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Fiber Orientation Prediction and Strength Evaluation of Composite Spur Gears Reinforced by Discontinuous Fiber

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FIBER ORIENTATION PREDICTION AND STRENGTH EVALUATION OF COMPOSITE SPUR GEARS REINFORCED BY DISCONTINUOUS FIBER

BY

NAWRIN JAHAN

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FIBER ORIENTATION PREDICTION AND STRENGTH EVALUATION OF COMPOSITE SPUR GEARS REINFORCED BY DISCONTINUOUS FIBER

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science in Mechanical Engineering degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidates are necessarily the conclusions of the major department.

Zhong Hu, Ph.D.
Thesis Advisor Date

Kurt Bassett, Ph.D.
Head, Department of Mechanical Engineering Date

Dean, Graduate School Date

This thesis is dedicated to my family.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

FIBER ORIENTATION PREDICTION AND STRENGTH EVALUATION OF COMPOSITE SPUR GEARS REINFORCED BY DISCONTINUOUS FIBER

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2016

Composite materials have been extensively used for their important role in attenuation of components design, low specific weight, high mechanical performance, and excellent corrosion resistance offer significant advantages over metallic materials. These superlative properties can be attained by tailoring different material in an appropriate combination of the reinforcing phase (carbon fiber, alumina, etc.) and matrix phase (polymer, ceramic, metals, etc.). Carbon fiber reinforced composites are mostly used on intricate stress sensitive structures like wings of aero plane or gear. Amount of fiber, fiber type, and size of the fiber and the orientation of reinforcing fibers directly influence the mechanical properties of polymer composites like elastic modulus, strength, thermal expansion, thermal conductivity, and electrical conductivity. Orientation state is varied due to the motion of fiber which is regulated by the flow of polymer matrix during processing. Injection molding is one of the most widely used manufacturing methods for the production of plastic parts. Injection molding has so many process parameters which directly influences the orientation of fiber and structural properties of molded compounds. To achieve proper power transmission in spur gears, fiber orientation can be made parallel to the flow direction in the skin layer by controlling injection molding process parameter like gate location, number of gates, injection pressure, injection temperature, cooling rate etc.

1. Introduction

1.1 Background

-From the starting day of innovation to the date, material science is changing their concept every day. For example, a lighter weight car or aircraft is highly demanded to achieve more efficiency as well as mileage. To meet the need of lighter weight, engineers take plastics as alternative of metal body.

-The material science is now its cutting edge and the collaboration of different industry (automobile industry, aircraft industry) has made this revolution possible. Nowadays, the plastics are used mainly to make cars more energy efficient by reducing weight, together with providing durability, corrosion resistance, design flexibility, resiliency and high performance at low cost. Besides that, plastic has its own disadvantages: low strength and brittleness.

-Then researcher came up with the idea by combining two or more distinct materials to achieve the desired combination of properties (e.g., light, strong, corrosion resistant).This new material is composite. Fiber Reinforced Polymer (FRP) composites is plastic, either thermoset or thermoplastic, that is embedded with a fiber to reinforce in one or more directions. FRP has its own advantages: light weight, high strength-to-weight ratio, directional strength, corrosion resistance, weather resistance, dimensional stability, low thermal conductivity, low coefficient of thermal expansion, radar transparency, non-magnetic, high impact strength, high dielectric strength (insulator), low maintenance, long term durability, part consolidation, small to large part geometry possible, tailored surface finish.

-To produce plastic parts with intricate and complex shape with the highest design flexibility along with considering the economical consideration, time constraint and also the environmental impact, the most popular method of plastic forming is injection molding. Almost 30% of all plastic products are produced using injection molding process. This is the most commonly used manufacturing process for the plastic forming. This is a manufacturing process for producing parts from both thermoplastic and thermosetting plastic materials. Plastic materials are inserted into a heated barrel, mixed, and forced into a mould cavity where it cools and hardens to the configuration of the cavity. A product is designed and moulds are made from metal, usually either steel or aluminum, and precision-machined to form the features of the desired part.

-The mechanical property of the molded part is characterized by the conditions under which it is processed. There are mainly four process parameters for injection molded compounds: pressure, temperature, time, and distance. The quality of the product is not only influenced by above parameters but the length and orientation of fibers used for reinforcing the plastics. Common injection molding defects are silver streaks, short shot, jetting, flow marks, color streaks, weld lines, flash, delamination, stringiness, sink marks and warping or twisting. This research aims to investigate and optimize of setting parameter in plastic injection molding. For the injection molding process, the parameters include ram speed, injection pressure, barrel and nozzle temperature, mold temperature, mold clamp force, dwell time, cooling time, and material properties.

-Changes in processing conditions can lead to improvements or degradation of accuracy, shape, surface finish, and fracture resistance and many other part properties and characteristics. The primary use of process models is to predict these effects. Often process models are inadequate for this task, usually because the process is very complex or because accurate material behavior descriptions at processing conditions are unavailable. So the defect of from the result will produce should be analyze and try to improve the quality of the product. Outcome of the defect will be defined to produce the better parameter. Chronological development of FRP composites and research programs which are carried out for improving processing FRP and enhancement of structural performance are described below:

1.2 Injection Molding

- Injection molding is a manufacturing process for producing parts by injecting material into a mould. Injection molding can be performed with a host of materials, thermoplastic and thermosetting polymers. A mold cavity is a negative of the part being produced, when the cavity is filled with plastic, it is cooled and the plastic becomes solid material resulting in a completed positive component. Typically injection pressures range from 5000 to 20,000 psi. Because of high pressures involved, molds must be clamped shut during injection and cooling by clamping forces measured in tons.

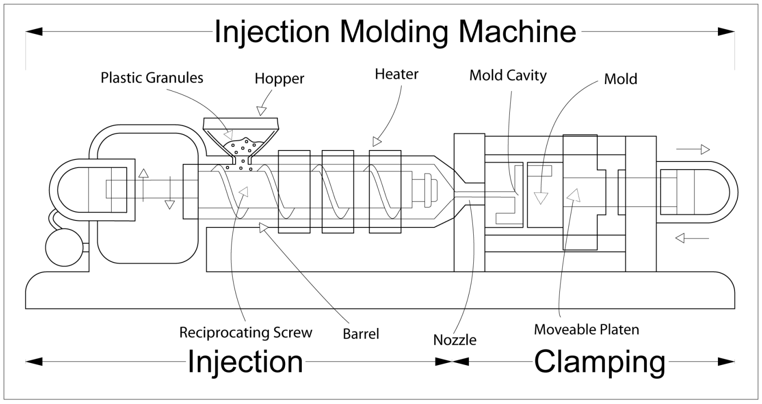


Figure 1: Injection Molding Machine[1]

1.2.1 Injection Molding Process Cycle

The process cycle for injection molding consists of the following four stages:

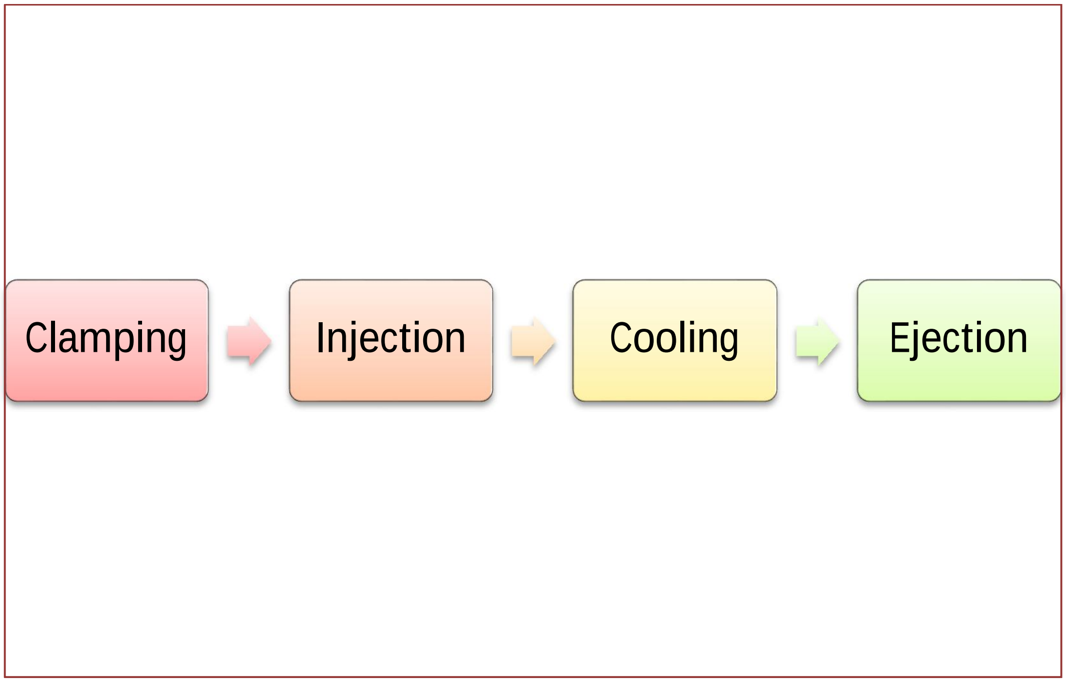


Figure 2: Process Cycle

1.2.1.1 Clamping

1) At first, the two halves of the mold must be securely closed by the clamping unit before injection of the material into the mold.
2) Both half of the mold is fastened to the injection molding machine and one of them has the freedom to slide.
3) The time required to close and clamp the mold is proportional to the machine size.

1.2.1.2 Injection

In this phase, pellets (the raw plastic material) are fed into the injection molding machine, and brought towards the mold by the injection unit. Then, the material is subjected to heat and pressure. The molten plastic is then injected into the mold very quickly and the buildup of pressure packs and holds the material.

1.2.1.3 Cooling

The molten plastic that is inside the mold begins to cool as soon as it makes contact with the interior mold surfaces. As the plastic cools, it will solidify into the shape of the desired part.

- Shrinkage of the part may occur. The packing of material in the injection stage allows additional material to flow into the mold and reduce the amount of visible shrinkage.
- The mold cannot be opened until the required cooling time has elapsed.

1.2.1.4 Ejection

1) There is an injection system attached to the rear half of the mold to remove the cooled part.
2) Mechanism to push the part out of the mold-Force must be applied to eject the part because during cooling the part shrinks and adheres to the mold.

3) In order to facilitate the ejection of the part, a mold release agent can be sprayed onto the surfaces of the mold cavity prior to injection of the material.

1.2.1.5 Post processing cycle

Trimming- Excess material is found when the material in the channels of the mold will solidify attached to the part must be trimmed from the part by using cutters.

Regrind-Regrinders are used to regrind the scrap material into pellets. Scrap material can be found from trimming. The regrind must be mixed with raw material to be reused in the injection molding process due to some degradation of the material properties.

1.2.2 Equipment

Injection molding machines have different configurations, including a horizontal configuration and a vertical configuration. Generally, all injection molding machines should have following components:

- a power source,
- injection unit,
- mold assembly, and
- clamping unit.

1.2.3 Injection unit

The main function of injection unit is to heat and inject the material into the mold.

Injection unit consists of the following unit:

1.2.3.1 Hopper

Hopper is a large container into which the raw plastic is poured. The hopper has an open bottom, which allows the material to feed into the barrel.

1.2.3.2 Barrel

The barrel has its own mechanism for heating and injecting the material into the mold. This mechanism consists of ram injector or a reciprocating screw. A ram injector forces the material forward through a heated section with a ram or plunger that is usually hydraulically powered. A reciprocating screw moves the material forward by both rotating and sliding axially, being powered by either a hydraulic or electric motor. The material enters the grooves of the screw from the hopper and is advanced towards the mold as the screw rotates. For its forwarding motion, the material is melted by pressure, friction, and additional heaters that surround the reciprocating screw. The molten plastic is then injected very quickly into the mold through the nozzle at the end of the barrel by the buildup of pressure and the forward action of the screw. Increasing pressure packs the material and force to be held in the mold. Once the material has solidified inside the mold, the screw can retract and fill with more material for the next shot.

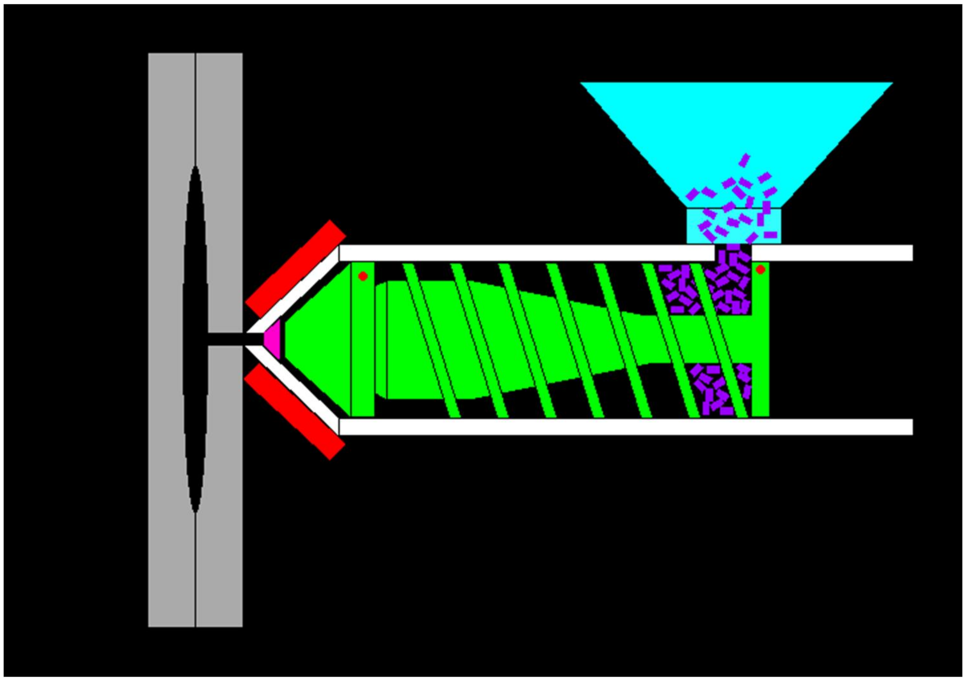


Figure 3: Injection unit[2]

1.2.3.3 Clamping unit

Before the injection of the molten plastic into the mold, the two halves of the mold will be firmly closed by the clamping unit.

1.2.3.4 Platen

A large plate, called platen is fixed to each half of the mold when the mold is attached to the injection molding machine.

1.2.3.5 Mold cavity

Mold Cavity is the front half of the mold is mounted to a stationary platen and aligns with the nozzle of the injection unit.

1.2.3.6 Mold core

The rear half of the mold, called the mold core, is set at a movable platen, which slides along the tie bars.

The hydraulically powered clamping motor actuates clamping bars that force the moveable platen towards the stationary platen and give sufficient force to keep the mold securely closed while the material is injected and subsequently cools. The mold is then opened by the clamping motor after cooling. The rear half of the mold is attached to an ejection system is mounted by the ejector bar and forces the solidified part out of the open cavity.

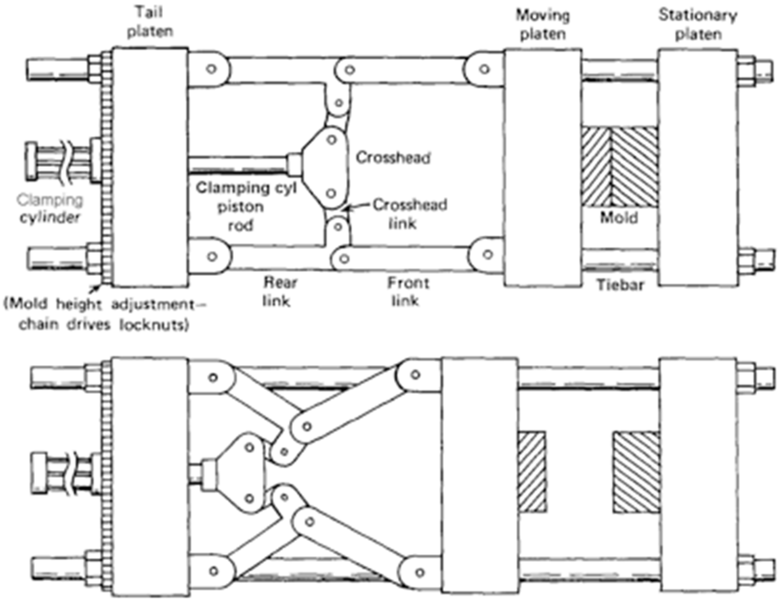


Figure 4: Clamping unit[3]

1.2.4 Machine specifications

Injection molding machines are typically specified by the following terms:

- Clamp force- The required clamp force is found by the projected area of the parts in the mold and the pressure with which the material is injected. Therefore, a larger part will require a larger clamping force. Also, certain materials that require high injection pressures may require higher tonnage machines.
- Shot capacity,
- Clamp stroke,
- minimum mold thickness, and
- platen size.

1.2.5 Mold channels Design

In order for the molten plastic to flow into the mold cavities, several channels are integrated into the mold design.

1.2.5.1 Sprue

Sprue is the main channel through which molten material enters a mold.

1.2.5.2 Runner

The sprue often connects to a series of channels that deliver the material into the mold cavities. These additional channels are called runners.

1.2.5.3 Gate

Gate is an opening at the end of a runner, which directs the flow of molten material into the mold cavity.

1.2.5.4 Hot Runners

Hot runner systems are sometimes used to heat the channels, allowing the contained material to be melted and detached from the part.

1.2.5.5 Cooling Channel

Cooling channels allow water to flow through the mold walls, adjacent to the cavity, and cool the molten plastic.

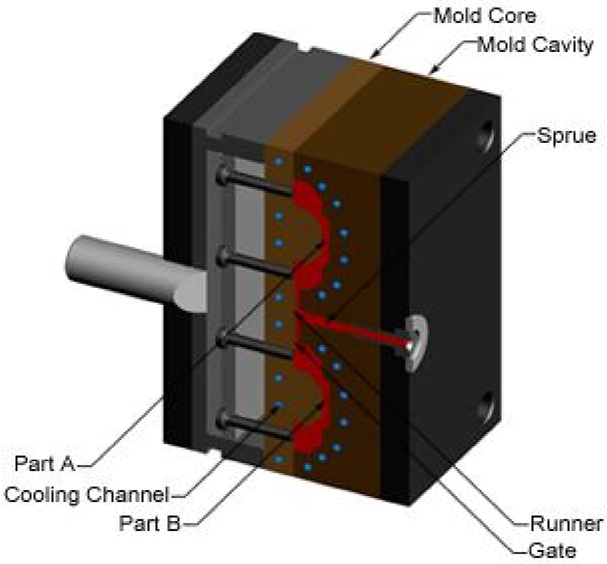


Figure 5: Mold Channel[4]

1.2.6 Process Parameter

1.2.6.1 Melt temperature

Melt temperatures for reinforced composites are 30–60°F higher than the unfilled resin.

1.2.6.2 Injection pressure

Injection pressure of 10–15,000 psi (70–105 MPa) is sufficient for reinforced composites.

First Stage Pressure-Lower first stage pressure can be subjected for unfilled compounds. Surface quality, orientation, and mechanical stressing of the melt are greatly influenced by the first stage pressure or boost pressure.

Holding Pressure-Holding pressure should be 50–75% of first stage pressure. Holding pressure should be sufficiently high to prevent voids sink marks and control shrinkage.

Back pressure-Screw back pressure settings should be low as possible with 25–50 psi (170-345 kPA) usually being sufficient. The back pressure displaces air in the screw feed section, enhances melt homogeneity, and facilitates heating of the melt. Excessive back pressure will overheat the melt and cause excessive fiber breakage.

1.2.6.3 Injection speed

- Fill rate should be quick for thin-walled parts.
- Fill rate should be moderately slow for thick-walled parts..
- High shear rates may be developed for higher injection rates.
- Excessive fill speed may cause gate blush, jetting, or discolored streaking.

1.2.6.4 Screw speed

- Optimum screw speed selection can be reached by adjusting screw return stoppage to occur just prior to the mold open sequence.

- High screw speeds can result in over heating of the melt and increased residence time in the molding machine.

1.2.6.5 Nozzle temperature

The nozzle temperature should approximate the desired melt temperature and may be lower for semi-crystalline compounds.

1.2.6.6 Mold temperature

Large cores or small diameter core pins may require lower temperatures or special cooling control to aid part ejection.

1.2.6.7 Cycle time

Cooling depends on the part thickness and the level of filler in a composite. Glass fiber and carbon fiber reinforced composites will cool faster than unfilled compounds due to the higher thermal diffusivity of these materials.

2. Literature Review

The literature reported in this chapter contains investigations of the fiber orientation and distribution predictions and emphasizes its importance for the structural performance of the injection molded compounds. The focus of this review will remain on studying different models for predicting fiber orientations and determining which models will be more accurate for accurate prediction of fiber orientation.

Composite materials have been extensively used for their important role in attenuation of components design, low specific weight, high mechanical performance, and excellent corrosion resistance offer significant advantages over metallic materials.[4-5] These superlative properties can be attained by tailoring different material in an appropriate combination of the reinforcing phase (carbon fiber, alumina, etc.) and matrix phase (polymer, ceramic, metals, etc.).[5] Amount of fiber, fiber type, and size of the fiber and the orientation of reinforcing fibers directly influence the mechanical properties of polymer composites like elastic modulus, strength, thermal expansion, thermal conductivity, and electrical conductivity. Orientation state is varied due to the motion of fiber which is regulated by the flow of polymer matrix during processing.[6] Injection molding has so many process parameters which directly influences the orientation of fiber and structural properties of molded compounds.

Orientation effects play a great role in material’s strength. Strength variation due to isotropic and anisotropic material has been analyzed by using Moldex3D-FEA interface.[7] Nguyen, Ba Nghiep (2008) established a procedure to anticipate the elastic properties of long-fiber injection-molded thermoplastics (LFTs). The fiber length distribution (FLD) represents number of fibers versus fiber length. To calculate the elastic properties of the composite, predicted orientation distribution are corrected to the experimented result. The probability density functions were built and used in the computation. In this investigation, Weibull’s distribution was also used to represent the actual FLD. To calculate the stiffness matrix of the aligned fiber composite containing the established FLD, the Mori–Tanaka model that employs the Eshelby’s equivalent inclusion method was followed. The composite elastic property variation with change in orientation was studied by performing a sensitivity analysis. The model successfully attained the corrected fiber orientation.[8]

Autodesk Simulation Moldflow Insight has been used as a predictive tool to study the fiber orientation and length of distribution In this investigation, polypropylene and polyamide 6,6 was used as the resin matrices. Local fiber orientation and length distributions have been studied. Finally, this project aimed to analyze the capacity of Autodesk Simulation Moldflow Insight (ASMI) to predict the fiber orientation and length of distribution.[9]

Vélez-García, Gregorio Manuel analyzed the fiber orientation with numerical precision. The final fiber orientation state is viewed with the images of a customized image analysis tool.[10] Result of the investigation shows that asymmetric profile of orientation is found at the gate for cavity wise measurements in two thin center-gated disks. In this measurement, Orientation profile diminished at entry region following 32 gap widths. To analyze the prediction of cavity wise orientation, a delay model was employed for fiber orientation with model parameters obtained from rheometrical experiments. Predicted model contains the slip correction and to validate this model, experimental fiber orientation data was compared to it. The result shows the predicted model is very closer to the experimental fiber orientation and length of fiber distribution.

Elastic stiffness has been assessed for different fiber polymer composites processed by injection molding in order to preliminarily estimate whether these composites could be used in hydropower systems for load-carrying components such as turbine blades. To ensure the best performance of compounds in hydropower system, the elastic stiffness is determined by the EMTA code. In this investigation, glass and carbon fibers as well as both thermoplastic and thermoset resins have been examined. This investigation shows that PEEK has better elastic properties than PP or PA6,6. So it is obvious that thermoplastic resin plays significant role in enhancing composite properties.[11]

A new matrix polyetheretherketone (PEEK) has been studied which consists of 30% by volume fraction of short carbon fibers. This study follows three sequences: 1) Determination of mechanical properties of carbon fiber reinforced (PEEK); 2) Using Moldflow software for prediction of fiber orientation; 3) Extracting the properties of carbon fiber and exporting the properties into ANSYS software; 4) For three constitutive material-istropy, transversely isotropy and orthotropic, load deflection curve is obtained. And this study shows that Ansys-Moldflow software can give more precise result by employing these two new configurations transversely isotropy and orthotropic rather than conventional isotropy. Coupling of Ansys and Moldflow software is better substitution of conventional physical testing which requires time, money and labor.[12]

Short fiber composites exhibit better tensile properties than long fiber composites. A computational approach has been used which employs Kelly-Tyson model as this model gives better computation of ISS ad tensile related properties. They incorporated injection-molded short and long-glass fiber/polyamide 6,6 composites. Under tensile stress, factors of fibers have been identified which reinforce polymers and they are computation of the fiber–matrix ISS, orientation factor, reinforcement efficiency, tensile, and fiber length-related properties.[13]

Mechanical performance of injection molded components can be improved by adding natural fiber and glass fiber. The property of vakka fibers in injection molding which are hybridized with glass fiber as reinforcement in the polypropylene matrix for making composites has been examined. The effect of the fiber content and the interfacial adhesion on the mechanical properties of VG/PP (vakka fiber, glass reinforced hybrid polypropylene composites) and VG/MAPP composites prepared by injection molding process has been determined. [14]

Adding carbon black or nucleating agent affects structural performance of an injection molded compound. The matrix crystallization is greatly enhanced by carbon black. Fracture behavior also changes with the mould temperature. In order to decrease cycle time or mould temperature, nucleating agents are useful to enhance rapid crystallization. Poly(ethylene terephtalate) (PET) reinforced by 30 wt% of 12.5 mm long glass fibres (LGF) having an 18 "m diameter was used in this study. There are four compounds formed: 1) Virgin (R0) 2) Carbon Black (R1) 3) Carbon Black and nucleating agents-1 (R2) 4) Carbon Black and nucleating agents-2. A 2000 kN clamping force injection-moulding machine was used and the dimension of prototype injection mould is 300x120x3 mm. To conduct Charpy impact tests a standard pendulum impact machine was used. V-shaped notched samples (type A: notched radius 0.25 mm, remaining width 8 mm) were used to carry out the test. [15]

Long Fiber Thermoplastics' microstructures depend on different factors: flow-induced fiber orientation, fiber breakage during injection molding, and processing conditions (e.g. pressure, mold and melt temperatures, mold geometries, injection speed, etc.) Autodesk Moldflow Insight (AMI) software packages have been used to compute the fiber orientation. To conduct the study, two materials have been chosen. They are 40% glass in polypropylene (PP) matrix and 40% glass in polyamide 6,6 (PA6,6) matrix. There are two injection rates for conducting injection molding process: slow-fill and fast-fill conditions. To change the molding parameters, there are two gating options: flows in edge- gated plaques and in center-gated plaques. The Moldflow mid-plane and 3-D models numerically anticipate weight-average lengths in the samples. The result of investigation shows that the Moldflow 3-D models can represent the asymmetric final fiber orientation state. The result also shows that Moldflow mid-plane models give more accurate fiber orientation predictions for all the samples than Moldflow 3-D models.[16]

High modulus of elasticity for the applied stress in the direction of fiber orientation, the mechanical property is highly influenced by fiber orientation and distribution. There are some factors for fiber orientation and distribution like geometrical properties of the fiber, visco-elastic behavior of the fiber filled matrix and mold design. As gating affects the final product's shrinkage property, so size if gating, its location and number of gates is an important parameter for the performance of final product. Injection speed plays a great role for fiber orientation. This numerical study can be applied only to the low content fiber because fiber interaction effect is not considered. [17]

Increasing gate location increases the stiffness and orthotropic material property can be precisely used to predict the structural performance of the parts. Some important issues are the outcome of this study-fiber orientation, density and material anisotropy are regulated by flow pattern of the mold and material stiffness can be changed by anisotropic properties.[18]

Reduced strain closure model has better prediction accuracy than the Folgar-Tucker model. Autodesk Moldflow exploits the Folgar-Tucker and the reduced strain closure model to predict the fiber orientation. To determine the more accurate model, Computer Tomography can be used as an essential tool. The whole cross section of a multipurpose specimen was scanned by CT device Nanotom. Here the required input is the fiber diameter, the difference in density of polymer and fibers and the length of the fibers.[19]

Mechanical strength of different areas of the injected part is influenced by fiber orientation in an injected composite. Fiber orientation is used to calculate the mechanical and thermal property as well as the residual stress in the cavity. The result shows that 1) transversely-aligned fibers are found in diverging flow area. 2) Randomly-oriented fibers are found near injection location. 3) Flow-aligned fibers are found in converging flow area. 4) Fibers parallel to the flow direction are found in restricted flow area. The experimental data shows that RSC model is very useful to predict the short fiber orientation and ARD prediction is well-suited for long fiber orientation.[20] But Folgar-Tucker model over predicts the fiber orientation, thus it is not applicable for commercially used software for simulation of injection molded reinforced plastic composites. Polybutylene terephthalate reinforced by 30% wt short glass fibers was used in this investigation. The molded parts have four thickness variations: 1.5, 2, 3, and 6 mm. There are three injection rates and different injection rate is applied for each thickness. Polypropylene with 40% wt glass fibers was used.[21] Thickness of each disk is

3mm. Process of filling is done by two different injection rates. Nominal length of fibers is 13mm. Same optical system is employed for measuring fiber orientation for both of the process. Cross section of each sample were polished and locations are selected which cut along the centerline of plaques and the radial direction of disks. An analytical approach has been employed by S. Patcharaphun, to anticipate the tensile strength of conventional, sandwich and push-pull injection molded short fiber reinforced composites[22]. To optimize the injection molding process, a number of simulations have been carried out. For the specialized injection molding process, a model has been developed. In this study, second order orientation tensor has been used to describe and calculate the local fiber orientation state. Then results are verified with the experimental data. This study successfully implemented sandwiched injection molding process to improve the mechanical performance of injection molded compounds. For the push-pull injection molding process the fiber attrition within the weld line area was independent of the holding pressure difference and the number of push-pull strokes. There is little different value of second order stress tensor at the center and close to the mold wall which may result from the fiber-fiber interaction coefficient used in the calculation.

Concentration of fiber has great influence on fiber orientation and the coupling between the fluid and fiber significantly plays a great role in the final orientation state. Fiber orientation in injection molding is also governed by fountain flow. A.Redjeb, L. Silva, P. Laure, M. Vincent and T. Coupez used Rem3d- a new software package to calculate the three-dimensional fiber orientation in injection molding process. In the 1st stage, they assume the orientation isotropic and determine the orientation. Later they investigated the solution of the evolution equation for fiber orientation, for a given velocity. In every step, a space-time discontinuous Galerkin method is used for the solution of evolution equation.[23]

Matrix density influences the mechanical performance. The study reveals that the matrix density and the base resin density is not dependent on each other for nucleating effects of the glass-fibers, kinetic of polymer chains at an interface, influence of sizing. Accuracy of some mechanical property such as tensile strength and Young's modulus is greatly influenced by these factors. Val A. Kagan and Christopher Roth (2004) employed SigmaSoft and Moldflow software package to examine the short-fiber orientation and distribution at the pre-welded bead, ribs and wall areas.[24] This software has its exclusive feature that it encounters the transient heat transfer within the mold and its components, including ejector pins, runners and other small bits that affect the molding process. Moreover, this software enables its users to make discrete evaluations of fiber alignment and dispersion anywhere in a molded part. The study tells that SigmaSoft may be a better substitution of Moldflow for optimizing the injection molding process for producing fiber reinforced plastic. The interaction coefficient has been used in the model for fiber orientation for concentrated suspensions. An elliptical profile is found and the orientation of any fiber may be calculated from the elliptical profile.

SOUSA, RA, et al. [25] studied the mechanical performance and fiber orientation of composites built by high density polyethylene (HDPE) and carbon fiber (C fiber). Two types of HDPE grades were employed to conduct this study. They are: 1) Hostalen GM 9255 (Melt flow rate= 0.37 ml/600 s (190uC, 5 kg) and 2) Vestolen A 6016 (Melt flow rate=26 ml/600 s (190uC, 5 kg). A single processing cycle is required by compounding and injection molding. An Instron tensile testing was employed to perform the tensile tests and strain is measured by the extensometer. Several stress parameters are determined and they are tangent modulus, the secant modulus, strain, the ultimate tensile strength (UTS), the strain at peak and the strain at break point. The force at peak (Fp), the peak energy (Up) and the failure energy (Uf) were determined by the impact test. Fiber lengths in the molded samples were determined by pyrolysis of the polymeric matrix for sections removed from the gauge length of the tensile test bars. After the test, mechanical performance for each of the composites is specific. Lower viscosity composite HDPE grade, A 6016 represents higher stiffness, higher strength and superior impact performance. Fiber length degradation is minimum for the A 6016 based composites in comparison with GM 9255 during mould filling and a wider fiber length of distribution is observed. The composites based on GM 9255 shows a larger transversely orientated core. To conclude, this study shows that each material model represents different mechanical performances, different morphological and fiber characteristics.

Final stress is totally different from structural performance modeled without taking fiber orientation into account. Fiber orientation depends on the importance of molding process, gate location and charges. To optimize the process, mold filling analysis is important to avoid mold defects like (knit lines) and assure the correct flow of mold.[26]

Fiber orientation though thickness and along the flow path fields and distribution of the fiber lengths define the composites processed by injection molding process. Second order tensor is used to identify the state of orientation of short fiber reinforced injection molded composites. The second-order tensor is calculated from the average orientation data obtained from each fiber on the sample (of N individual fibers) using following equation:

$$a_{ij} = \frac{\sum_{n=1}^{N} p_i p_j F_n}{\sum_{n=1}^{N} F_n}$$

N.M.Neves, A.J.Pontes and A.S.Pouzada[27] examined the effect of fiber contents on the fiber orientation and final properties of injection molded short glass fiber reinforced polypropylene edge gated rectangular plates. Polypropylene homopolymer was used for injection molding and a cell consisting of injection molding machine and mold temperature control unit with clamp force of 600 kN is incorporated to conduct the injection molding program. Image analysis tools in photographs obtained by reflection microscopy of polished cross sections were used for measuring the fiber orientation. The investigation shows that a symmetric distribution of fiber orientation about mid plane is found and the fiber orientation is planar. The shear and other stresses are developed during injection molding. Greater value of fiber orientation is obtained for higher fiber contents.

Visco-elasticity and the coupling of fiber orientation to rheology rarely influence the fiber orientation state. As there is transient heat transfer and filling, it is required to model the flow past the feature after it has been filled. VerWeyst, Brent E., et al. [28] used Galerkin finite element method to anticipate the fiber orientation and verified the prediction with experimental data. They incorporated a new material-polycarbonate resin (GE Plastics LexanÒ LS2) with thirty percent by weight glass fiber. For filling simulation, a standard Hele-Shaw model has been used. The equation of fiber orientation is hyperbolic. Boundary conditions are given for the inlet and no boundary condition is given for fiber orientation. In this investigation, C-MOLD-a commercial injection molding software is used to perform the mold filling analysis. To verify the prediction of final fiber orientation state, reflected light microscopy is used on the polished section of molded part. Appearance of fiber on polished section is elliptical. Experimental data proves this fiber orientation model accurate.

Fiber length has a great influence on the tensile stress of short fiber reinforced polymer. The tensile strength accelerated with the increase of the mean fiber length at small mean fiber lengths. And the composite strength increases with the decrease of critical fiber length; increase of interfacial adhesion strength and marginally with the decrease of the mode fiber length. [29]

Hele-Shaw equation is modified by the Dinh-Armstrong model and a new pressure equation is developed for the filling process. Chung, S. T. and Kwon, T. H. established a numerical simulation program to anticipate the short-term behavior of fiber orientations.[30] A mold filling simulation has been done for short-fiber-reinforced thermoplastics in arbitrary three-dimensional injection mold cavities. With the help of the solution of pressure equation, mold filling simulation is carried out. This study shows the fiber orientation tensor at every layer of each element across the thickness of molded parts and also the appropriate tensor transformations for arbitrary three-dimensional cavity space.

3. Issues and Motivation

3.1 Issues

Injection molding is economical only for large production quantities. Thus, the product of produced using injection molding have are troubleshooting. Most of the defects of the product come from improper parameter setting in plastic injection molding. Besides that, in this project also have to optimize the parameter of the injection and determine the accurate value of the parameter. Before this, the parameter is manually setting and don't have the accurate value. Material property (fiber length and fiber orientation) affects the structural properties of injection molded compounds which results in over engineering of components, lead to increased costs and material usage, or under-engineering, also in premature failure of parts. The elastic modulus can change significantly for a little change on part weight. The orientation direction and the degree of orientation of the fibers have a strong influence on the mechanical properties of the molded part. The extensive usage of fiber-filled thermoplastic materials has been not expanded in many cases due to the inability to accurately predict performance and durability as the behavior of the polymer composites depends primarily on the fiber length and the fiber orientation distribution. It is a complex task to predict fiber orientation and there are not so enough models to predict.

The fiber orientation pattern exhibits a layered pattern during injection molding process.[27] This orientation depends on the different parameters like speed, processing conditions, material viscosity, fiber aspect ratio and the volume fraction. There are different methods to predict the influence of the reinforcement (fiber) and matrix on the behavior of the composite material as a whole. Geometric arrangement of reinforcement phase in the matrix is considered by some methods. Other methods do not consider the reinforcing arrangement. [28]

The other side, the problem is to minimize of the defect of the injection molding. Due to the higher quality requirement and reduction of the cycle time, CAE tools have been used increasingly. Though structural property of plastic parts depend on molding parameters, conventional application of CAE tools considers only one or several isotropic material, no molding parameters are considered. This is why the characterization of the flow or the calculation of fiber orientation in composite materials induced by injection molding process parameter is major concern. CAE tools can be used to perform the sensitivity analysis of different molding and process conditions on the moldability and quality of the final part. Part design, gate or initial charge location and processing conditions can be altered with the help of different CAE tools like ANSYS and Moldflow. [29]

3.2 Motivation

Composites have widespread application because they can be processed with techniques used for unfilled polymers, provided the fiber length is below a certain limit. However, the application of fiber-filled thermoplastic materials has been limited in many cases by the inability to accurately predict performance and durability. Application of Carbon fiber-reinforced polymer composites (CFRPs) are micro-scale devices such as micro-robots including micromechanical flying insects, crawling robots as it gives the combination of high stiffness with high aspect ratio geometries.

Designing and molding composite parts have potential challenges. When molding composite parts fibers will tend to orient in different directions. This orientation enhances mechanical properties in the fiber direction while diminishing in the transverse direction.

By predicting accurate fiber orientation and controlling, the designer can optimize the geometry and process to produce a lighter weight and lower cost product.Fiber orientations affect the elasto-thermo-mechanical properties of the parts. Prediction of fiber orientation is important as it is directly related to the warpage and structural integrity of molded parts. An accurate prediction of fiber orientation can be used as input in the structural analysis for parts. This is why fiber orientation prediction is major concern for the different industry especially in the automotive and aerospace industries.

Injection molding has so many process parameters which directly influences the orientation of fiber and structural properties of molded compounds. Die production and tooling in injection molding process is not inexpensive. Problems occurred in production in injection molding, may not be solved by varying process conditions as with other processes. To change the process parameter and optimize the process is not economical. It is also time consuming to run the production process to optimize the injection molding. To find the best design and also the process parameter, application of CAE tools in Injection Molding Simulation is inevitable.

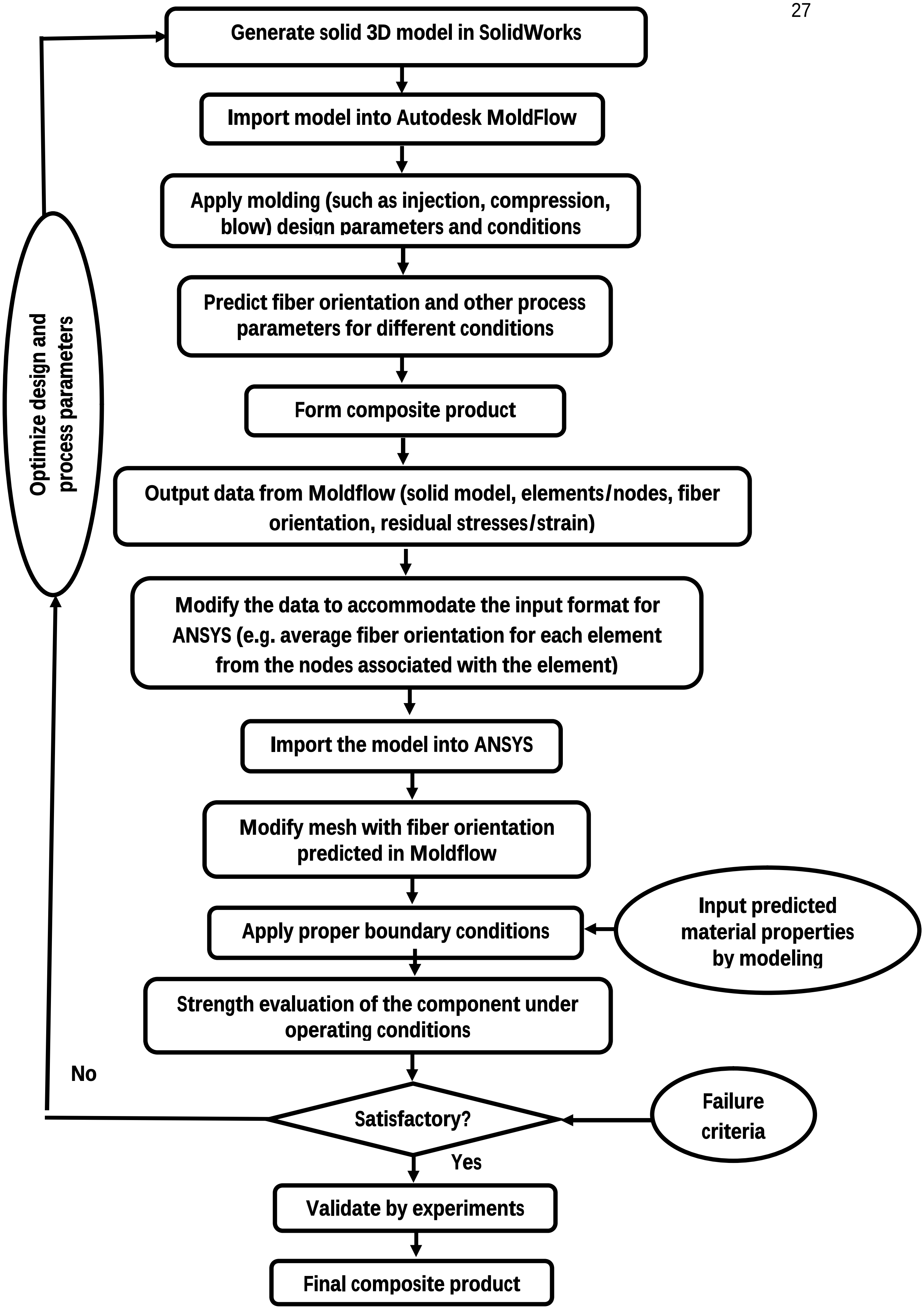
3.3 Objectives

This project is to investigate the fiber orientation and influence of fiber orientation in structural performance under different conditions. They are described as:

1. To check the fiber orientation for different matrix.
2. To check the fiber orientation for different gate location.
3. To investigate the structural performance due to fiber orientation.

3.4 Methodology

To continue overall thesis, the following flowchart has been followed:


Generate solid 3D model in SolidWorks
Import model into Autodesk MoldFlow
Apply molding (such as injection, compression, blow) design parameters and conditions
Predict fiber orientation and other process parameters for different conditions
Form composite product
Output data from Moldflow (solid model, elements/nodes, fiber orientation, residual stresses/strain)
Modify the data to accommodate the input format for ANSYS (e.g. average fiber orientation for each element from the nodes associated with the element)
Import the model into ANSYS
Modify mesh with fiber orientation predicted in Moldflow
Apply proper boundary conditions
Input predicted material properties by modeling
Strength evaluation of the component under operating conditions
Satisfactory?
Failure criteria
No
Yes
Optimize design and process parameters
Validate by experiments
Final composite product

4. Modeling Approach

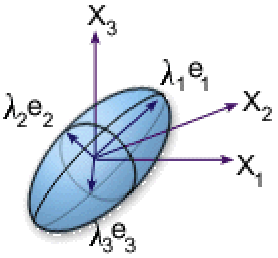
4.1 Definition and prediction of fiber orientation

- Three dimensional fiber orientations is calculated with the mold filling analysis on the same finite element mesh.

-Each triangular element contains several layers in the local molding thickness.

-Individual grid point has been used to identify the layers through which it passes. The three-dimensional orientation solution for each element is described by a second order tensor.

$$a_{ij} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \longrightarrow \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix}; [e_1\ e_2\ e_3]$$



- a_{11} fiber orientation in the flow direction, varying from 0 to 1.0.
- a_{22}, fiber orientation transverse to flow, varying from 0 to 1.0.
- a_{13}, tilt of orientation in the 1-3 plane, varying from -0.5 to 0.5.

4.2 A fiber orientation model

Fibers suspend in viscous medium-this is the main concept for fiber orientation model.

Suspension may be of three types:

- Dilute- the fibers are never close to one another and do not interact.

- Semi-concentrated- no mechanical contact between the fibers, but the hydrodynamic interactions become significant.
- Concentrated-the fiber orientation behavior becomes very complex, since both mechanical and hydrodynamic fiber interactions apply.

4.3 Moldflow's fiber orientation models

Governing Equations for 3D Meshes:

$$\begin{aligned}\frac{Da_{ij}}{Dt} = -\frac{1}{2}\left(\omega_{ik}a_{kj} - a_{ik}\omega_{kj}\right) + \frac{1}{2}\lambda\left(\dot{\gamma}_{ik}a_{kj} + a_{ik}\dot{\gamma}_{kj} - 2a_{ijkl\dot{\gamma}_{kl}}\right) \\ + 2C_l\dot{\gamma}\left(\delta_{ij} - 3a_{ij}\right)\end{aligned}$$

This equation is called the Folgar-Tucker orientation equation. Here,

- a_{ij} is the fiber orientation tensor.
- $\frac{1}{2}w_{ij}$ is the vorticity tensor, and $\frac{1}{2}\dot{\gamma}_{ij}$ is the deformation rate tensor.
- C_l is the fiber interaction coefficient, a scalar phenomenological parameter, the value of which is determined by fitting to experimental results.

Governing Equations for Midplane and Dual Domain meshes:

$$\begin{aligned}\frac{Da_{ij}}{Dt} = -\frac{1}{2}\left(\omega_{ik}a_{kj} - a_{ik}\omega_{kj}\right) + \frac{1}{2}\lambda\left(\dot{\gamma}_{ik}a_{kj} + a_{ik}\dot{\gamma}_{kj} - 2a_{ijkl\dot{\gamma}_{kl}}\right) \\ + 2C_l\dot{\gamma}\left[\delta_{ij} - (2 + D_z)a_{ij}\right]\end{aligned}$$

An extra term called a thickness moment of interaction coefficient (D_z) has been introduced into the model.

4.4 Reduced Strain Closure model

Objective-The main objective of this model is to find the the slow orientation dynamics.

Principle- This model is based on the concept of reducing the growth rates of the eigenvalues of the orientation tensor by a scalar factor, while leaving the rotation rates of the eigenvectors unchanged.

Governing Equation-

$$\begin{aligned}\frac{Da_{ij}}{Dt} = -\frac{1}{2}\left(\omega_{ik}a_{kj} - a_{ik}\omega_{kj}\right) \\ + \frac{1}{2}\lambda\left(\dot{\gamma}_{ik}a_{kj} + a_{ik}\dot{\gamma}_{kj} - 2\left[a_{ijkl\dot{\gamma}_{kl}} + (1-\kappa)\left(L_{ijkl} - M_{ijmn}a_{mnkl}\right)\right]\dot{\gamma_{kl}}\right) \\ + 2\kappa C_I\dot{\gamma}\left(\delta_{ij} - 3a_{ij}\right)\end{aligned}$$

Here,

$$L_{ijkl} = \sum_{p=1}^{3} \sigma_p e_i^p e_j^p e_k^p e_l^p$$

$$M_{ijkl} = \sum_{p=1}^{3} \sigma_p e_i^p e_j^p e_k^p e_l^p$$

σ_p = p^{th} eigenvalue of the orientation tensor

a_{ij}= the i^{th} component, and

e_i^p =the p^{th} eigenvector of the orientation tensor a_{ij}.

K= phenomenological parameter

$\kappa \leq 1$ to model the slow orientation dynamics.

κ = 1, the RSC model is reduced to the original Folgar-Tucker model.

4.5 Anisotropic Rotary Diffusion model for long-fiber composites

Objective-

- To calculate fiber orientation for long-fiber composite material. Long fibers are the fibers longer than 1mm.
- To find the fiber-fiber interactions in long-fiber materials and predict all fiber orientation components simultaneously.

Principle- Anisotropic rotary diffusion (ARD) replaces the isotropic diffusion.

Governing Equation-

$$\frac{Da_{ij}}{Dt} = -\frac{1}{2}\left(\omega_{ik}a_{kj} - a_{ik}\omega_{kj}\right) + \frac{1}{2}\lambda\left(\dot{\gamma}_{ik}a_{kj} + a_{ik}\dot{\gamma}_{kj} - 2a_{ijkl\dot{\gamma}_{kl}}\right)$$
$$+ \dot{\gamma}\left[2c_{ij} - 2c_{kk}a_{ij} - 5\left(c_{ik}a_{kj} + a_{ik}c_{kj}\right) + 10c_{kl}a_{ijkl}\right]$$

Assumption-

c_{ij} is assumed as a quadratic function of a_{ij} and $\dot{\gamma}_{ij}$ and is defined as:

$$c_{ij=}b_1\delta_{ij} + b_2a_{ij} + b_3a_{ik}a_{kj} + b_4\frac{\dot{\gamma}_{ij}}{\dot{\gamma}} + b_5\frac{\dot{\gamma}_{ik}\dot{\gamma}_{kj}}{\dot{\gamma}^2},$$

where each is a scalar constant, and its values are determined by matching experimental steady-state orientation and requiring stable orientation.

Fiber orientation tensor and Fiber orientation angle:

The orientation of a single fiber can be expressed in polar coordinates by the two angles (θ,Φ). For the second-order tensor, it has nine components but only six of these are independent because of the symmetry condition. The components of the second-order tensor for a group of *n* fibers are calculated as follows:

$$a_{ij} = \frac{1}{n}\left(\sum_{k=1}^{n} p_i^k p_j^k\right) = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \quad i, j = 1,2,3$$

Six independent components for an individual fiber as follows:

$$a_{11} = sin^2\theta cos^2\emptyset$$

$$a_{22} = cos^2\theta cos^2\emptyset$$

$$a_{33} = cos^2\theta$$

$$a_{12} = a_{21} = sin^2\theta cos^2\emptyset sin\emptyset$$

$$a_{13} = a_{31} = sin\theta cos\theta cos\emptyset$$

$$a_{23} = a_{32} = sin\theta cos\theta sin\emptyset$$

From the above equations, fiber orientation angles are computed.

Table 1: Fiber Orientation angle computation

NodID	Txx	Tyy	Tzz	Txy	Txz	Tyz	Φ	θ
1793	3.33E-01	3.33E-01	3.33E-01	2.92E-06	-1.08E-07	-3.70E-06	89.99981	9.00E+01
10809	3.49E-01	3.76E-01	2.76E-01	-1.86E-01	-1.25E-01	2.66E-02	114.266	8.50E+01
10811	2.83E-01	3.74E-01	3.42E-01	1.30E-01	5.60E-02	1.06E-02	80.70496	8.82E+01
10801	4.08E-01	1.57E-01	4.34E-01	3.35E-02	-5.56E-02	-9.22E-03	97.29857	9.12E+01
12196	3.96E-01	3.21E-01	2.83E-01	-8.29E-02	5.46E-02	5.93E-02	79.30646	7.84E+01
---------	-----------	-----------	------------	------------	--------------	------------	------------	--------------
upto 24285 nodes	---------	-----------	------------	------------	--------------	------------	------------	--------------

Step 2-Assign fiber orientation angles into their corresponding nodes:

Table 2: Codes for assigning angles into nodes

```
*GET,NDMAX,NODE,0,NUM,MAX

*DIM,NDANGLE,ARRAY,NDMAX,2

*SET,    NDNUM,          1793                 *SET,NDANGLE(NDNUM,1),      88.32785083
                   *SET,NDANGLE(NDNUM,2),      33.06311241
*SET,    NDNUM,          10809                *SET,NDANGLE(NDNUM,1),      -12.0133163
                   *SET,NDANGLE(NDNUM,2),      30.10066968
*SET,    NDNUM,          10811                *SET,NDANGLE(NDNUM,1),      10.71843724
                   *SET,NDANGLE(NDNUM,2),      33.50693243
--------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------
------upto 24285 nodes
```

Step 3- Compute the average orientation angle and assign the value to corresponding elements

Table 3: Codes for average fiber orientation angle and assign the value into nodes

```
                                        *DIM,EANGLE,ARRAY,ENMAX,2


*SET,    ENUM,    262                   *SET,    EANGLE (ENUM,1),    0.25*(    NDANGLE(    3542
         ,1)+     NDANGLE(              3533     ,1)+     NDANGLE(   3356      ,1)+    NDANGLE(
         6534     ,1)                   *SET,    EANGLE (ENUM,2),    0.25*(    NDANGLE(    3542
         ,2)+     NDANGLE(              3533     ,2)+     NDANGLE(   3356      ,2)+    NDANGLE(
         6534     ,2)       )
*SET,    ENUM,    492                   *SET,    EANGLE (ENUM,1),    0.25*(    NDANGLE(    4718
         ,1)+     NDANGLE(              5196     ,1)+     NDANGLE(   531       ,1)+    NDANGLE(
         5236     ,1)                   *SET,    EANGLE (ENUM,2),    0.25*(    NDANGLE(    4718
         ,2)+     NDANGLE(              5196     ,2)+     NDANGLE(   531       ,2)+    NDANGLE(
         5236     ,2)       )
-------------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------------------------------------
------------------
-----------------------------------------------------------------------------------------upto 138416 elements
```

Step 4- Apply the material property using emodify in ANSYS.

Table 4: Emodify codes for material property

```
*GET,ENMAX,ELEM,0,NUM,MAX
*DO,I,1,ENMAX,1
EMODIF,I,MAT,1
*ENDDO
```

Step 5- Modify the mesh for computed average orientation angle

Table 5: Codes for modified mesh

```
*DO,I,1,ENMAX,1
LOCAL,I+10,0,0,0,0,EANGLE(I,1),0,EANGLE(I,2)
EMODIF,I,ESYS,I+10
*ENDDO
```

5. Results

5.1 Case Study:

Spur gears are most common type of gears that their teeth are straight and mounted on parallel shafts. They are used in: metal cutting machines, power plants, washing machines, mechanical clock and watches, fuel pumps, washing machines, gear motor and gear pumps. Numerous applications of spur gears are observed in construction site. Construction equipment requires the need of spur gears. Specialized spur gears are used for special requirements. In every step of power generation, spur gears power transmission equipment have been used. Spur gears are used in different processes of power generation, coal power electric and so on.

Autodesk Simulation Moldflow Insight 2014 has been used to determine the fiber orientation tensor, fill and warp analysis for a helical gear.

Material:

Trade Name: Lubricomp QCL-4036

Manufacturer: SABIC Innovative Plastics US, LLC

Family abbreviation: PA610

Material structure: Crystalline

30% Carbon Fiber High Modulus Filled, 15% Teflon Filled

Elastic Modulus, 1st Principal Direction (E1) = 2.87858e+006 psi

Elastic Modulus, 2nd Principal Direction (E2) = 1.21678e+006 psi

Poisson Ratio, $\nu 12$= 0.487

Poisson Ratio, $\nu 23$= 0.5046

Shear modulus, G12= 593933 psi

Transversely isotropic coefficient of thermal expansion

α1= 4.166e-006

α2= 2.114e-005

Mold Temperature=46 C

Melt Temperature=240 C

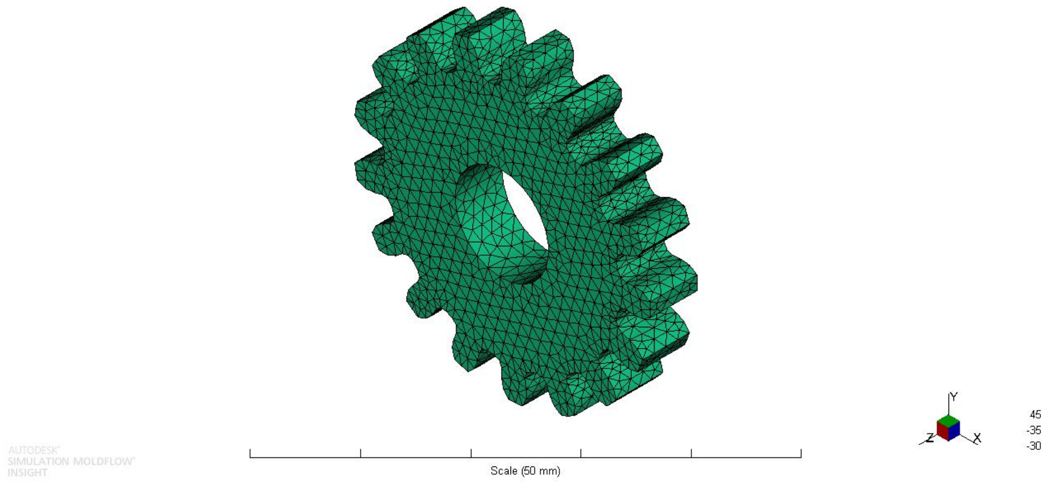


Figure 6: Mesh Generation

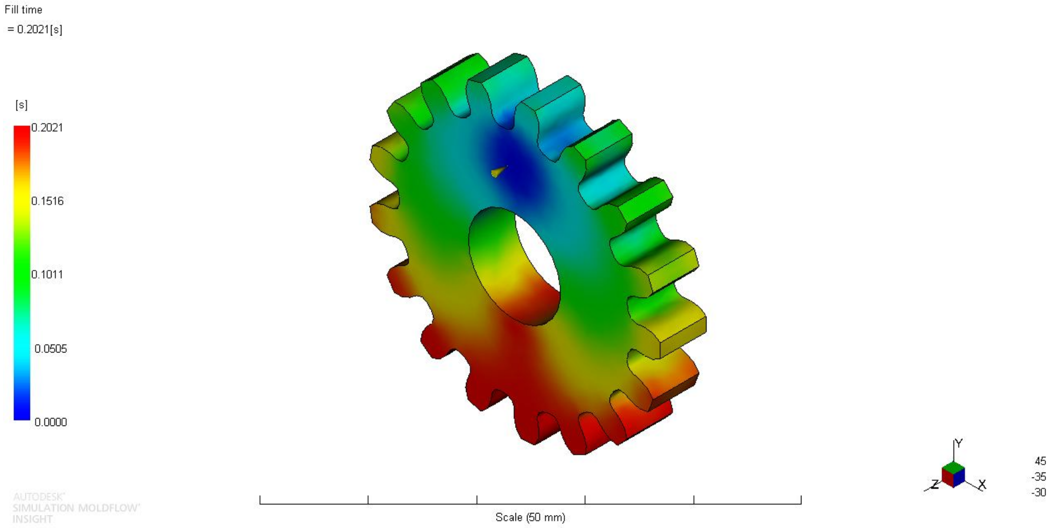


Figure 7: Fill time

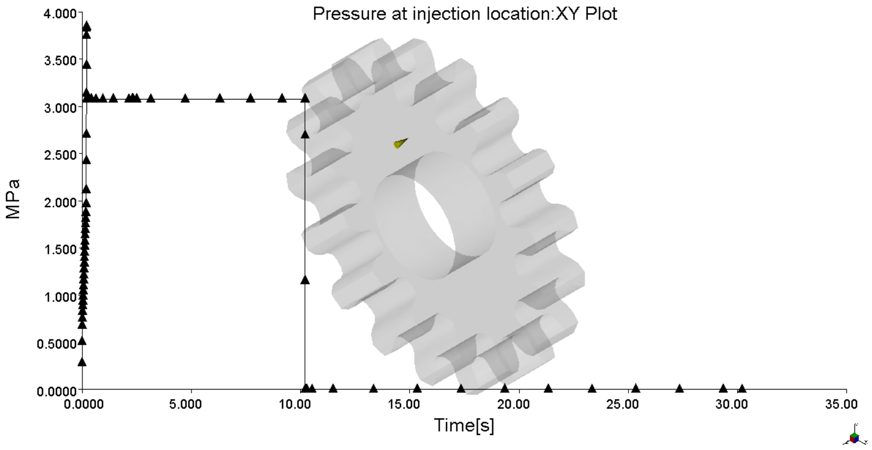


Figure 8: Pressure at injection location

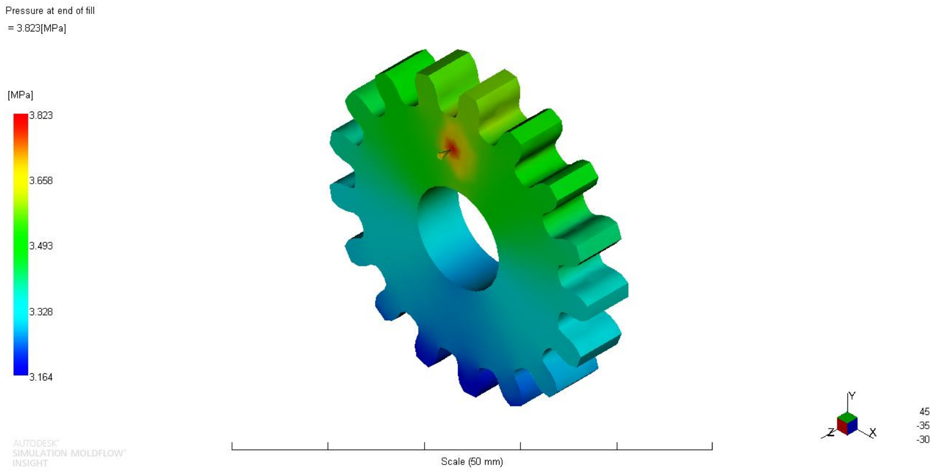


Figure 9: Pressure at end of fill

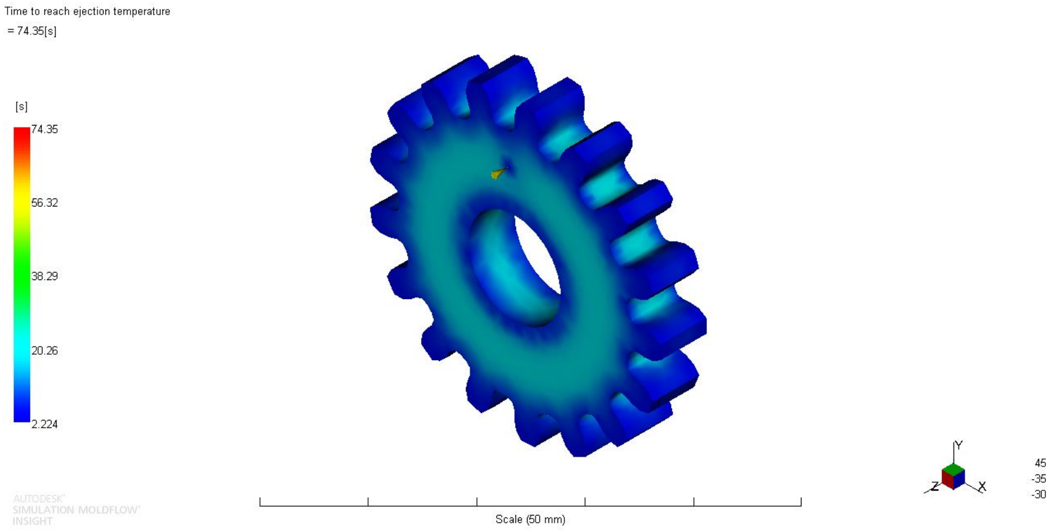


Figure 10: Time to reach ejection pressure

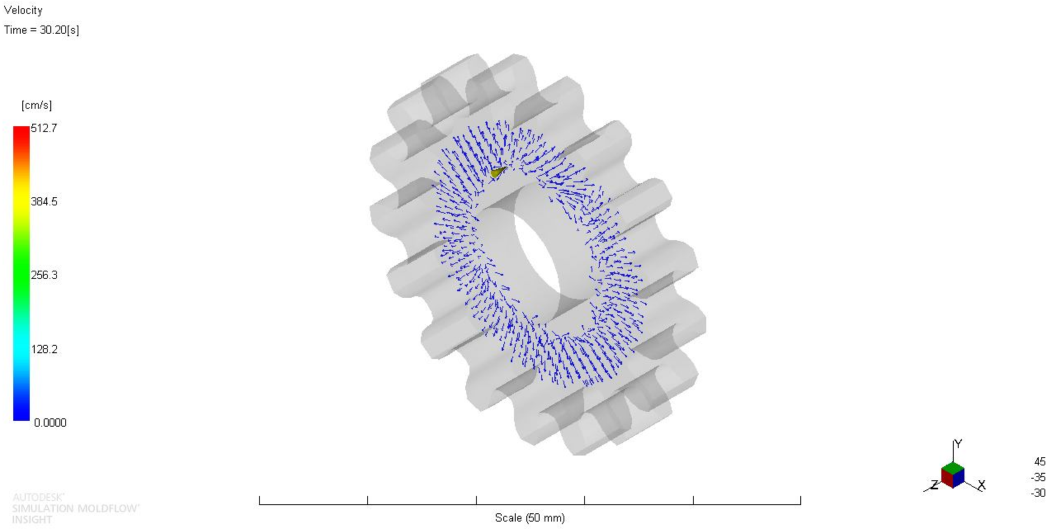


Figure 11: Velocity

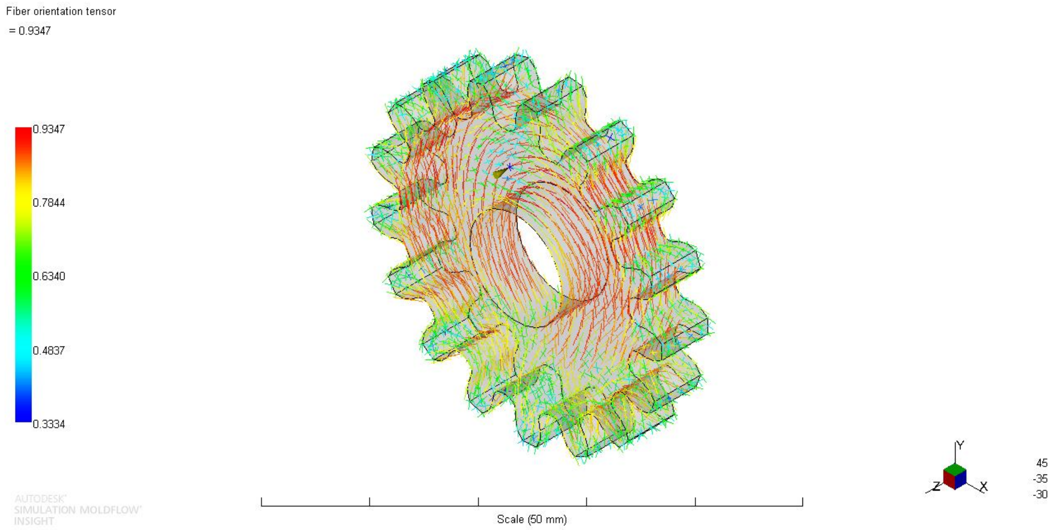


Figure 12: Fiber Orientation Tensor

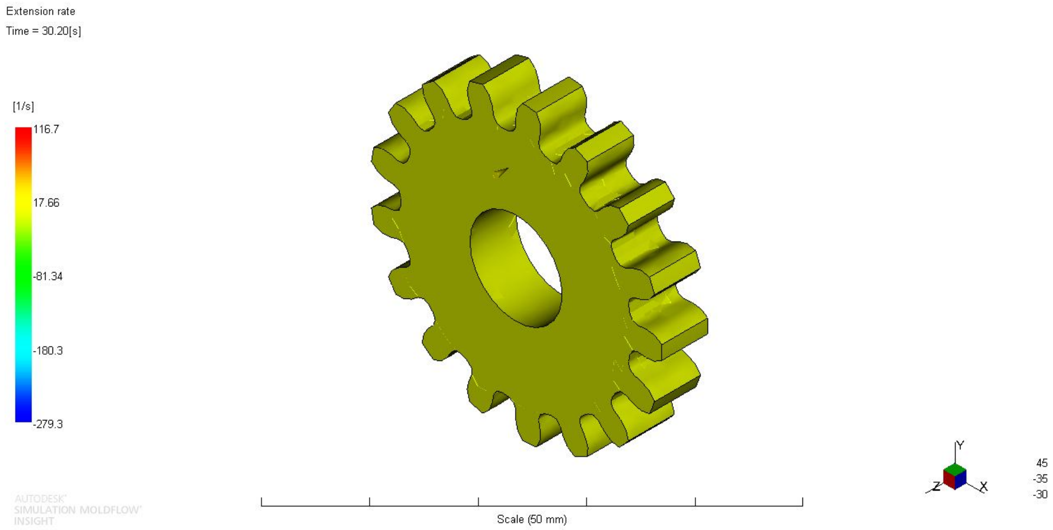


Figure 13: Extension rate

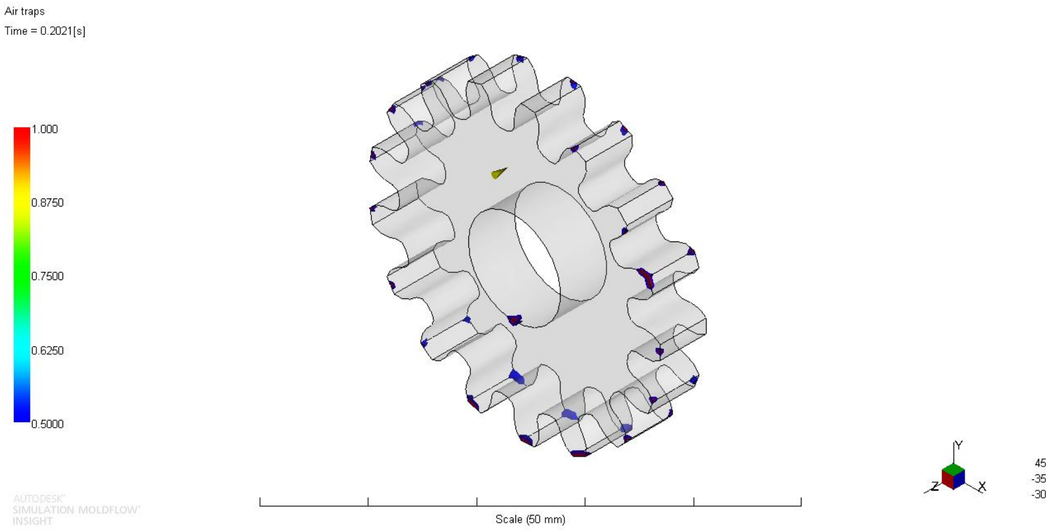


Figure 14: Air Traps

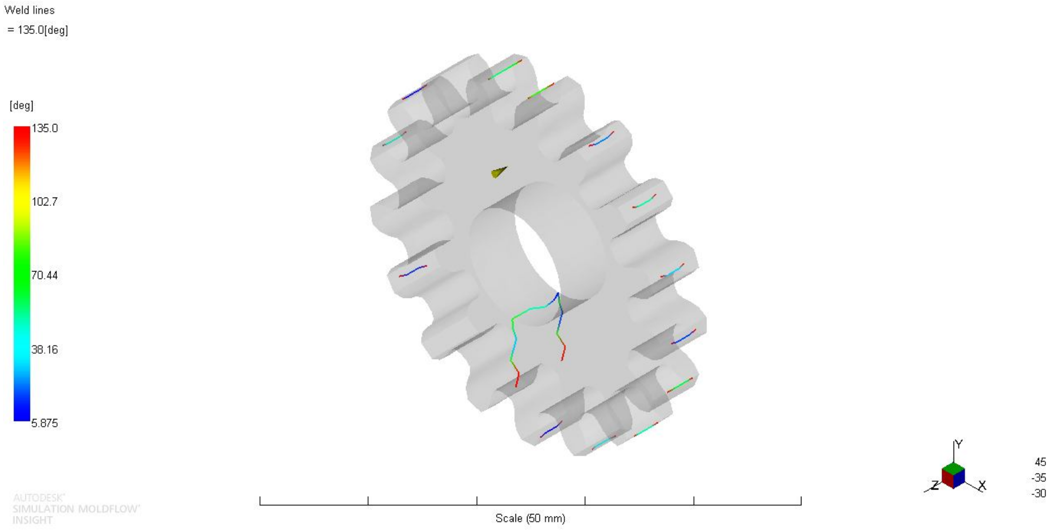


Figure 15: Weld lines

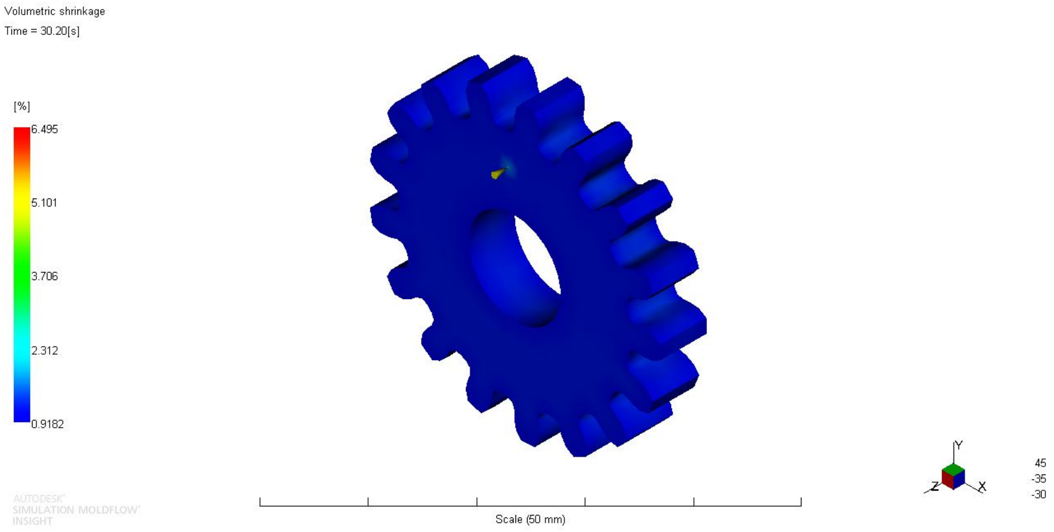


Figure 16: Volume shrinkage

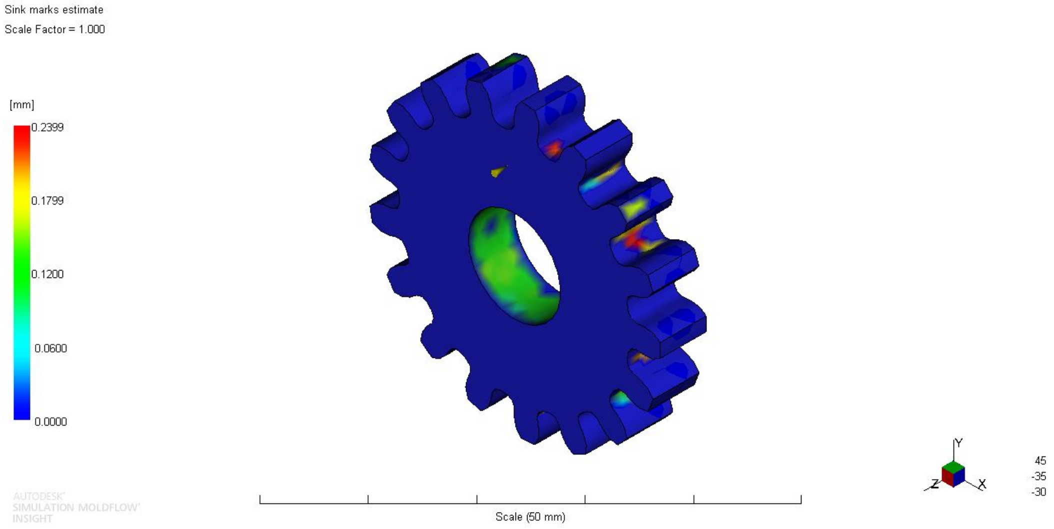


Figure 17: Sink Mark Estimated

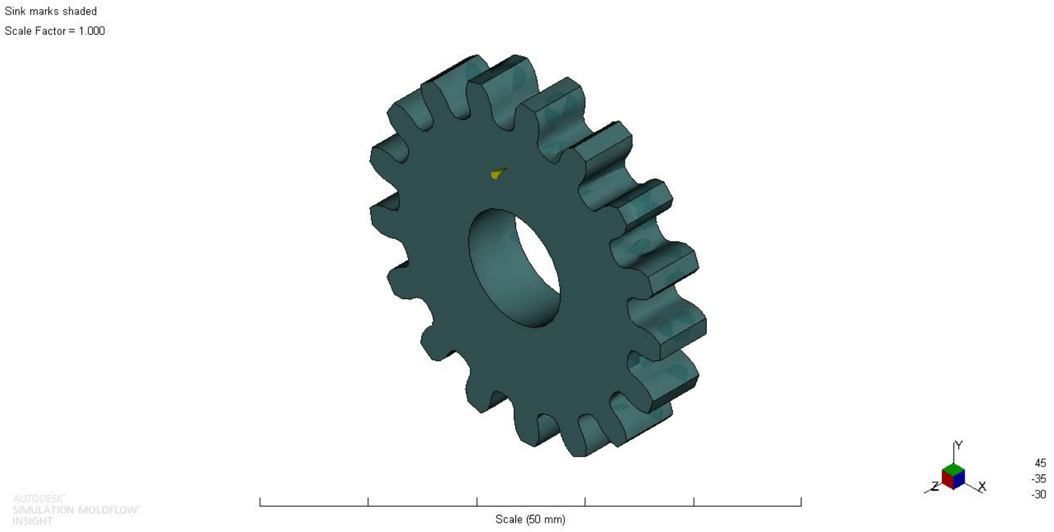


Figure 18: Sink Mark Shaded

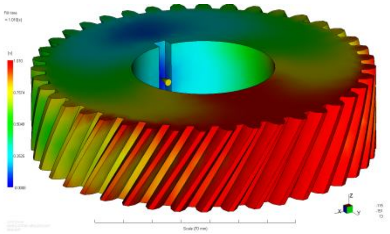
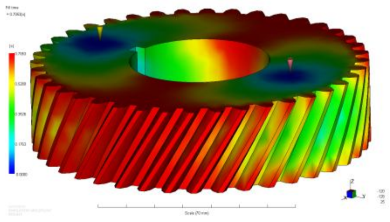
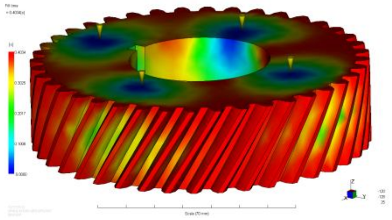
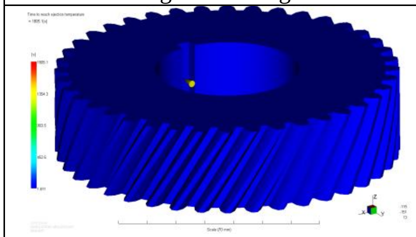
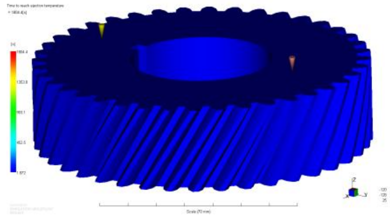
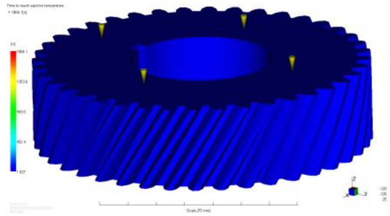
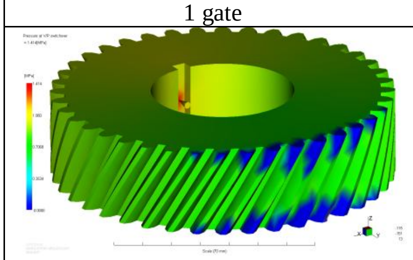
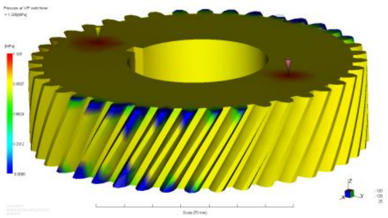
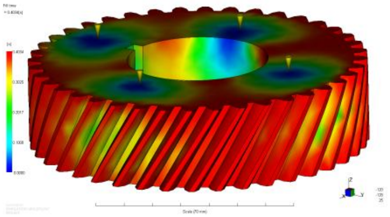
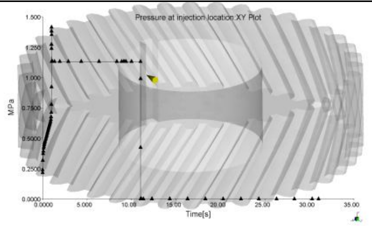
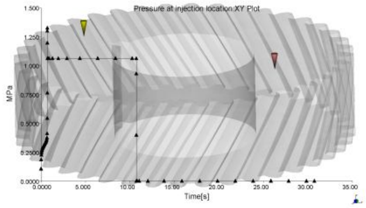
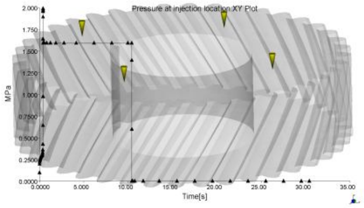
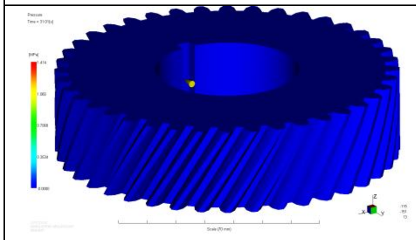
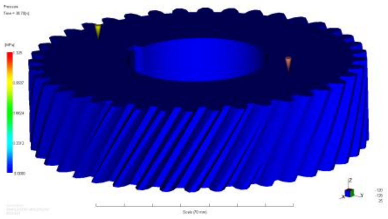
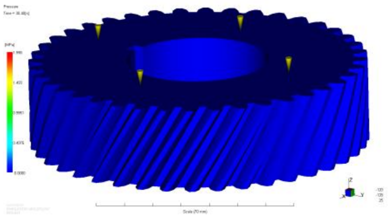
5.1.1 Effect of number of gates and change in structural property:

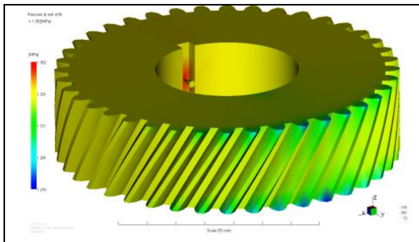
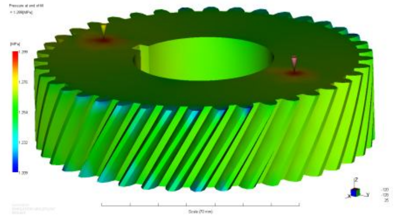
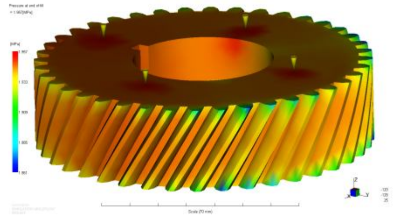
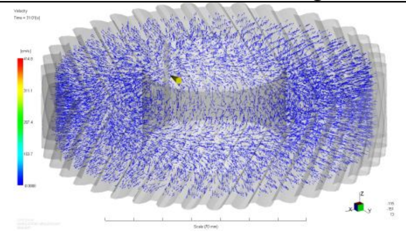
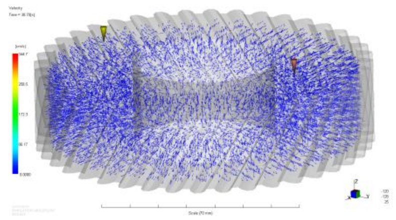
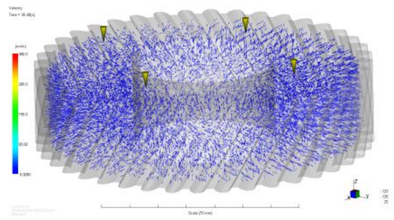
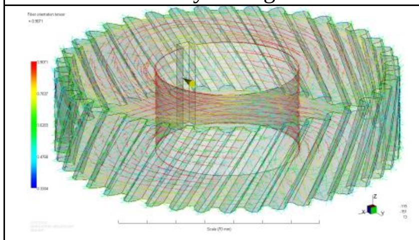
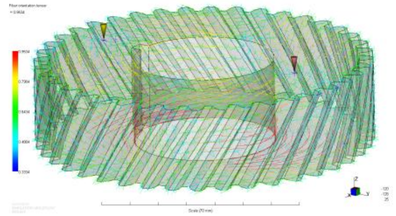
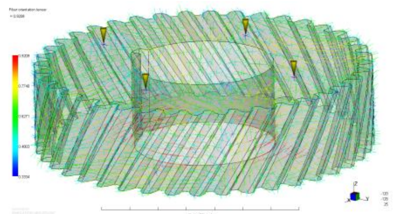
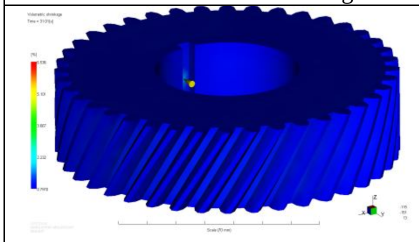
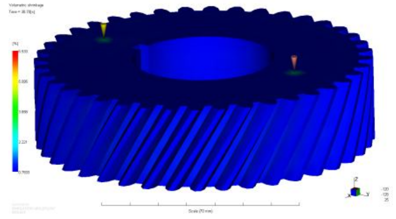
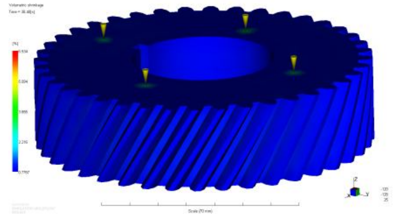
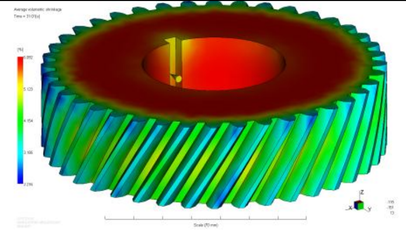
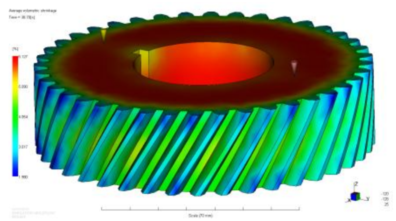
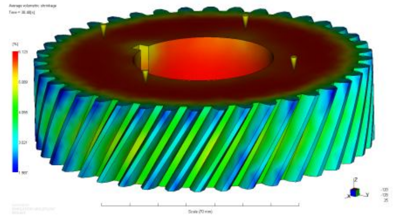
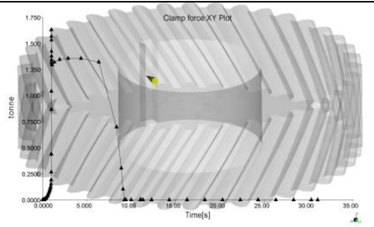
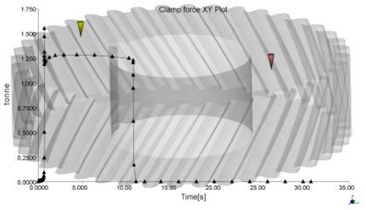
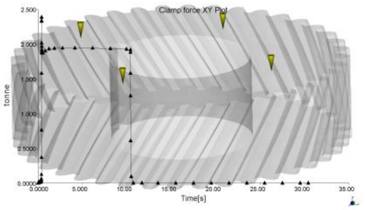
Condition 1: 1 gate in gear key

Condition 2: 2 gates in oposite direction

Condition 3: 4 Gates in oposite direction

Table 6: Different process results for changing position of gates and numbers

 Filling time for 1 gate	 Filling time for 2 gates	 Filling time for 4 gates
 Time to reach ejection temperature for 1 gate	 Time to reach ejection temperature for 2 gates	 Time to reach ejection temperature for 4 gates
 Pressure at v/p switchover for 1 gate	 Pressure at v/p switchover for 2 gates	 Pressure at v/p switchover for 4 gates
 Pressure at injection location for 1 gate	 Pressure at injection location for 2 gates	 Pressure at injection location for 4 gates
 Pressure for 1 gate	 Pressure for 1 gate	 Pressure for 4 gates

 Pressure at end of fill for 1 gate	 Pressure at end of fill for 2 gates	 Pressure at end of fill for4 gates
 Velocity for 1 gate	 Figure:Velocity for 2 gates	 Figure:Velocity for 4 gates
 Fiber Orientation Tensor for 1 gate	 Fiber Orientation Tensor for 2 gate	 Fiber Orientation Tensor for 4 gates
 volumetric shrinkage for 1 gate	 volumetric shrinkage for 2 gates	 volumetric shrinkage for 4 gates
 Average volumetric shrinkage for 1 gate	 Average volumetric shrinkage for 2 gates	 Average volumetric shrinkage for 4 gates
 Clamp force for 1 gate	 Clamp force for 2 gates	 Clamp force for 4 gates

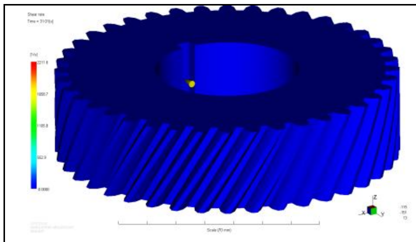
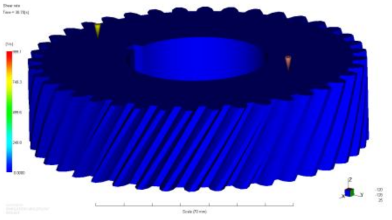
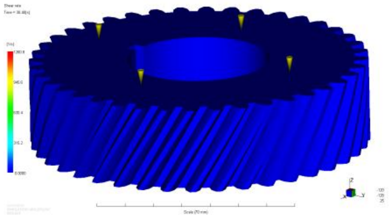
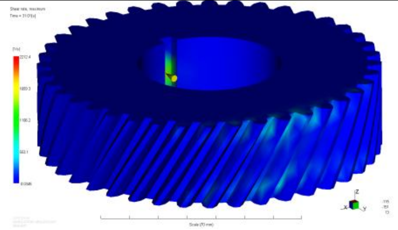
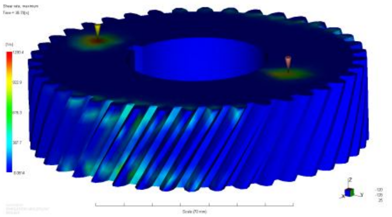
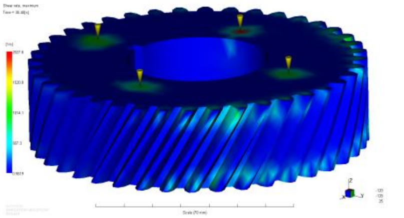
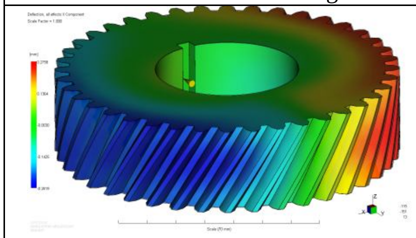
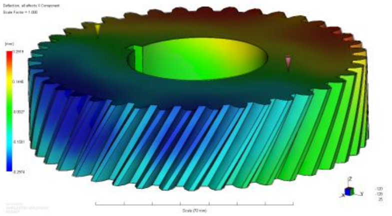
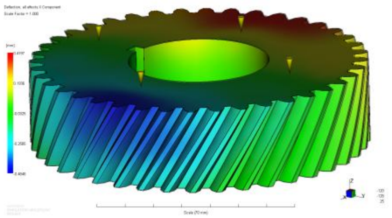
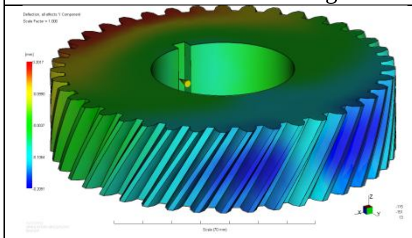
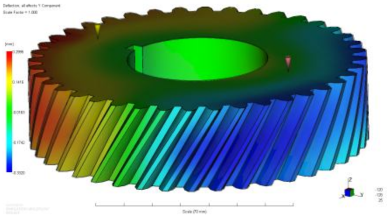
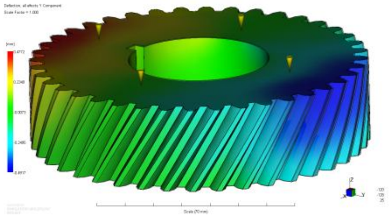
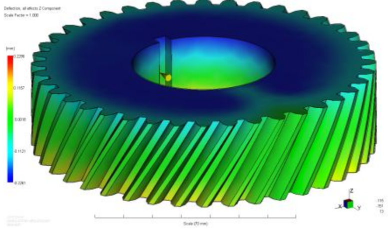
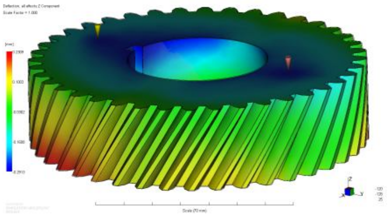
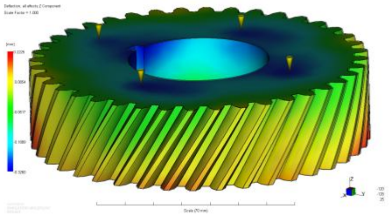
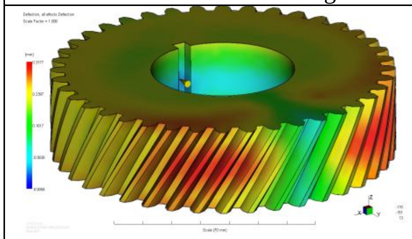
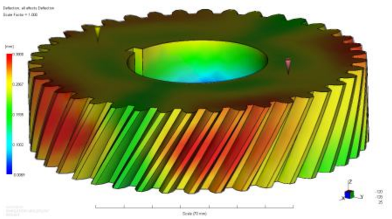
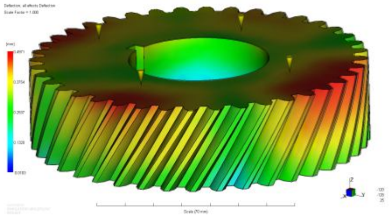
 Shear Rate for 1 gate	 Shear Rate for 2 gates	 Shear Rate for 4 gates
 Shear Rate maximum for 1 gate	 Shear Rate maximum for 2 gates	 Shear Rate maximum for 4 gates
 Deflection in x direction for 1 gate	 Deflection in x direction for 2 gates	 Deflection in x direction for 4 gates
 Deflection in y direction for 1 gate	 Deflection in y direction for 2 gates	 Deflection in y direction for 4 gates
 Deflection in z direction for 1 gate	 Deflection in z direction for 2 gates	 Deflection in z direction for 4 gates
 Deflection in all direction for 1 gate	 Deflection in all direction for 2 gates	 Deflection, all effects for 4 gates

Table 7: Optimization of gate location and numbers

	1 gate	2 gates	4 gates
Fiber orientation tensor	0.9071	0.9534	0.9209
Deflection in x direction	0.2758	0.2919	0.4197
Deflection in y direction	0.2017	0.2995	0.4772
Deflection in z direction	0.2296	0.2309	0.2225
Deflection, all effects	0.3177	0.38	0.4971

The best gate location result is generated by the gate location analysis. The main crieteria for this optimized location is suitability and flow resistance indicator. This result rates each place on the model for its suitability as an injection location. A best location rating does not necessarily mean that the part can be filled from this location. This must be checked by running a full analysis. In this the fill time, shear rate, quality prediction, warpage analyses, air taps and weld lines are needed to be done. The best option is the minimum of all the values. The next objective is to find the optimum injection location (with respect to minimum warpage, fill time,shear rate) by running the above analysis for different gate numbers. The data below is extracted from the modeling results of Autodesk Simulation Moldflow Insight 2014 and red lines indicate the most optimized location for each number of gates.

Table 8: Different gate locations and corresponding values

1 gate				
Gate Location	Fill time	Shear Rate(1/s)	Warpage(mm)	Fiber Orientation tensor
1	2.46s	708.2	0.3243	0.8909
2	2.148s	748.9	0.3213	0.8767
3	2.454s	1906.5	0.3284	0.9004
4	2.967s	1349.3	0.3184	0.9176
5	2.351s	1008.2	0.3232	0.9192
6	2.661s	1012.3	0.3287	0.9229
7	2.353s	574.4	0.3146	0.9286
8	2.353s	718	0.3101	0.9039

2 gates				
Gate Location	Fill time	Shear Rate(1/s)	Warpage (mm)	Fiber Orientation Tensor
1	1.327s	1235.9	0.3585	0.8733
2	1.43s	505.1	0.3092	0.9364
3	1.429s	687.5	0.3505	0.9306

3 gates				
Gate Location	Fill time	Shear Rate(1/s)	Warpage (mm)	Fiber Orientation Tensor
1	1.122s	585.9	0.4097	0.9232
2	1.225s	783.7	0.4224	0.8851

4 gates				
Gate Location	Fill time	Shear Rate(1/s)	Warpage (mm)	Fiber Orientation Tensor
1	0.9176s	596.2	0.487	0.8976
2	1.021s	768.2	0.4903	0.8918

The Quality prediction result is usually applied to predict the quality of the mechanical properties and appearance of the part. This result is generated from the pressure, temperature, and other results. There are three types of quality prediction messages in Autodesk Simulation Moldflow Adviser 2015-high, medium and low.

Low Quality predictions are occurred due to:

- Pressure drop exceeded maximum injection pressure limit
- Temperature dropped below minimum limit
- Temperature exceeds the maximum limit
- Cooling time is very high, there will be packing problems
- Shear rate greatly exceeds the recommended limit
- Shear stress greatly exceeds the recommended limit

Medium Quality predictions are occurred due to:

- Needs a high injection pressure to fill
- Temperature is low
- Temperature rise (caution zone)
- Cooling time is too high, there might be packing problems
- Shear rate exceeds the recommended limit
- Shear stress exceeds the recommended limit

A simulation has been carried out to compare the quality of finished product of optimized and non-optimized injection location. The results are given below:

Table 9: Different number of gates and quality prediction

Number of gates=1		
Condition	Fill time	Quality Prediction
Optimized	3.286s	H-61.3, M-38.1, L-.59
Non optimized	2.363s	H-62.7,M-37.1,L-.24
Number of gates=2		
Condition	Fill time	Quality Prediction
Optimized	1.537s	H-63.2,M-36.8,L-.01
Non optimized	1.538s	H-63.7,M-36.3, L-0.0

Number of gates=3		
Condition	Fill time	Quality Prediction
Optimized	1.227s	H-63.7,M-36.3,L-0.01
Non optimized	1.333s	H-63.9,M-36,L-0.12

Number of gates=4		
Condition	Fill time	Quality Prediction
Optimized	0.9214s	H-62.6,M-37.3,L-0.08
Non optimized	1.126s	H-63.8,M-36,L-0.2

From the above data, it reflects that optimized gate condition does not offer the higher mechanical quality. As the optimized gating condition in moldflow simulation are mainly based on gating suitability and flow resistance indicator. Quality results are derived from pressure and temperature data which implies that pressure and temperature have a great influence on the quality of the final product. Average fiber orientation angle and modified mesh:

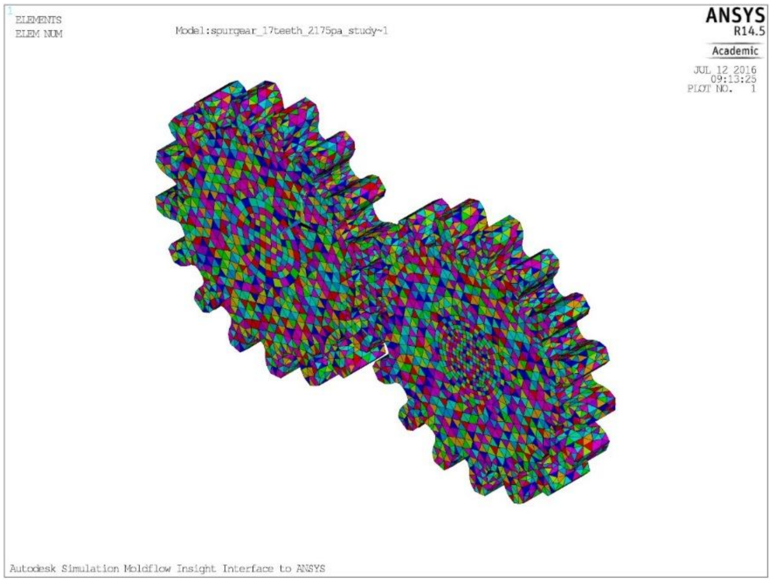


Figure 19: Modified Mesh

Applied Boundary Condition:

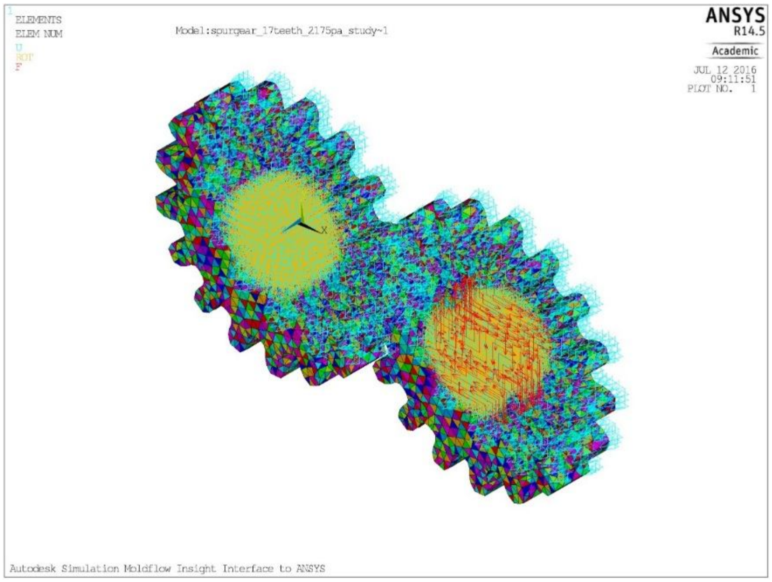


Figure 20: Applied Boundary Conditions

Stress Analysis:

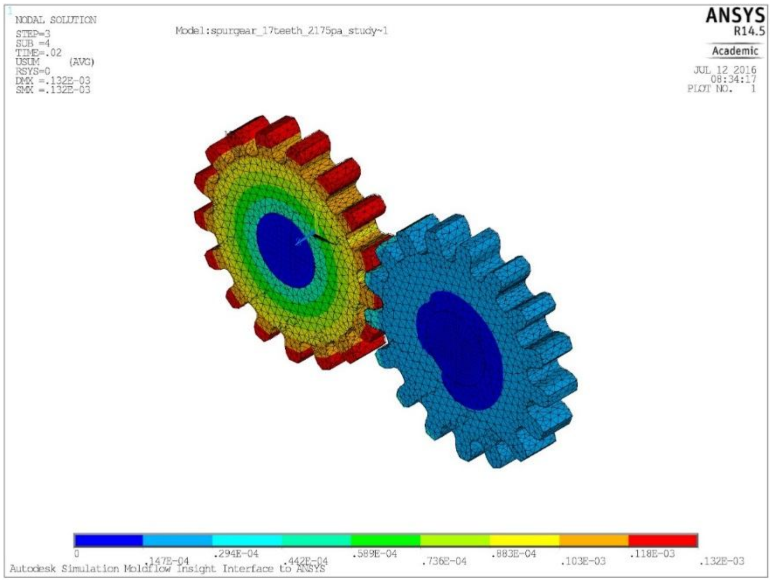


Figure 21: Displacement Vector Sum

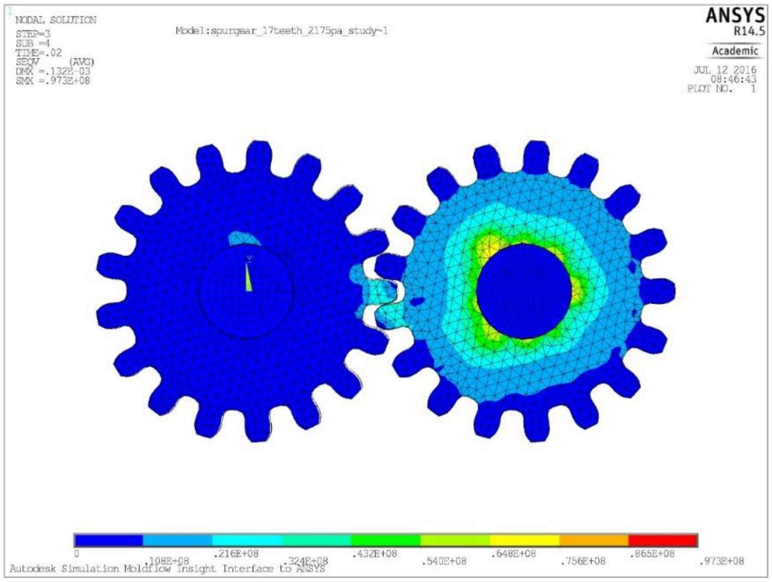


Figure 22: von Mises Stress (front view)

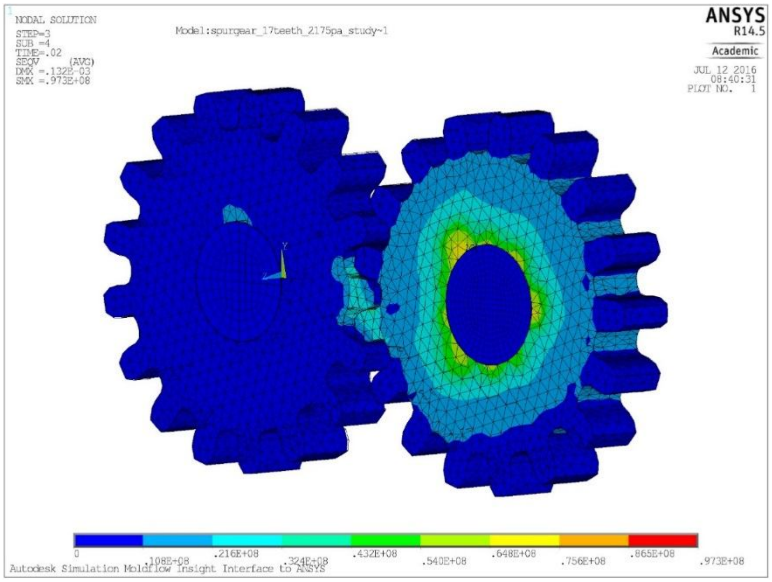


Figure 23: von Mises stress (isometric view)

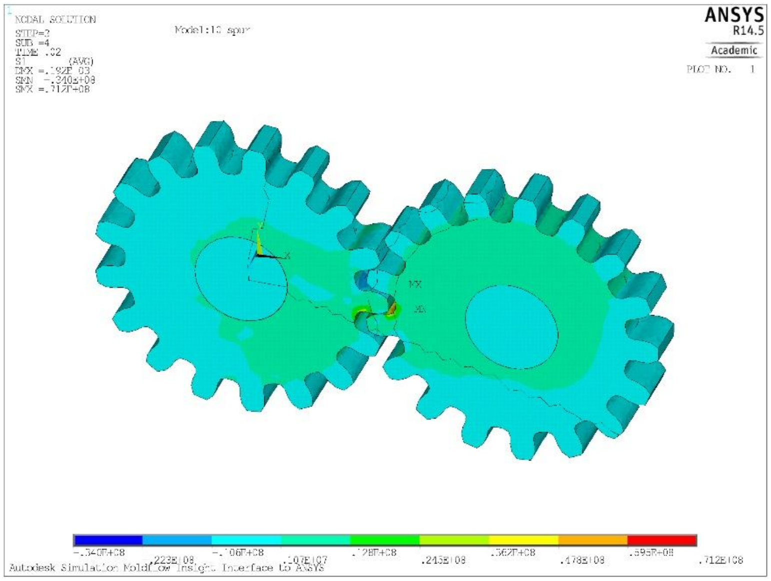


Figure 24: 1st Principal Stress

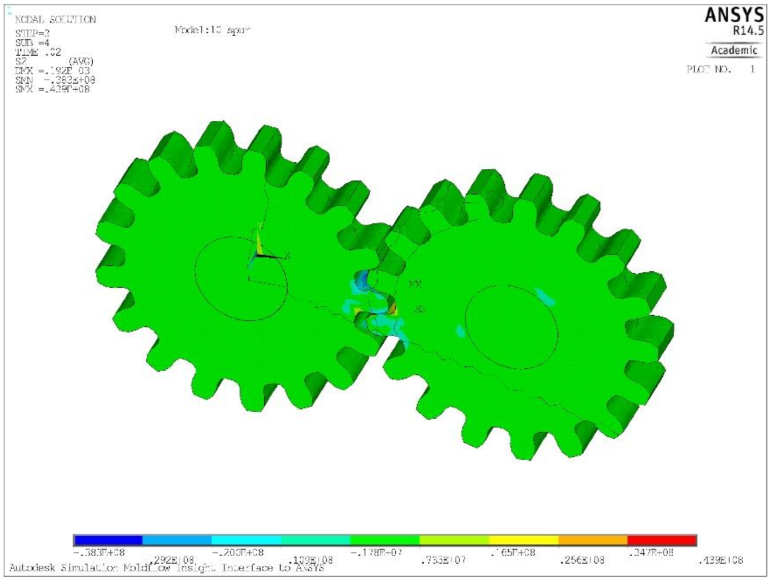


Figure 25: 2nd Principal Stress

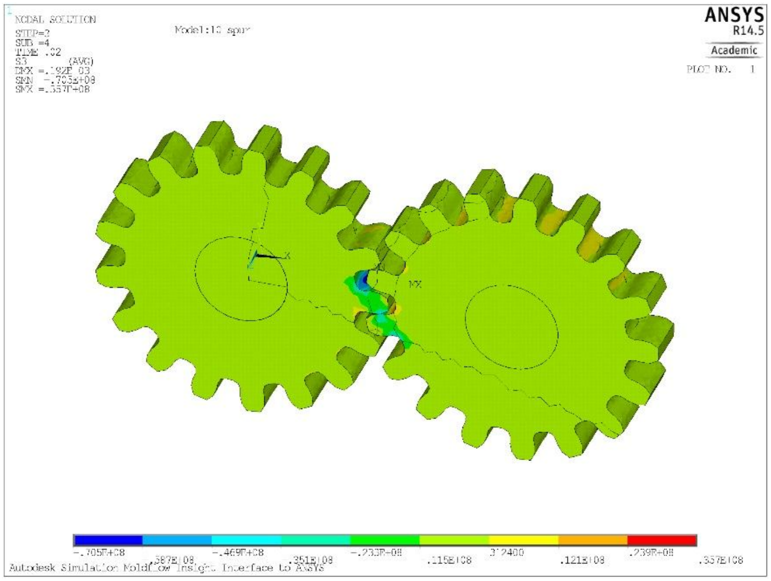


Figure 26:3rd Principal Stress

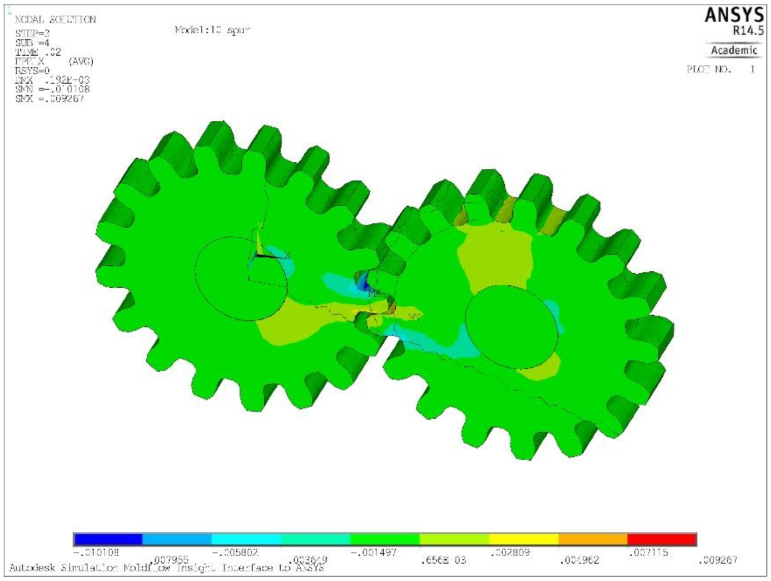


Figure 27: Strain in x direction

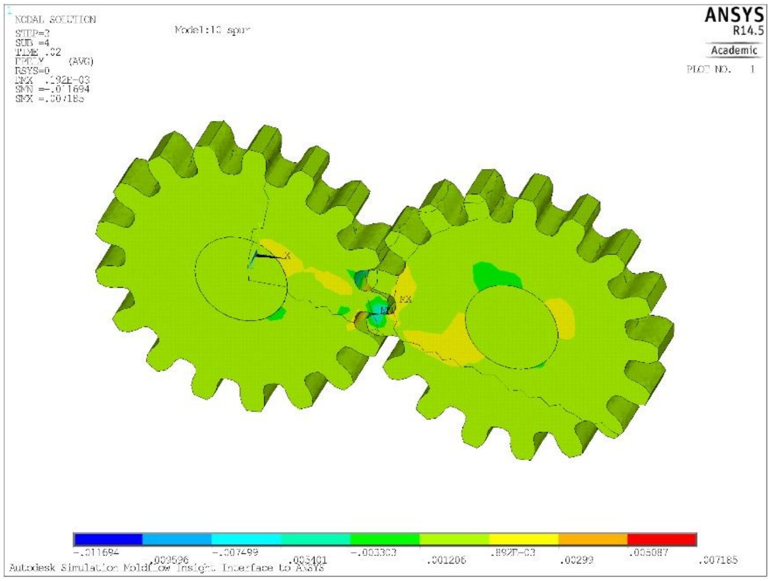


Figure 28: Strain in y direction

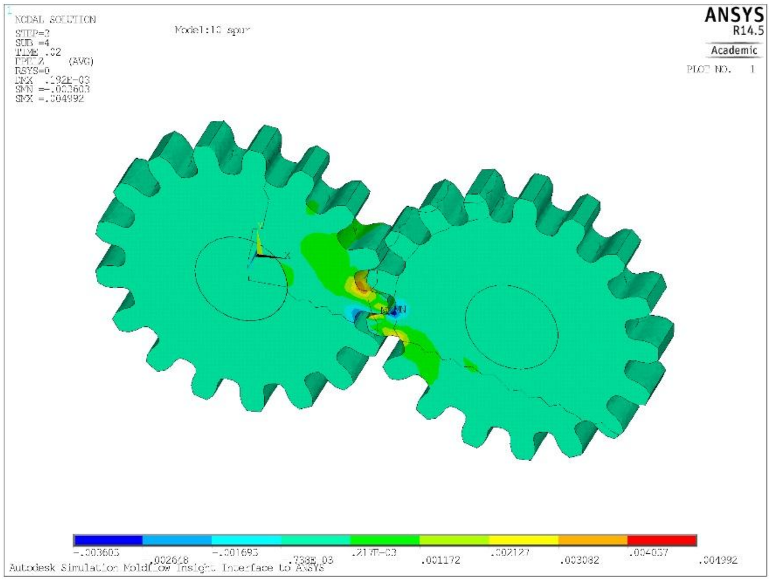


Figure 29: Strain in z direction

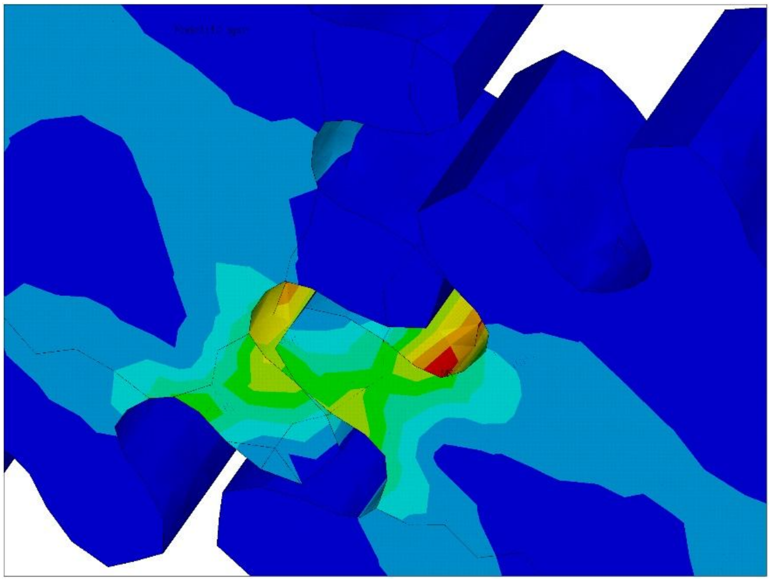


Figure 30: Stress in tooth region

Stress variation in tooth region with change of volume fraction of fiber:

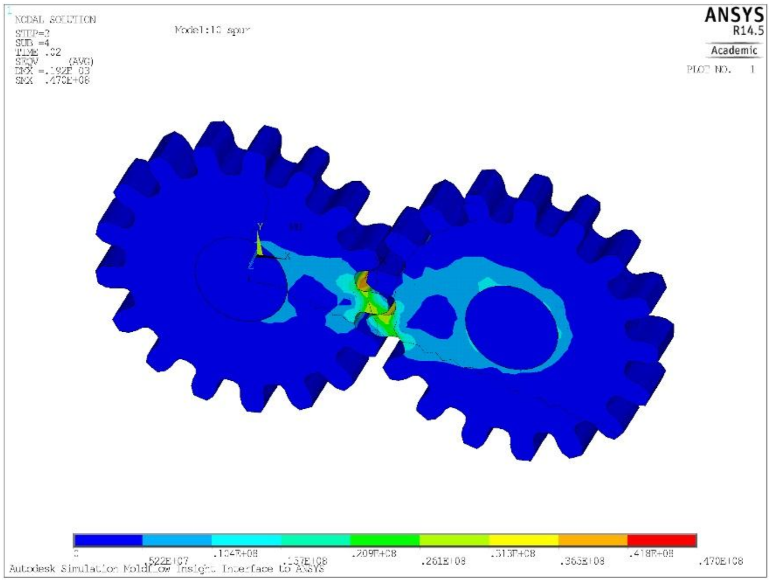


Figure 31: von Misses stress for 10% fiber

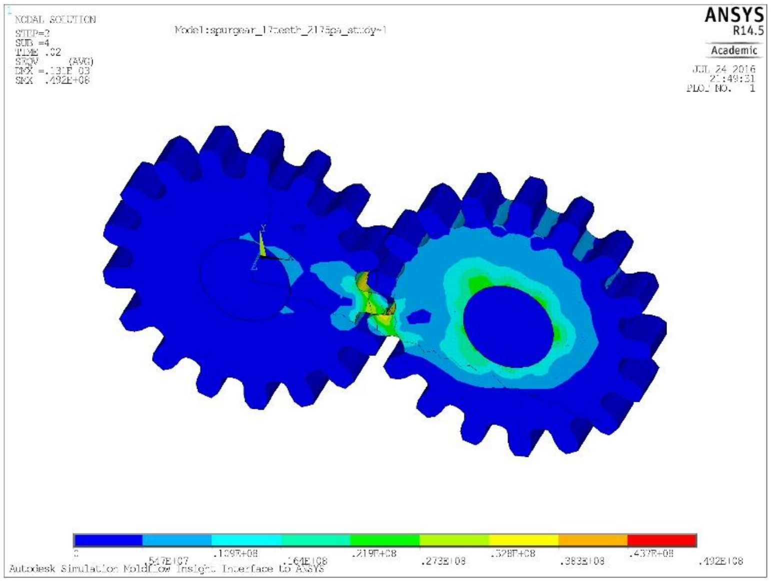


Figure 32: von Mises stress for 20% fiber

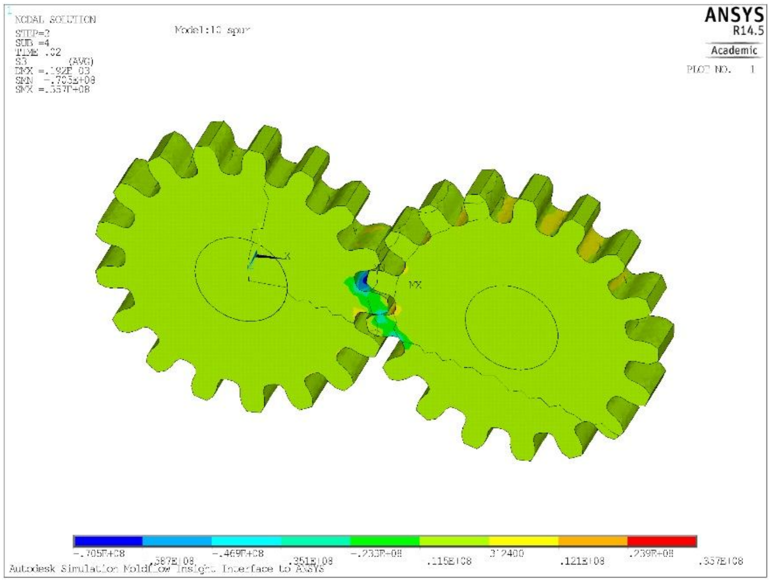


Figure 33: von Mises stress for 30% fiber

6. Conclusion

The aim of this work is to investigate the influence of the material configuration and fiber orientation over the structural analysis of the composite components. Using Autodesk Simulation Adviser, a simulation has been conducted to compare the quality of finished product of optimized and non-optimized injection location. Fiber orientation tensor from Autodesk Simulation Moldflow Insight has been used to compute the fiber orientation angle. Average fiber orientation has been computed and then imported into ANSYS. Structural properties are evaluated using ANSYS under ideal operating condition. Both Autodesk Simulation Moldflow and ANSYS software enables us to do the simulation and optimization. Cost of CAE analysis is high initially, but it compensates the vast cost which is incurred at later design stages.CAE is a very powerful tool to eliminate costs, improve quality and reduce cycle time. Fiber orientation should be considered as most important factor to evaluate structural performance of composite molded parts. The molding process, and the location of gates and charges have a great influence on the final strength of the part. Combination of Moldflow and ANSYS in analyses allows the optimization of the process and geometry to achieve a part with the optimal structural integrity, lower weight and lower cost. This indicates that the methodology exploit in this work can be extended for other cases also, which substitutes the need for extra time and cost of physical testing incurred at the optimum material and design configuration.

7. Future Works

- Failure criteria: Using different failure criteria, like Maximum stress failure criteria, maximum strain failure criteria, Tsai-Wu failure criteria can be used to finally analyze the structural performance of gear with different volume fraction of carbon fiber.
- Different Gear type (Helical gear or bevel gear): There are different types of gear like helical gear, rack and pinion gear, face gear, worm gear, hypoid gear, screw gear. This work can be extended by using different types of gear and to compute the stress as well as failure criteria.
- Cooling channels: Cooling channels is another important factor for molding process. By incorporating cooling channels into analysis, different characteristics of stress value can be achieved.
- In Autodesk Moldflow, there are a lot of potential material like PC with 35% carbon fiber and 10% Teflon filled, PA66 with 20% carbon fiber, PEEK with 30% carbon fiber. By using different, matrix fiber combination into the analysis, optimum fiber-matrix combination can be found by extracting final stress analysis result.
- Gear rotation angle can be changed to observer structural performance under different operating conditions.

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OBJECTIVE

Highly motivated to get a full time position in an organization adapting plastic injection molding as I am currently working on an active project linked with Injection Molding Process.

PROFESSIONAL SUMMARY

- Solid background in Injection Molding Process.
- Experienced in working with Injection Molding Simulation Software.
- Project work experience in a renowned company.
- Proficient on FEA Model software ANSYS and fluid simulation software Star CCM+.
- Experienced on design software AutoCAD, SolidWorks and CATIA V5R20**.**

EDUCATION

MS in Mechanical Engineering	May’16
South Dakota State University (SDSU)	Brookings, SD
BS in Industrial and Production Engineering	August’09
Bangladesh University of Engineering and Technology (BUET)	Dhaka, Bangladesh

WORK EXPERIENCE

Graduate Research Assistant
Jan’13-Till Date
South Dakota State University
Brookings, SD

- Design injection molding process.
- Provide appropriate tooling.
- Design plastic parts.
- Predict fiber orientation for further stress analysis for fiber reinforced composites.
- Digital Prototyping solution to avoid manufacturing defects.

Project Engineer April’12-July’13
Pipeliners Limited
Dhaka, Bangladesh

- Coordinate the planning issue.
- Preparation of work breakdown structures.
- Update computer network schedule.
- Support the schedule control requirements.