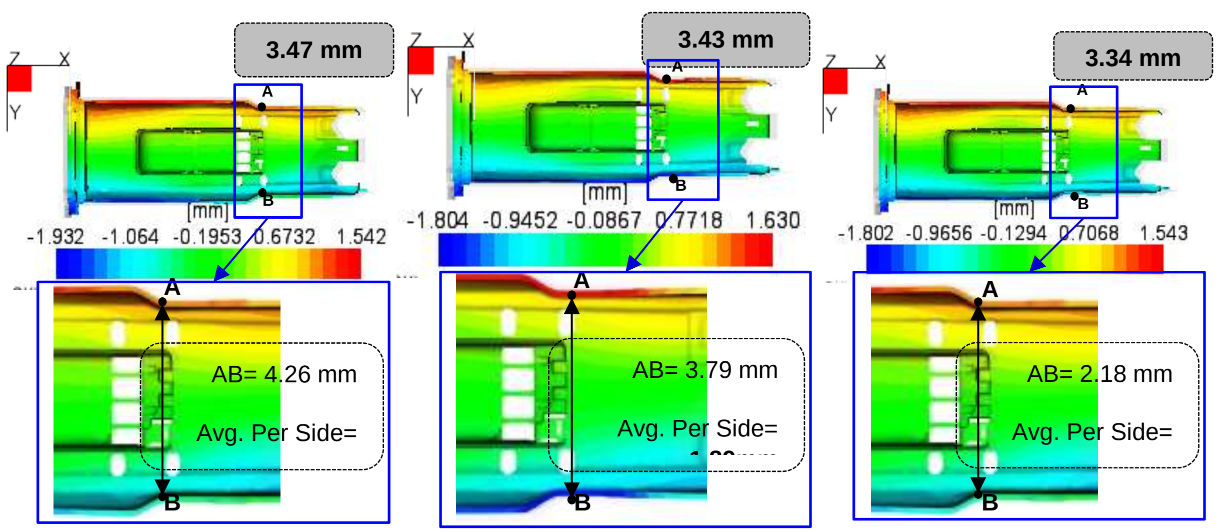
Figure 3.20: Total Deflection: Z results

Figure 3.20 corresponds to total deflection for a component in z-direction. Figure 3.20 (a) corresponds to total deflection in z-direction for Titan Big-Drawer part with already existing cooling channels and with already existing thickness i.e. without any modification which is 3.05mm. Similarly, Figure 3.20 (b) corresponds to total deflection in z-direction for Titan Big-Drawer part with a modification in existing cooling channels and with no modification in already existing thickness of the component and it comes out to be 2.70mm. Further, Figure 3.20 (c) corresponds to total deflection in z-direction for Titan Big-Drawer part with a modification in thickness of the component and with no modification in already existing cooling channels of the component and it comes out to be 2.66mm. It can be seen that there is no increase in total deflection for a component in z-direction as we optimize the cooling channels or thickness of component for warpage results and even there is a little decrement in Case 02 and Case 03 as compared to Case 01.

Case	Total Deflection: Z
Case 01	3.05 mm
Case 02	2.70 mm
Case 03	2.66 mm

Table 3.11: Total Deflection: Z CAE results

3.20 Total Deflection: Y Results



(a) (b) (c)

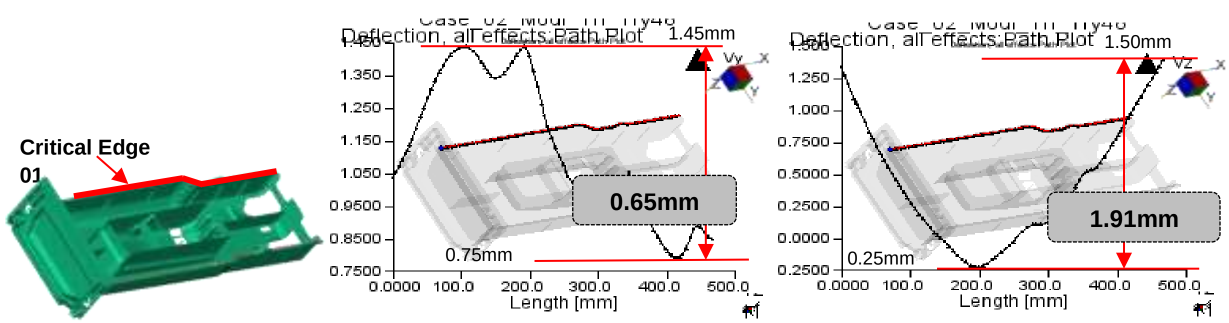
Figure 3.21: Total Deflection: Y results

Figure 3.21 corresponds to total deflection for a component in y-direction. Figure 3.21 (a) corresponds to total deflection in y-direction for Titan Big-Drawer part with already existing cooling channels and with already existing thickness i.e. without any modification which is 3.47mm. Similarly, Figure 3.21 (b) corresponds to total deflection in y-direction for Titan Big-Drawer part with a modification in existing cooling channels and with no modification in already existing thickness of the component and it comes out to be 3.43mm. Further, Figure 3.21 (c) corresponds to total deflection in y-direction for Titan Big-Drawer part with a modification in thickness of the component and with no modification in already existing cooling channels of the component and it comes out to be 3.34mm. It can be seen that there is no increase in total deflection for a component in y-direction as we optimize the cooling channels or thickness of component for warpage results rather there is a little decrement in Case 02 and Case 03 as compared to Case 01. Further Average deflection at point AB decreases to great extent in Case 02 and even more in Case 03 as compared to Case 01

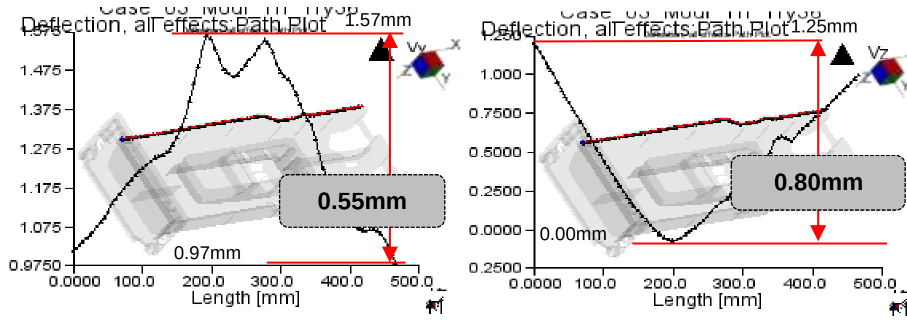
Case	Total Deflection: Y	Deflection at point AB	Avg. Deflection at point AB
Case 01	3.47 mm	4.26 mm	2.13 mm
Case 02	3.43 mm	3.79 mm	1.89 mm
Case 03	3.34 mm	2.18 mm	1.09 mm

Table 3.12: Total Deflection: Y CAE results

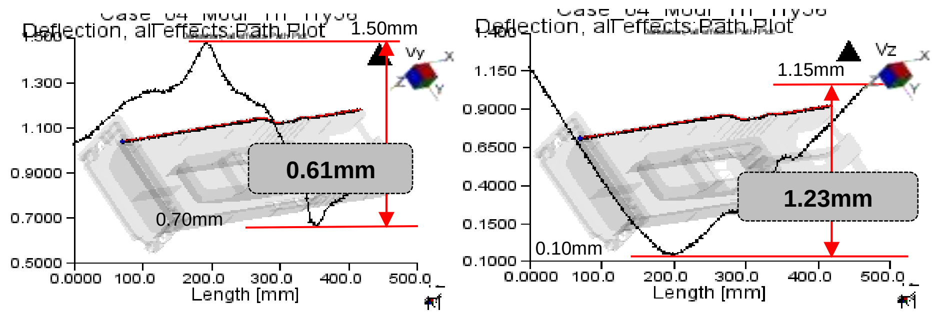
3.21 Flatness Results for Critical Edge 01



(a)



(b)



(c)

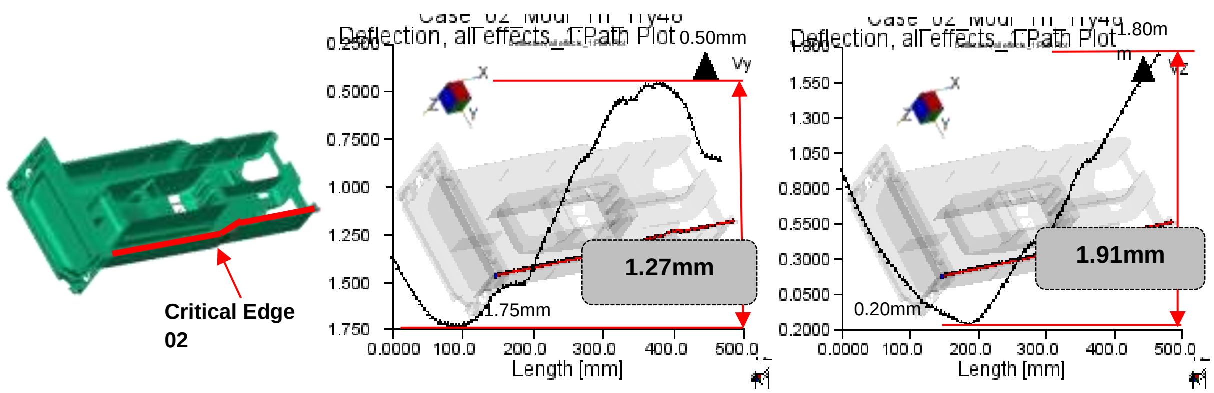
Figure 3.22: Flatness results for critical edge 01

Figure 3.22 corresponds to flatness results for critical edge 01 of the component. Figure 3.22 (a) corresponds to flatness results for critical edge 01 of Titan Big-Drawer part with already existing cooling channels and with already existing thickness i.e. without any modification which is 0.65mm (Vy) and 1.91mm (Vz). Similarly, Figure 3.22 (b) corresponds to flatness results for critical edge 01 of Titan Big-Drawer part with a modification in existing cooling channels and with no modification in already existing thickness of the component and it comes out to be 0.55mm (Vy) and 0.80mm (Vz). Further, Figure 3.22 (c) corresponds to flatness results for critical edge 01 of Titan Big-Drawer part with a modification in thickness of the component and with no modification in already existing cooling channels of the component and it comes out to be 0.61mm (Vy) and 1.23mm (Vz). It can be seen that flatness results for critical edge 01 has improved in Case 02 and Case 03 as compared to Case 01.

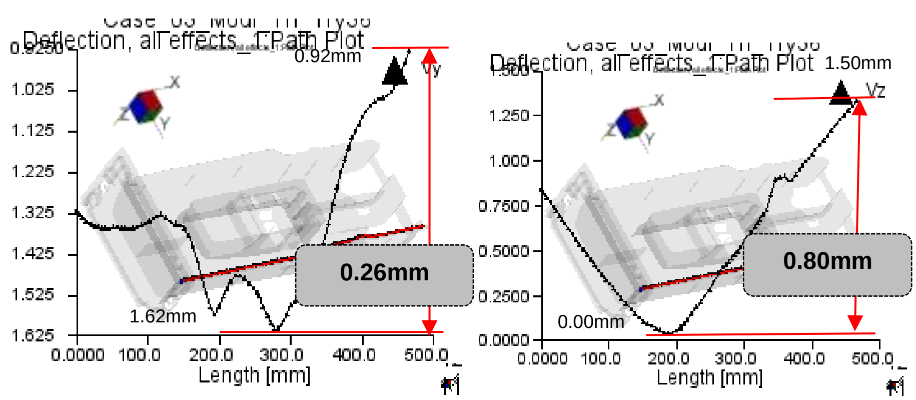
Critical Edge01	Case01	Case02	Case03
Flatness (Vy)	0.65 mm	0.55 mm	0.61 mm
Flatness (Vz)	1.91mm	0.80 mm	1.23 mm

Table 3.13: CAE results for critical edge 01

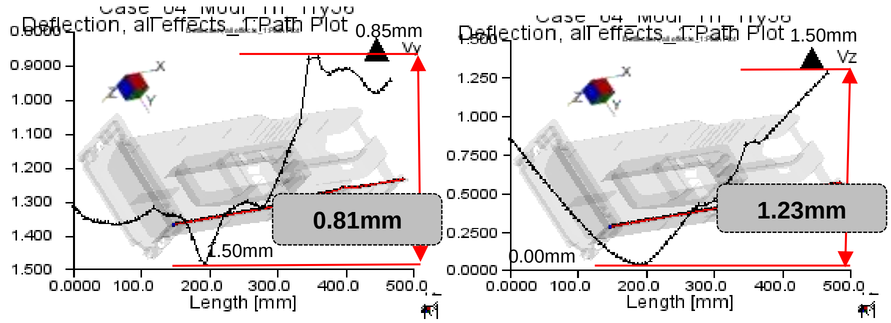
3.22 Flatness Results for Critical Edge 02



(a)



(b)



(c)

Figure 3.23: Flatness results for critical edge 02

Figure 3.23 corresponds to flatness results for critical edge 02 of the component. Figure 3.23 (a) corresponds to flatness results for critical edge 02 of Titan Big-Drawer part with already existing cooling channels and with already existing thickness i.e. without any modification which is 1.27mm (Vy) and 1.91mm (Vz). Similarly, Figure 3.23 (b) corresponds to flatness results for critical edge 02 of Titan Big-Drawer part with a modification in existing cooling channels and with no modification in already existing thickness of the component and it comes out to be 0.26mm (Vy) and 0.80mm (Vz). Further, Figure 3.23 (c) corresponds to flatness results for critical edge 02 of Titan Big-Drawer part with a modification in thickness of the component and with no modification in already existing cooling channels of the component and it comes out to be 0.81mm (Vy) and 1.23mm (Vz). It can be seen that flatness results for critical edge 02 has improved in Case 02 and Case 03 as compared to Case 01.

Critical Edge02	Case01	Case02	Case03
Flatness (Vy)	1.27 mm	0.26 mm	0.81 mm
Flatness (Vz)	1.91mm	0.80 mm	1.23 mm

Table 3.14: CAE results for critical edge 02

Chapter 4
CAE CORRELATION

4.1 Background

The innovative boondocks of mankind are consistently extending. In every aspect of our general public, specialists are continually looking for new and innovative developments so as to build efficiency [49,50,51]. From last decade, noteworthy hotspot for these advancements is automation which is a marvel that has empowered associations to build their profitability and addition upper hand. With this scenario of automating the work process leads to the ample decrement in the requirement for consideration and exertion from human workers which will further permit a huge increment in efficiency for each individual. All such has enabled the public by and large to develop that is in money related dependency as well as in innovative measurements.

In the past this process altered businesses depending on substantial physical endeavors. For instance, to plough in the ranch, earlier a lot of dependency was on substantial physical endeavors but with this on rising process the need of physical endeavors got diminished to prominent extent. Besides this, while supplanting physical endeavors, this process has changed the ability necessities like a rancher a long time back must have a lot of dependency on physical endeavors but with this process, now a day's ranchers for the most part need to know the basic upkeeps of the process [52]. Another case of ventures with totally changed business procedures is the vehicle based or production based business. Assembling components earlier was done by physical endeavors. After that with the development of the sequential construction system and then with the presentation of gadgets has molded the business completely. Over the past time, Information oriented job is being reformed totally by the virtue of this process. With the creation of PCs along with their far reaching accessibility to associations has transformed the path individuals in learning oriented businesses job.

With this, the advanced devices available to laborers have grown extensively from earlier content tools to completely robotized hard manufacturing forms. Regarding the improvement in level of these processes is that there are ton of things still pending to be explored. Vital viewpoints that structure the foundation of information oriented job is information flow and information control. The process spins for the most part around these vital view points, and kinetic upgrades in the level of process is a consequence of exploring better approach to automate the assignments [53]. With all the hindrance, to have the option to expand the utilization of this process with all the obsolete frameworks and for increment the degree of this process, in a take a stab at expanded efficiency, another arrangement is required.

4.2 Mold Flow Steps Identified for Automation

	Steps	Time Duration	CAE Skills Requirement
1. Pre- Processing			
1.6	Midplane mesh Thickness Levels generation		
1.7	Feed System Design		
1.8	Cooling System Design		
2. Solving			
2.3	Error Troubleshooting		
3. Post- Processing			
3.1	**Result Interpertation**		
3.1.3	Flatness (Vx, Vy, Vz)/ Roundness(Vr) Results~ Pictorial and Values		
3.1.3.1	*Node Collection of Critical Edges for Graph Plots*		
3.1.3.2	*Flatness (Vx, Vy, Vz)/ Roundness(Vr) Graph Plots using Collected Nodes*		
3.1.3.3	*Flatness (Vx, Vy, Vz)/ Roundness(Vr) values capture on every node*		
3.1.3.4	*Find Max / Min Values of Vx, Vy, Vz & Vr and Find overall values of all Cases.*		
3.2	**Result Optimization**		
3.2.2	Thickness Optimization		
3.3	**Report Generation**		
3.3.1	Set Display Property of All Results as per LG standards		
3.3.2	All Animation / Pictorial Results Capture Insert in Report		
3.3.3	Flatness (Vx, Vy, Vz) & Roundness (Vr) value and pictorial results Insert in report.		
3.3.4	Give Analysis Objective, Boundary Condition, Material Details In Report		
3.3.5	Show all Animations, Change Points, and resolution summary		
3.3.7	Give CAD Information and Feed Information in Report		
3.3.8	Complete all slides as per LG standards		
3.3.9	Provide Result Table listing comparison between Results of all Cases in Tabular for		

❖ **Process Steps Identified for Automation:-**

1. Midplane mesh Thickness Levels generation
2. Feed Design Automation
3. Cooling Circuit Design Automation
4. Error Diagnostics Automation
5. Automation of Node Collection on Critical Edge
6. Flatness (Vx, Vy, Vz)/ Roundness(Vr) Results Generation Automation
7. Warpage Optimization Automation
8. Automation of Properties Assign of all results as per LG Standards.
9. Result Generation (Numeric & Pictorial) as per LG Standard Report Format
10. CAE Result Table generation Automation
11. Create Templates as Per LG Standard Report Format

Figure 4.1: CAE Mold Flow process steps identified for automation

4.2.1 Automation Step 01

Midplane mesh Thickness Levels generation: This is a Pre-Processing step. A Midplane mesh is created in Hypermesh, and all thickness of various plastic part surfaces is assigned in separate levels. However, when a Midplane mesh, created in Hypermesh is imported in Autodesk Mold Flow, it loses these individual levels and only the assigned thickness value exists in a single level.

Present Scenario: manually separating all thickness values in separate layers for thickness optimization, is a huge waste of time for CAE Analysts, yet it is unavoidable (Figure 4.2).

Wishlist: A program to Automatically generates 100's of thickness levels, with a single button click, in a few seconds (Figure 4.3).

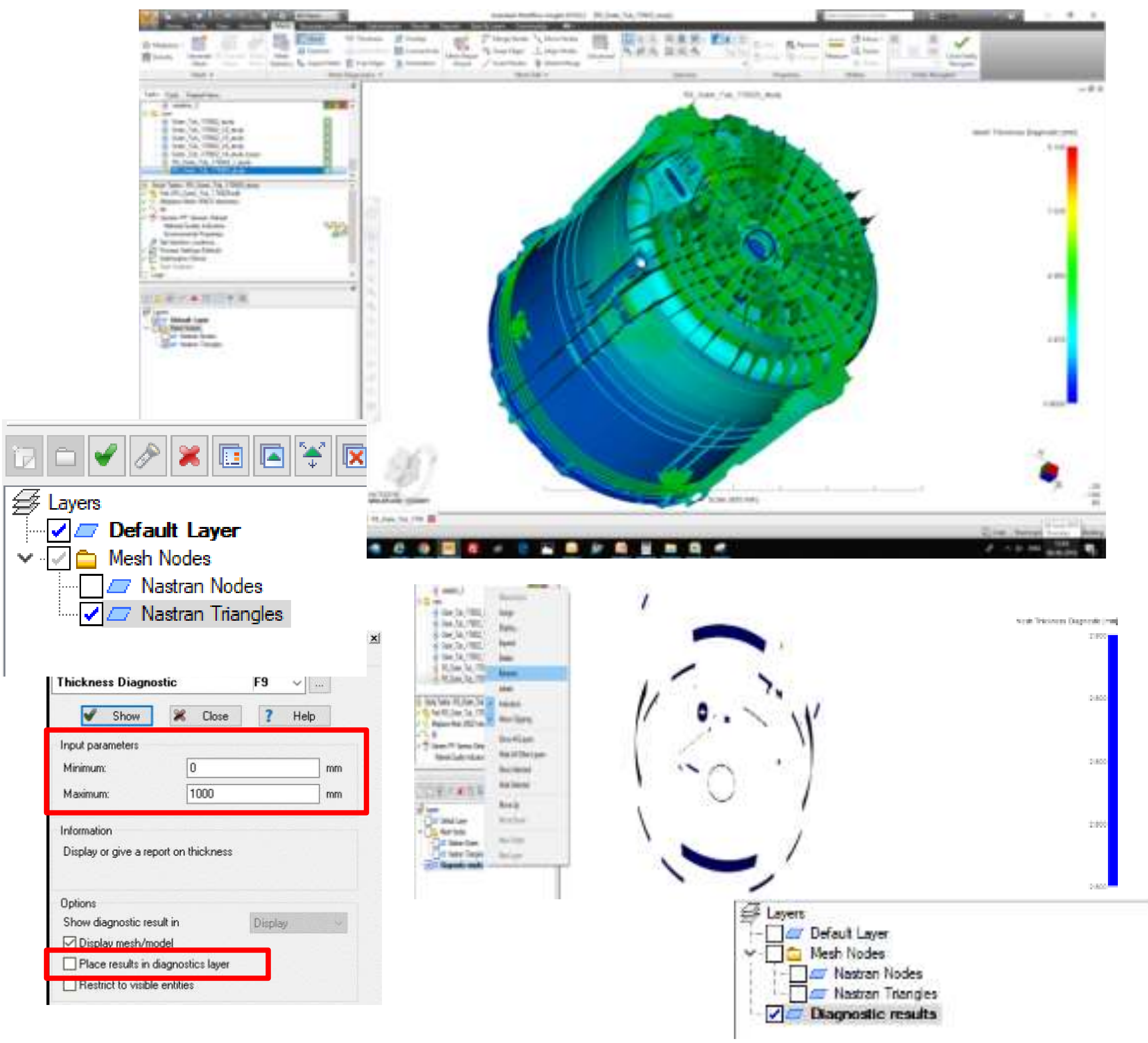


Figure 4.2: Midplane mesh thickness levels generation manually

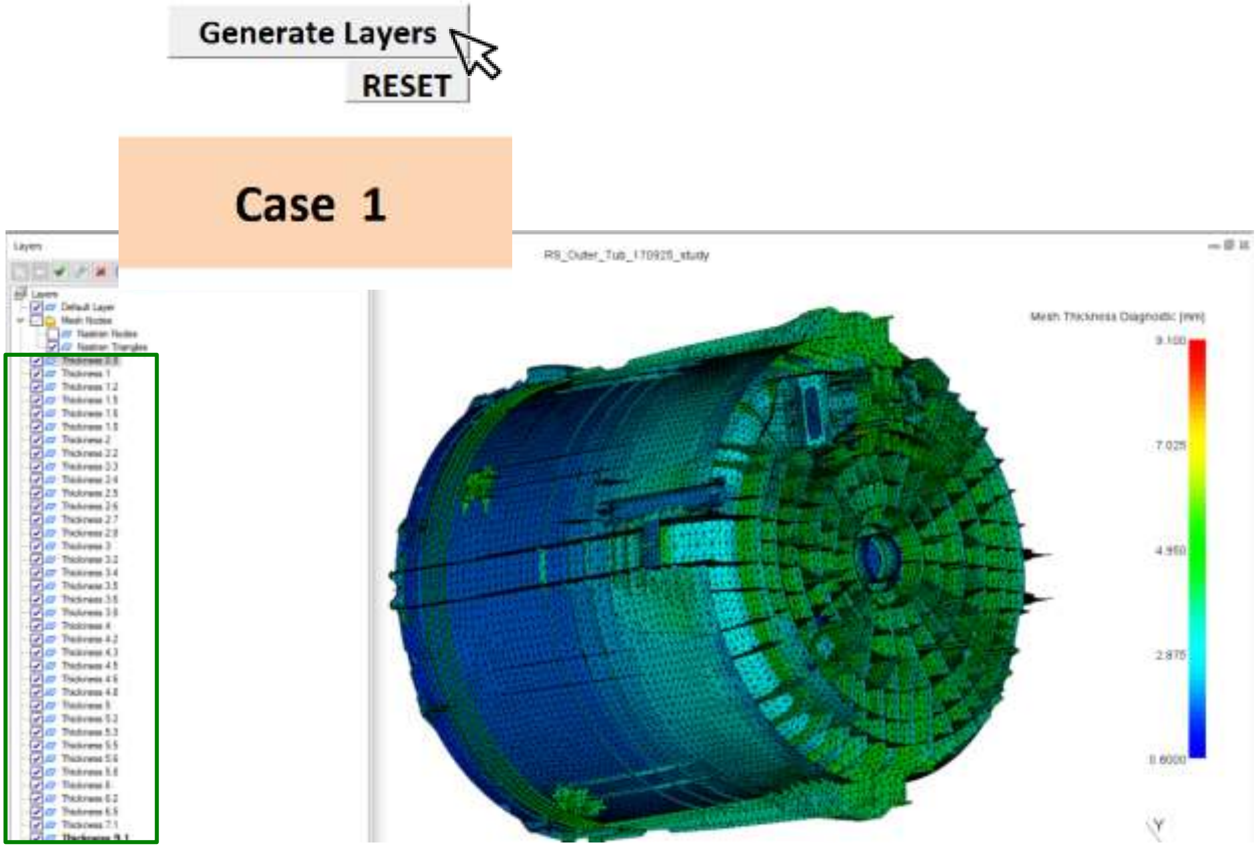


Figure 4.3: Midplane mesh thickness levels generation automatically

- Time taken Manually = **<u>1043secs (17m 23s)</u>**
- Time taken Automatically with Single Button Click = **<u>58secs</u>**

4.2.2 Automation Step 02

Automation of Node Collection on Critical Edge: This is a Post-Processing step. For plotting any graphical result along an edge, we need to collect all the nodes in an incremental manner, in order to get a perfectly smooth graph.

Present Scenario: Collecting nodes one by one manually, not missing any node and also avoiding to select any node outside an edge, can be extremely frustrating task for the analyst as it wastes a lot of time and requires no skill to do it, especially for a scenario of a huge critical edge with hundreds of nodes (Figure 4.4) .

Wishlist: A program to Automatically collect sorted nodes real time, with simple user inputs (Figure 4.5).

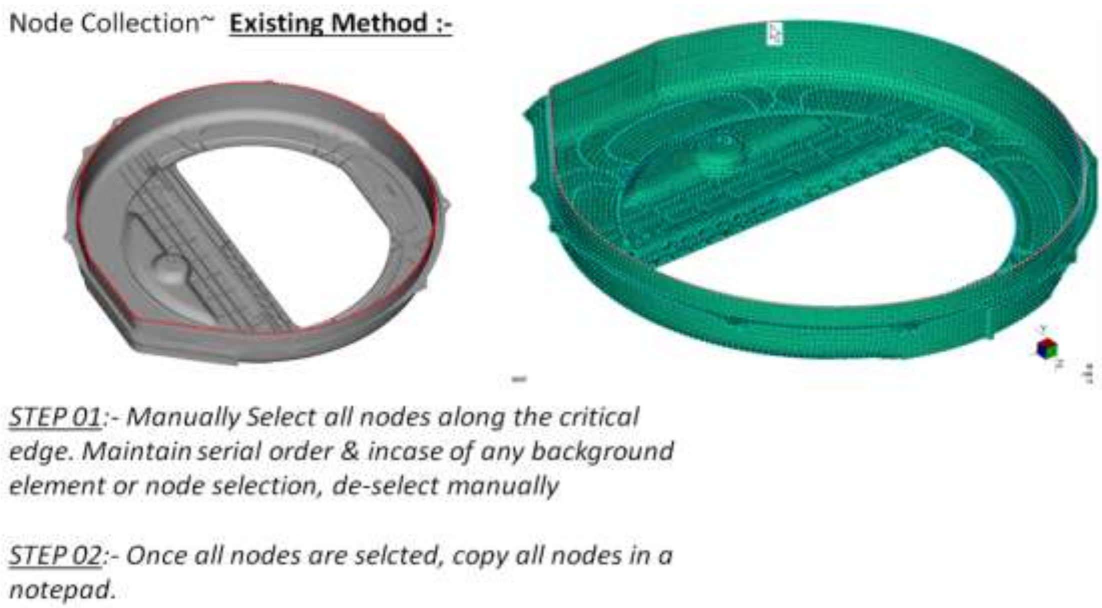


Figure 4.4: Node Collection on Critical Edge manually

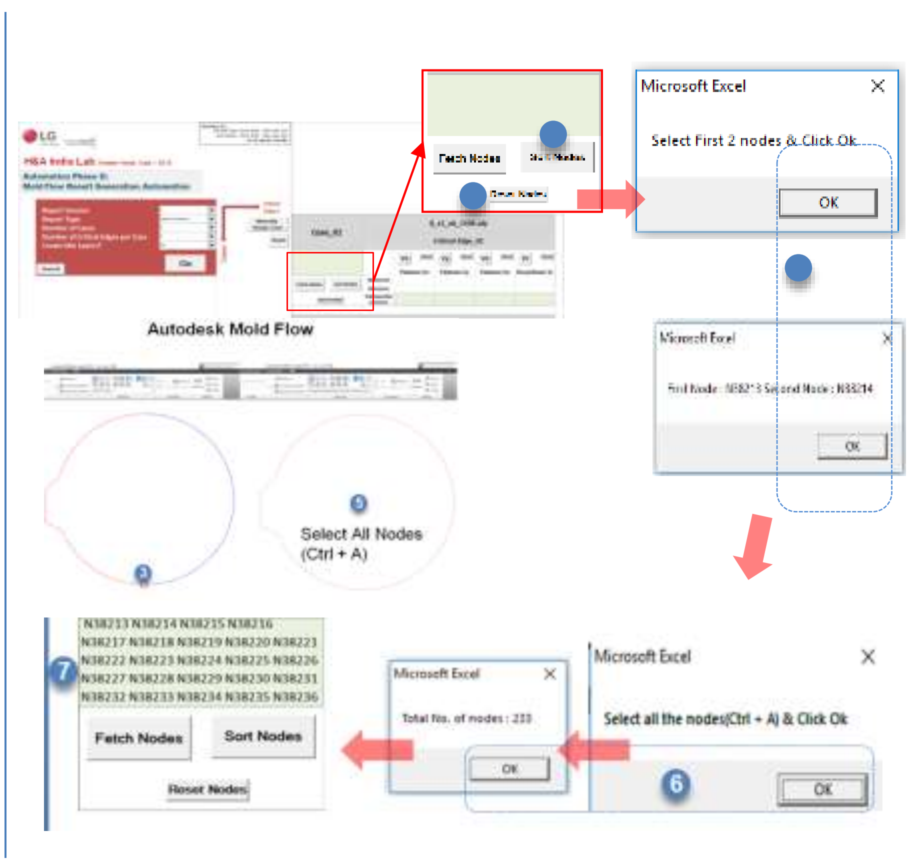


Figure 4.5: Node Collection on Critical Edge automatically

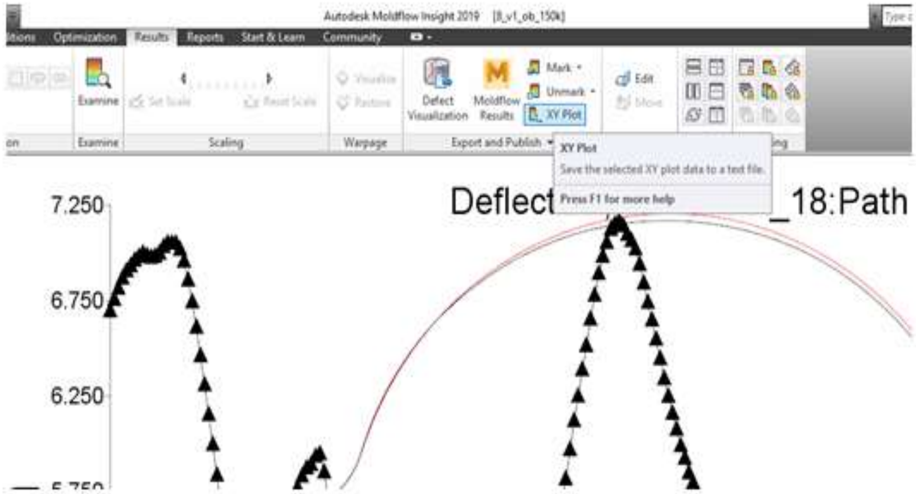
- Time taken Manually = **551secs (09m 11s)**
- Time taken Automatically with Single Button Click = **89secs (01m 29s)**

4.2.3 Automation Step 03

Flatness (Vx, Vy, Vz)/ Roundness (Vr) Results Generation Automation: This is a Post-Processing step. Flatness (Vx, Vy, Vz) and Roundness (Vr) results are key results in CAE Mold Flow as they depict the deflection of a particular edge, which might be critical to avoid and Fitment (Gap/Flush) issues in an assembly.

Present Scenario: A lot of manual steps are required till we reach the final Flatness and Roundness Values, and in multiple Case and multiple Critical edge scenario, things can get pretty lengthy and complicated, with huge risks of error (Figure 4.6).

Wishlist: A program to Automatically collect sorted nodes real time, with simple user inputs (Figure 4.7).



Vz

Screw Locations 01		Screw Locations 02		Screw Locations 03		Screw Locations 04		Screw Locations 05		Screw Locations 06		Screw Locations 07	
Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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2.80	2.55	0.06	-0.09	-0.10	-0.42	0.88	0.88	1.28	1.24	0.61	0.26	0.04	-0.07
2.56	2.32	0.01	-0.16	-0.26	-0.57	0.68	0.66	1.09	1.04	0.45	0.10	-0.02	-0.16
0.23	0.23	0.05	0.07	0.16	0.15	0.20	0.22	0.19	0.20	0.17	0.16	0.06	0.09

Vr

Screw Locations 01		Screw Locations 02		Screw Locations 03		Screw Locations 04		Screw Locations 05		Screw Locations 06		Screw Locations 07	
Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.07	1.09	1.87	1.84	1.27	1.30	2.05	2.03	2.06	0.19	1.21	1.26	2.07	2.01
-1.11	-1.13	-1.88	-1.85	-1.29	-1.33	-2.08	-2.07	-2.09	0.07	-1.23	-1.28	-2.09	-2.03
2.18	2.22	3.75	3.69	2.56	2.64	4.13	4.10	4.15	0.11	2.44	2.54	4.16	4.04

Figure 4.6: Flatness / Roundness results generation manually

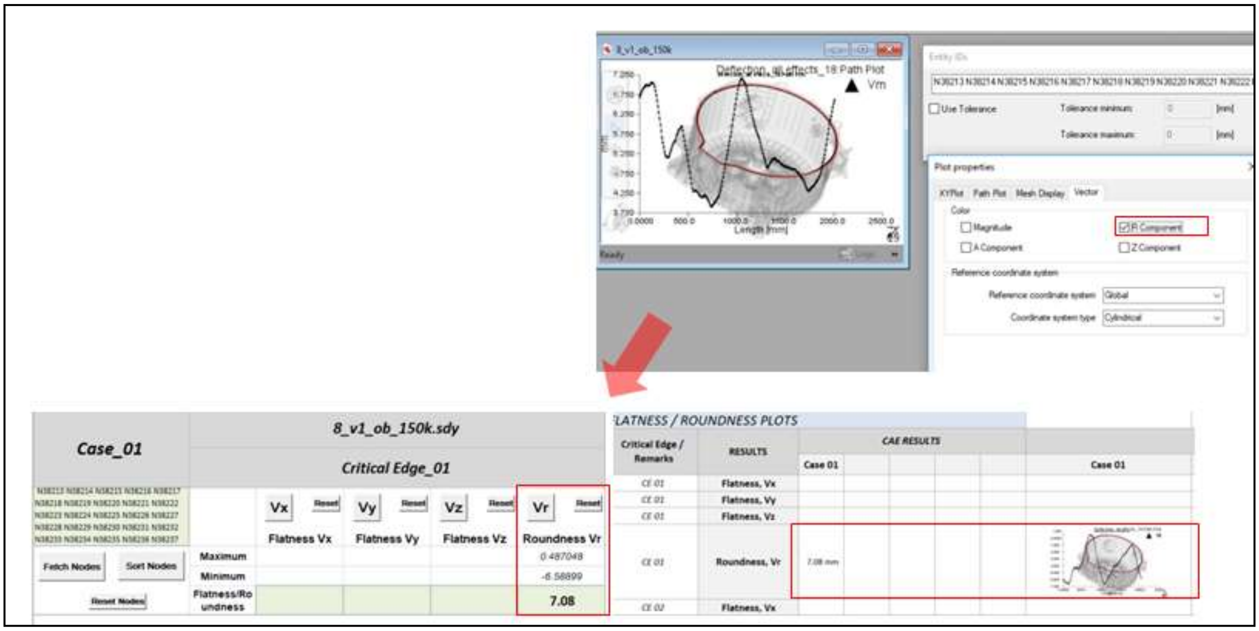


Figure 4.7: Flatness / Roundness results generation automatically

- ➢ Time taken Manually = **<u>533secs (08m 53s)</u>**
- ➢ Time taken Automatically with Single Button Click = **<u>72secs (01m12s)</u>**

4.2.4 Automation Step 04

Automation of Properties Assign of all results as per company's standards: This is a Post-Processing step. There is a standardization of the display properties which need to be set for every Mold Flow result, for best representation in the Mold Flow report.

Present Scenario: We have to open each result separately, to modify or confirm the compliance to display standards. As sometimes we might need to represent as much as 15 results, it takes away huge time, performing repetitive steps for every analysis (Figure 4.8).

Wishlist: A program to Automatically collect sorted nodes real time, with simple user inputs (Figure 4.9).

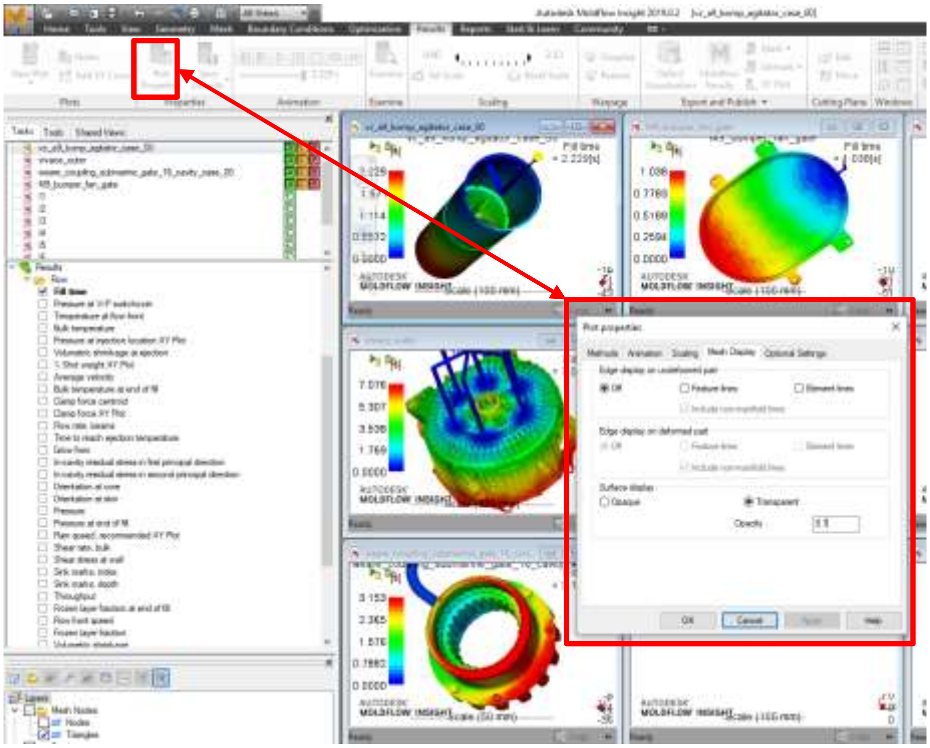


Figure 4.8: Properties Assign manually of all results as per company's standards

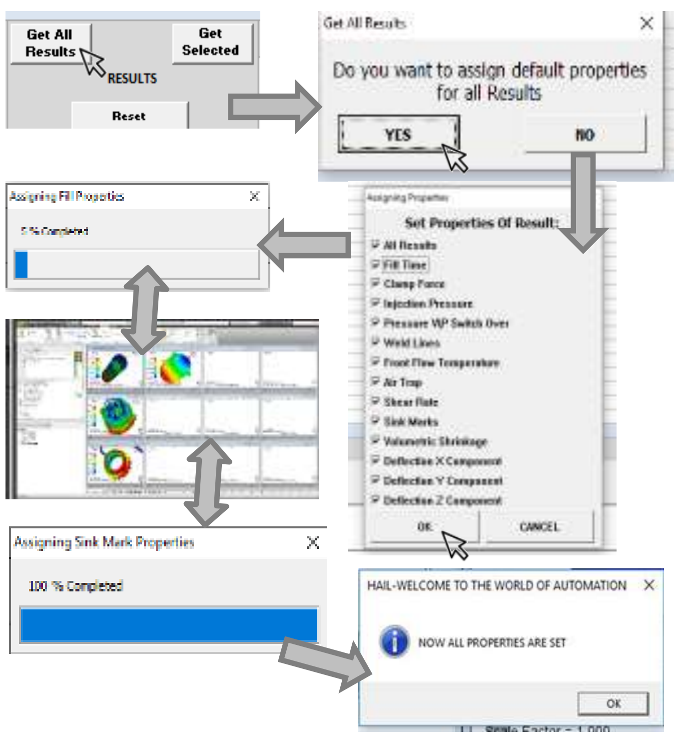


Figure 4.9: Properties Assign automatically of all results as per company's standards

- ➢ Time taken Manually = <u>**1068secs (17m 48s)**</u>
- ➢ Time taken Automatically with Single Button Click = <u>**407secs (06m47s)**</u>

4.2.5 Automation Step 05

Result Generation (Numerical & Pictorial) as per company's standard report format: This is a Pre-Processing step. An ultimate goal of every analyst is to generate a Technical Report of all results and findings, and it is the report which is communicated to Part developers, Team Members and management.

Present Scenario: Expressing results in Company's Standard report format is done one by one for every result, and the process takes away a major chuck of analyst's time, and also hugely affects project delivery (Figure 4.10).

Wishlist: A program to Automatically generate all Numeric and Pictorial results in LG standard report size and format (Figure 4.11).

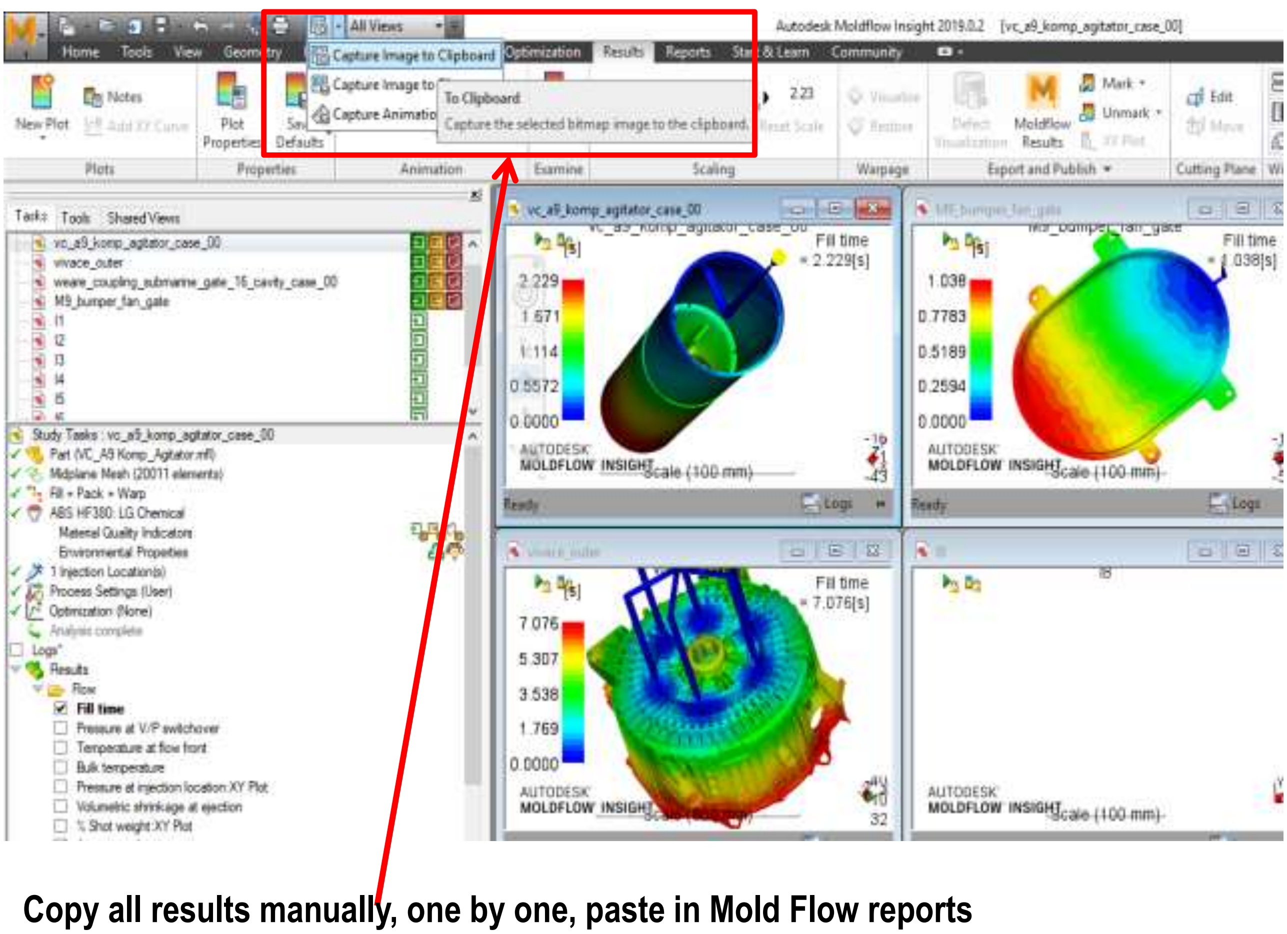


Figure 4.10: Manually result generation as per company's standard

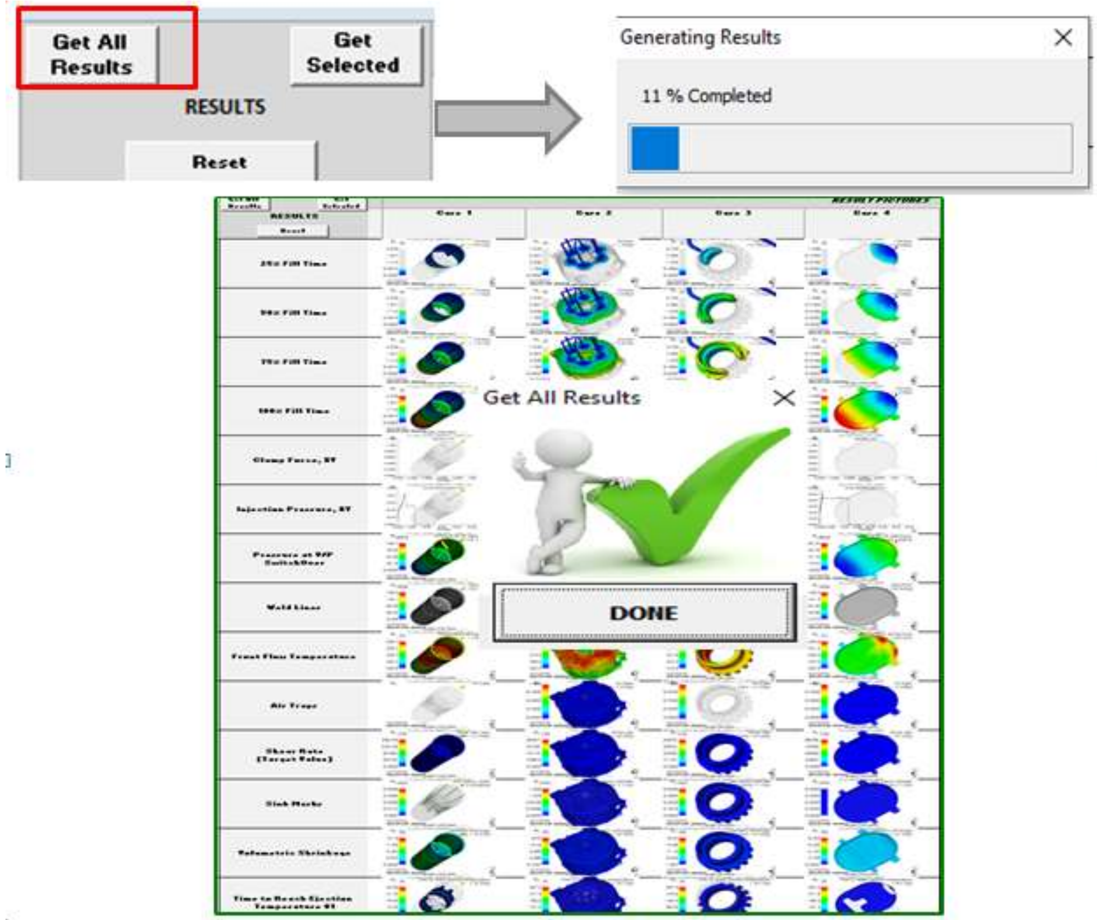


Figure 4.11: Automatically result generation as per company's standard

- Time taken Manually = **1335secs (22m 15s)**
- Time taken Automatically with Single Button Click = **423secs (07m03s)**

4.2.6 Automation Step 06

CAE Result Table generation Automation: This is a Pre-Processing step. A result table enlists all the key results of all the Cases in a simple tab format, which can easily show a comparison and help it deriving overall conclusions of Analysis.

Present Scenario: Once all the report slides are finished, all results from each slide, are one by one copied in the Result table slide. This process is duplicate and wastes time (Figure 4.12).

Wishlist: A program to Automatically generate result table (Figure 4.13).

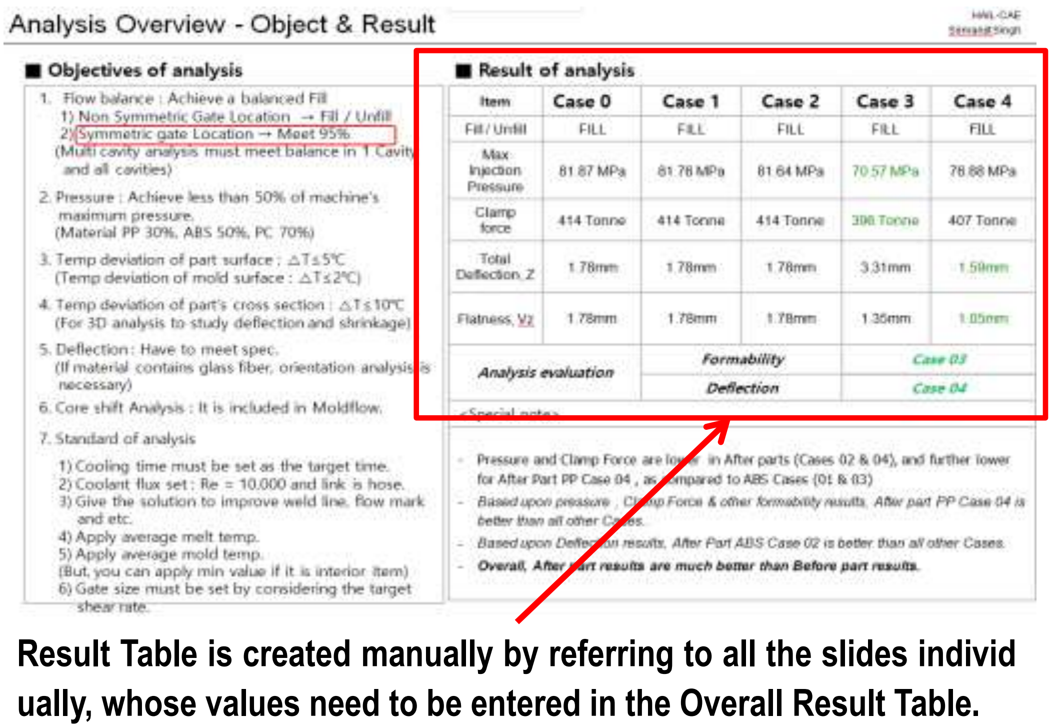


Figure 4.12: CAE result table generation manually

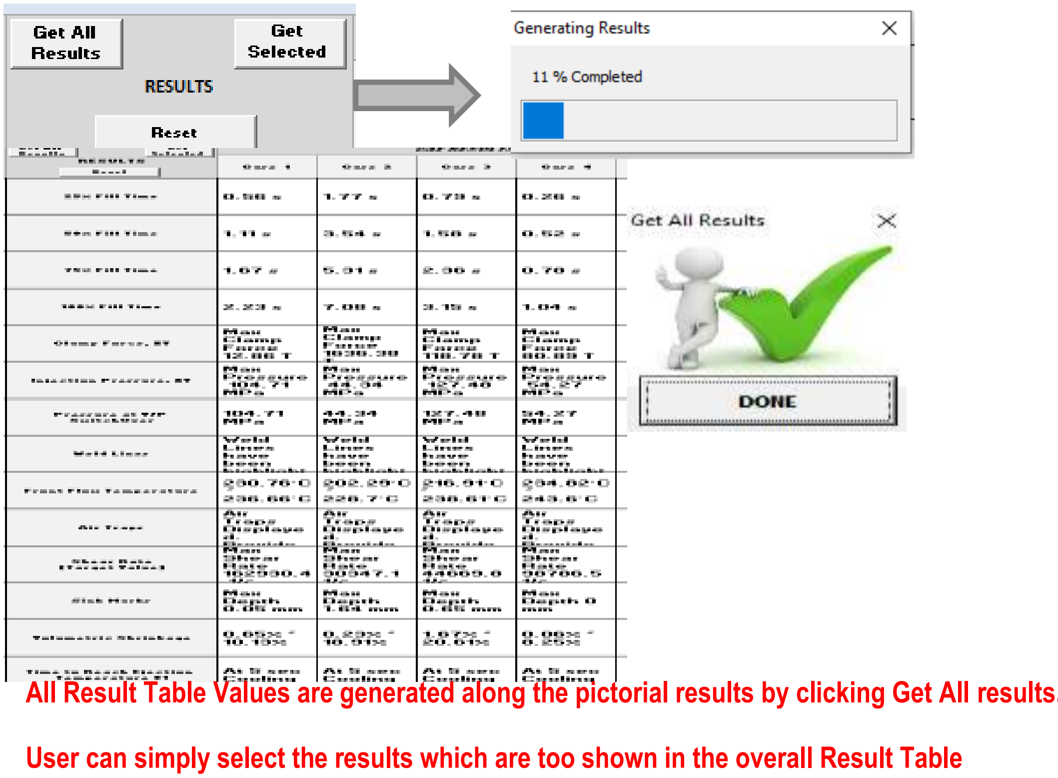


Figure 4.13: CAE result table generation automatically

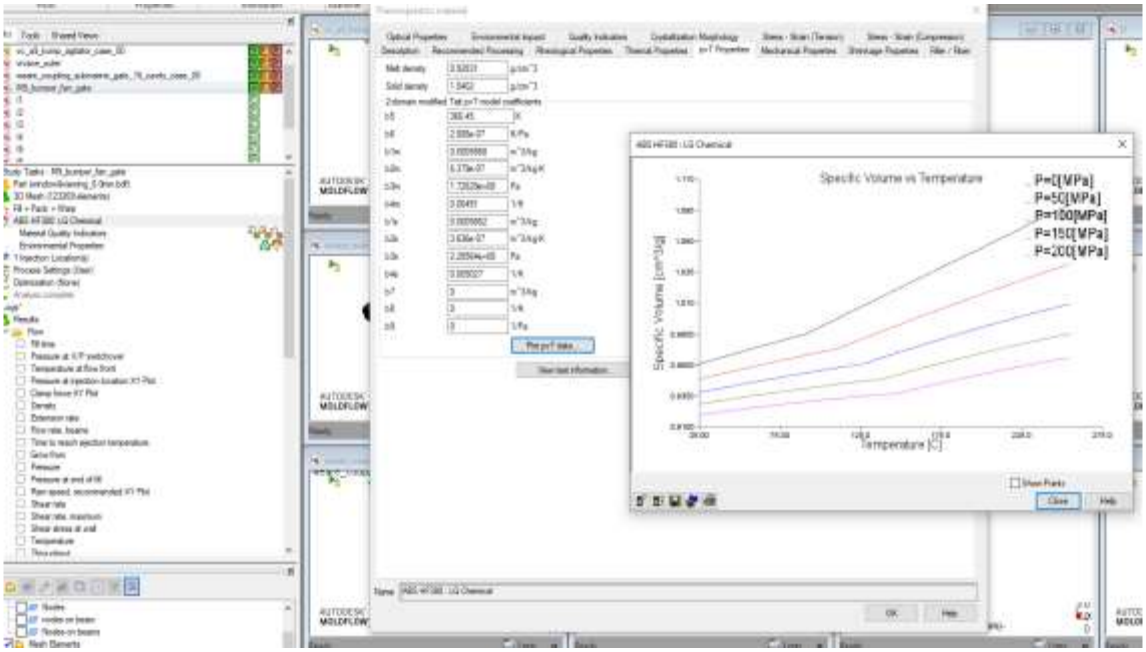
- Time taken Manually = **256secs (04m 16s)**
- Time taken Automatically with Single Button Click = **47secs**

4.2.7 Automation Step 07

Create Templates as Per LG Standard Report Format: Many templates like Mesh Statistics, Material Information, Boundary Conditions, PVT diagram etc. need to be shown in the report.

Present Scenario: Creating these report templates is a repetitive procedure, which wastes time, and monotony may lead to errors (Figure 4.14).

Wishlist: A program which Automatically generates these templates in report friendly format (Figure 4.15).



Standard template Data provided is all reports, is gathered from various different locations.

Data Such as, Material details, PVT Diagram, Part Volume, Cross-sectiona l Area etc.

Figure 4.14: Manually creating templates

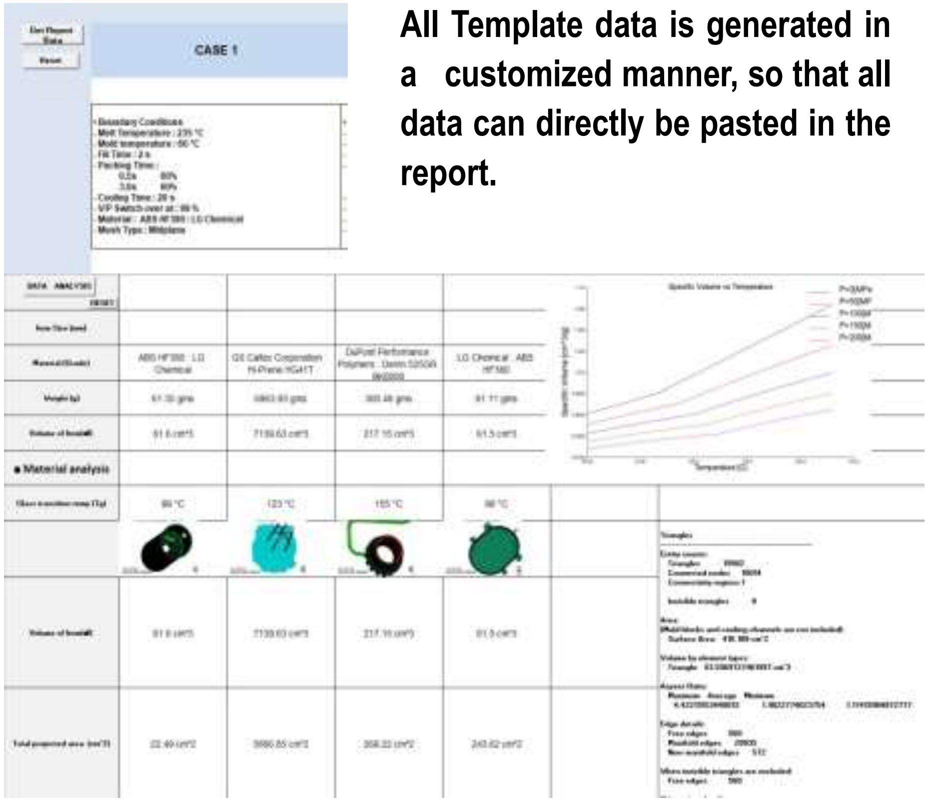


Figure 4.15: Automatically creating templates

- Time taken Manually = <u>**192secs (03m 12s)**</u>
- Time taken Automatically with Single Button Click = <u>**84secs (1m24s)**</u>

4.3 Cumulative Benefits of All Automation Steps

	Time taken Without Automation	Time taken With Automation	Time Saving	Percentage Saving
Step 01: Midplane mesh Thickness Levels generation	1043 secs (17min 23secs)	58 secs	**985secs (16min 25 secs)**	**94%**
Step 02: Automation of Node Collection on Critical Edge	551 secs (9min 11sec s)	89secs. (1mins 29secs)	**462 secs (7mins 42 secs)**	**87%**
Step 03: Flatness (Vx, Vy, Vz)/ Roundness (Vr) Results Generation Automation	533 secs (8min 53secs)	72 secs. (1 mins 12 secs)	**461 secs (7 mins 41 secs)**	**86%**
Step 04: Automation of Properties Assign of all results as per LG Standards.	1068 secs (17m 48 secs)	527 secs (8 mins 47secs)	**541 secs (9mins 1 secs)**	**51%**
Step 05: Result Generation (Numeric & Pictorial) as per LG Standard Report Format	1335 secs (22 min 15 sec)	423 secs (7 mins 3 secs)	**912 secs (15 mins 12 secs)**	**68%**
Step 06: CAE Result Table generation Automation	256secs (4 mins 16 secs)	108 secs. (1 min 48 secs)	**148 secs (2 mins 28 secs)**	**58%**
Step 07: Create Templates as Per LG Standard Report Format	192 secs (3 min 12 secs)	84secs (1 min 24 secs)	**108 secs (1 mins 48 secs)**	**56%**

Table 4.1: Cumulative benefits of implemented automation steps

Chapter 5
CONCLUSIONS

Basic thought along with its way of the approximate and numerical examination was done so as to recreate the various strides from the infusion of the material to the launch of the molded product. The various factors affecting the warpage and shrinkage results were considered and as mostly the warpage can be seen once the molded product is formed so at that point there were some restrictions that can't be altered so some factors affecting the warpage can't be optimized. Remaining factors that can be optimized are:

- Optimization of Cooling System
- Optimization of Thickness

In the previous section, Case 01 corresponds to the already existing system. Case 02 corresponds to the system in which cooling channels were modified so as to optimize the warpage results. Case 03 corresponds to the system in which part thickness was modified so to optimize warpage results. Conclusion drawn from all the results were:

- Fill Pattern is almost balanced in all the cases.

- Clamp Force is almost same in all the cases.

- Maximum Injection Pressure is almost same in all the cases.

- Pressure at V/P Switchover decreases to some extent in Case 02 and Case 03

- Weld Line positions are almost same in all the cases.

- Front flow temperature is above the range in all the cases

- Air traps are visible in all the cases for which we have to provide parting line venting.

- The maximum shear rate measured is below the permissible Resin shear rate in all cases.

- Max Sink Mark depth is almost same in all cases.

- Volumetric shrinkage range is almost same for all cases.

- Total Deflection in X and Z direction is less in Case 02 and Case 03 as compared to Case 01.

- Total Deflection in Y component is almost same in all the cases but Average deflection at point AB decreases to great extent in Case 02 and even more in Case 03

- For Critical Edge 01 and Critical Edge 02, Flatness Vy and Vz are comparatively less in Case02 and Case 03 with respect to Case 01.

5.1 Scope for Future Work

Despite the huge amount of work that has been done in the development of automation correlation for the result generation, in future scenario there can be an automated system that can correlate with the optimization of the factors affecting warpage. With this future scenario automated system, there will be a revolution in term of Mold Flow analysis. With this scenario we can achieve the results along with following benefits:

- Elimination of error
- Process simplification
- Time reduction

Although it is quite a challenging task but with the macro of Mold Flow and with a deep knowledge of Visual Basics, it can be done. Along with this further research can be done to find new ways for the reduction of warpage effects on a molded component.

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