Parametric Modelling and Analysis of Reciprocating Screw of Injection Moulding Machine

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Parametric Modelling and Analysis of Reciprocating Screw of Injection Moulding Machine

Major Project Report

Submitted in partial fulfilment of the requirements

For the Degree of

Master of Technology in Mechanical Engineering

(CAD/CAM)

By

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This is to certify that

1. The thesis compromises my original work towards the degree of Master of Technology in Mechanical Engineering (CAD/CAM) at Nirma University and has not been submitted elsewhere for a Degree.

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Abstract

Injection moulding is one of the most widely used methods of conversion of plastic into various products applicable to various plastic materials from plastic raw material to engineering plastic.

Injection moulding machine is the most widely used for the fabrication of plastic parts. The reciprocating screw is a critical component of injection moulding machine. The plastic being melted in injection moulding machine and then injected into the mould. The barrel contains reciprocating screw for injecting the material into the mould and the material is also melted into the barrel. Material is melt by the ceramic heaters into the barrel. This project deals with, the solution of problem occurred in reciprocating screw of Injection moulding machine while reciprocating screw varies model to model. It identifies and solves the problem by the parametric modelling.

The aim of the project is to carry out parametric modelling of reciprocating screw whenever screw diameter varies in different models for easy modification of dimensions.

For 69.8 mm diameter, static structural analysis is carried out. For static structural analysis of 69.8mm diameter, the directional deformation and factor of safety of reciprocating screw checked for design life.

For 69.8 mm diameter, transient thermal analysis is carried out. For static structural analysis of 69.8mm diameter, temperature, total heat flux and directional heat flux of reciprocating screw checked to reduce wearing of threads.

Keywords: - Injection Moulding Machine, Reciprocating Screw, Parametric Modelling, Static Structural Analysis, Transient Thermal Analysis.

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Nomenclature

D Core diameter of reciprocating screw, mm

σ Shear stress, N/m^2

F Force, N

A Area, m^2

ε Strain

E Young modulus, Pa

Chapter 1

Introduction

1.1 Introduction of Injection Moulding Machine

Plastics are the most adaptable of all known material and have built up themselves in good position. The aggregate utilization of item plastic is more than 750,000 MT and is evaluated to cross 2500,000 MT i.e. ascend more than 4 times before this present decade's over. A standout amongst the most well-known techniques for changing over plastics from the crude material frame to an article of utilization is the procedure of injection moulding. This procedure is most regularly utilized for thermoplastic materials which might be progressively softened, reshaped and cooled. Injection moulded segments are an element of practically every useful fabricated article in the cutting edge world, from car items through to nourishment bundling. This adaptable procedure enables us to create top notch, straightforward or complex segments on a completely mechanized premise at rapid with materials that have changed the substance of assembling innovation in the course of the most recent 50 years.

The most commonly used thermoplastic materials are polystyrene (low cost, lacking the strength and longevity of other materials), ABS or acrylonitrile butadiene styrene (mixture of compounds used for everything from Lego parts to electronics housings), polyamide (chemically resistant, heat resistant, tough and flexible – used for combs), polypropylene (tough and flexible – used for containers), polyethylene, and polyvinyl chloride or PVC (more common in extrusions as used for pipes, window frames, or as the insulation on wiring where it is rendered flexible by the inclusion of a high proportion of plasticiser).

Most popular methods for converting plastics into useful products are as follows:

- Blow Moulding
- Compression Moulding
- Injection Moulding
- Extrusion

The plastic injection moulding process can be described into eight steps:

1. The part is designed and prototypes are created and tested.
2. A durable steel or aluminium mould (or tool) is designed and built. This process takes several weeks and includes a lot of complicated systems to control the process.
3. In production, raw material is loaded into a “feed hopper.”
4. The material is feed into a heated “barrel” where it becomes viscous—a state somewhere between solid and liquid.
5. The viscous material is forced by a plunger into a mould, which is held shut by hydraulics to withstand the pressure of the incoming material.
6. The material freeze quickly in the mould and it is ejected as a finished part after a predetermined time.
7. Quality assurance checks are performed on the part.
8. The mould is closed again in preparation for the next processing cycle.

Injection moulding machine has two basics parts:

1. Injection Unit
2. Clamping Unit

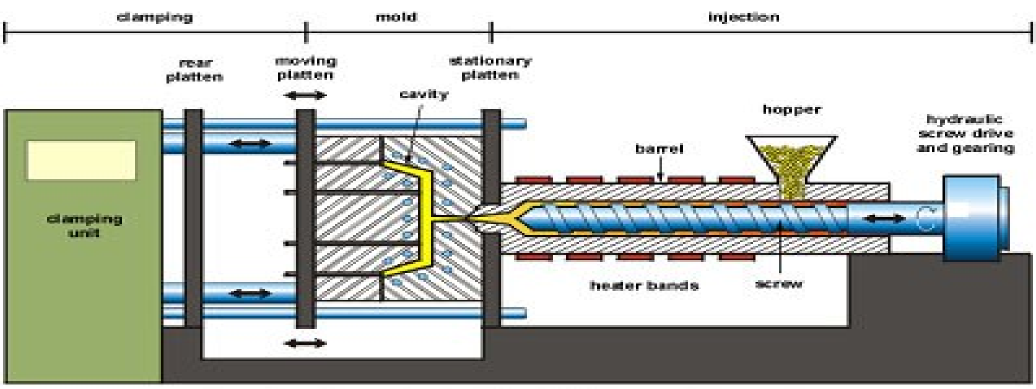

Figure 1.1: Line Diagram of Plastic Injection Moulding Machine [4]

1.2 Types of Injection Moulding Machine

Injection moulding machine can be divided into two basic types [1]:

1. Plunger machine
2. Reciprocating screw machine

1.2.1 Plunger Machine

As per the name of machine, it has a plunger to power the molten plastic into mould. A screw is used as the main part of pre plasticizing system, which is used for improving the mixing and melting of the melt.

As time passed plunger machine is supplanted by the responding screw machine which is more effective than plunger machine. In this advanced period, the machine is having a control framework for measuring temperature, weight and infusion times for the best nature of items.

1.2.2 Reciprocating Screw Machine

The reciprocating screw machine has an extruded type screw which is used for two purposes:

- To plasticize the polymer
- To inject it in mould

The series of proceeding is as follows in figure 1.2:

1. The mould closes and the screw begins moving forward for injection.
2. The cavity fills as the reciprocating screw moves forward as a plunger.
3. The cavity is packed as the screw continuously moves forward.
4. The cavity cools as the gate freezes off and the screw begins to retract to plasticize material for the next shot.
5. The mould opens for part ejection.
6. The mould closes and the next cycle begins.

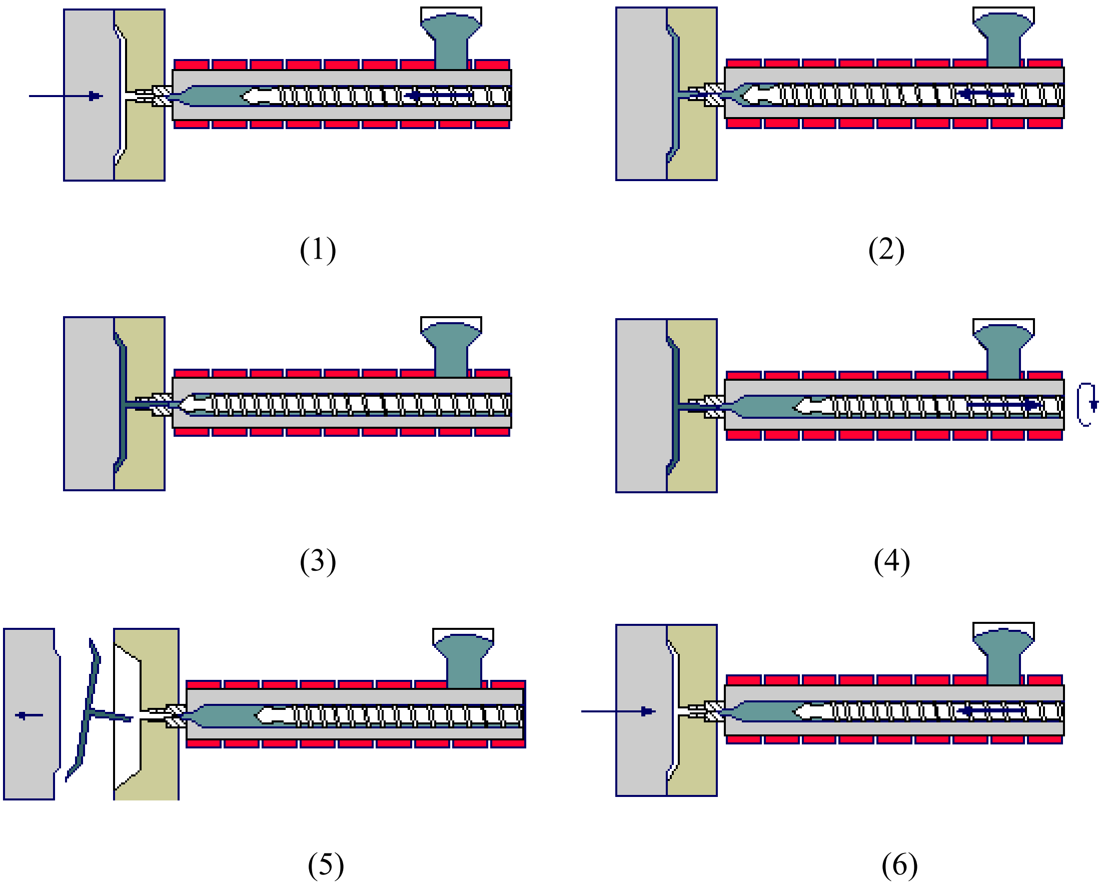

Figure 1.2: Cycle for Reciprocating Screw Injection Moulding Machine [4]

1.3 Components of Plastic Injection Moulding Machine

As Injection moulding machine has been divided into two basic parts i.e. Injection Unit and Clamping Unit, its components are briefly discussed below.

1.3.1 Injection Unit

The Injection Unit's principle objective is to heat the material to the predefined temperature until the point that it achieves a consistency that will enable the material to stream into the form while under power. Line diagram of injection unit is given in below figure 1.3

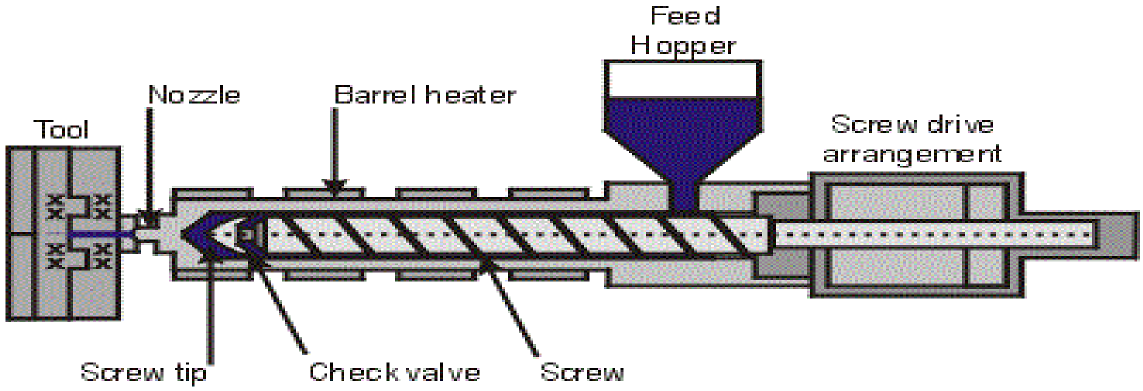

Figure 1.3: Line Diagram of Injection Unit [2]

The injection unit must take after a procedure keeping in mind the end goal to finish its undertaking of infusing the softened plastic. That procedure will require the accompanying main parts.

Hopper

The hopper holds the raw material that is used in the moulding process. This can be in the form of virgin granules, regrind, master batches or in some applications powder. The hopper located over the barrel and the feed throat connects them.

Barrel

Barrel is a noteworthy part that melts resins transmitted from hopper through screw and organized a way that can warm up resins to the best possible temperature. A ceramic band heater, which can control temperatures in five segments, is appended outside the barrel. Melted resins are provided to the mould going through barrel head, shot-off spout, and one-touch spout. Thermocouple fitted on the barrel detects the real temperature.

Reciprocating Screw

The reciprocating screw shown in figure 1.4 has mainly three functions that are compressing, melting, and conveying the plastic material.

The reciprocating screw has three main zones:

- Feeding Zone
- Compressing Zone
- Melting Zone

In feeding zone, there is no adjustment in size of plastic material. In melting zone or compressing zone or transition zone dissolving of plastics happens and it is additionally transmitted to metering zone. In the metering zone it is homogeneous and is prepared to use as material for next process.

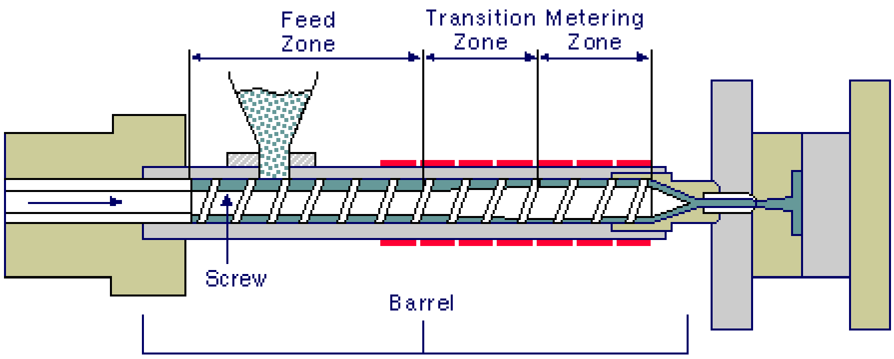

Figure 1.4: Different zones of Reciprocating Screw [2]

Nozzle

The nozzle associates the barrel to the sprue bushing of the mould and structures a seal between the barrel and the mould. Temperature of the nozzle should be set to the material's liquefying temperature. At the point when the barrel is in its full forward handling position, the range of the spout should rest and seal in the sunken span in the concave radius with a locating ring. During purging of the barrel, the barrel pulls out from the sprue, so the purging compound can free tumble from the nozzle. Positions of the barrel are outlined in Figure 1.5

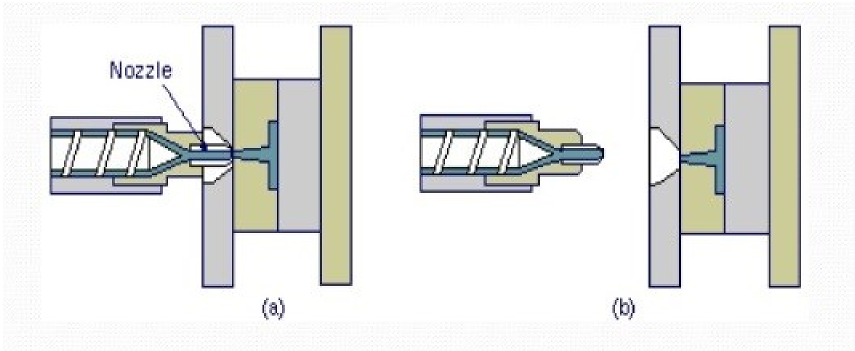

Figure 1.5: Nozzle with barrel (a) Processing Position (b) Backed out for Purging [2]

Check Valve

Check valve which allows the material to pass during the refilling, but do not allow reverse flow of material during the injection.

Injection Cylinders

The injection cylinders are coordinated into the injection platen (for Inj. frame up to 45). The cylinder rods are connected to the feed throat platen. These cylinders are utilized to propel the injection platen forward and reverse, which thus advances the injection screw forward and reverse. For Injection frame 50 or more the injection cylinder rods are combined with the Injection platen, which advances the screw and in reverse by pulling and pushing the plate.

Extruder Motor

This is a hydraulic motor that is used to rotate the reciprocating screw during the refilling cycle.

1.3.2 Clamping Unit

The main working of clamping unit is to open and close the mould along with ejecting the parts. The two main common types of mould clamps are the direct hydraulic and the toggle clamps. Toggle clamps are actuated by hydraulic cylinders. These clamps utilize mechanical linkages to generate higher forces than a direct connection from a hydraulic cylinder of the same size.

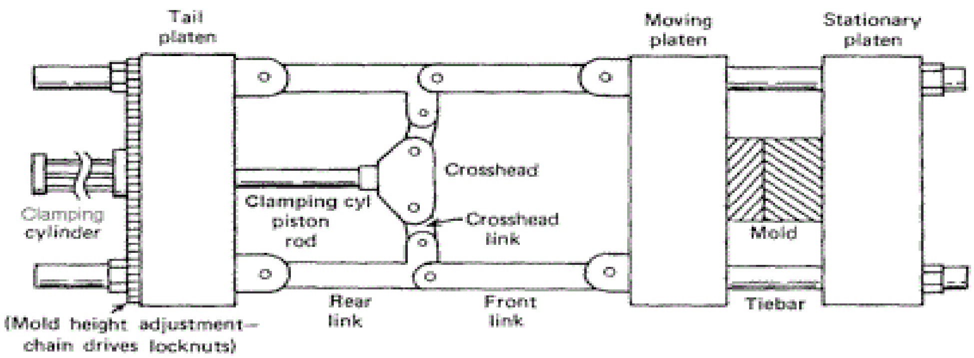

Figure 1.6: Clamping Unit [4]

Stationary Platen

The stationary platen provides an area for mounting one half of the mould. It also acts as a stationary object against which the moving platen can build tonnage.

Moving Platen

The moving platen provides an area for mounting the other half of the mould. This platen that moves back and forward to open and close the mould.

Die Height Adjust Platen (Tail Platen)

This platen is used to adjust the clamp assembly to accommodate varying die heights (mould thickness). It can also be used tom adjust the amount of tonnage that is applied to the mould.

Clamp Cylinder

The clamp cylinder is mounted to a support yoke underneath the toggle mechanism. This cylinder that causes the mould to open and close. When the clamp is closing, the cylinder rod pushes the cross-head upward, which causes the toggle mechanism to extend. When the clamp is opening, the cylinder rod pulls the cross-head down-ward, which causes the moving platen to pull away from the stationary platen.

Crosshead

The cross-head is the mechanical link, or coupling, between the clamp cylinder and the toggle mechanism.

Strain Rods (Tie Bars)

All three clamp platens are tied with four strain rods. The strain rods also act as guide bars for the moving platens. It is the strain force acting on the tie rods, which determines the overall clamping force acting on the mould.

Die Height Mechanism

For toggle machines, to accommodate molds of various sizes, one has to move the complete clamping mechanism either back or forth. This requires a feature called die- height adjustment. Hydro motor drives the main gear couples with the driven gears fitted on die-height nuts by a chain. Thus rotation of the hydro motor causes rotation of the nuts which either thread out or thread in depending upon the direction of rotation.

Hydraulic Ejector mechanism

The ejector mechanism is used to force parts from the mould after the moulding process is completed. This mechanism includes two cylinders. Knockout bar is supplied in option if multiple ejection points are necessary. The back and forth movement of the centre ejector rod causes the ejector pins in the mould to move back and forth, thus forcing the parts from the mould.

Toggle Mechanism

The toggle mechanism ties the moving platen and the die height adjusts platen together. It is this mechanism that maintains clamp tonnage during the injection sequence.

1.3.2.1 Types of Clamps

Clamping units are divided into three categories:

1. Toggle Clamping Unit
2. Hydraulic Clamping Unit
3. Hydro Mechanical Clamping Unit

Toggle Clamping Unit

Most mechanical clamps are toggle clamps. The links of the toggle are activated by the use of a small hydraulic cylinder. Since the extended toggle is always the same, the nuts on the tie rods are used to adjust the clamp for deferent mould heights. Adjustments normally have to be made after the moulding cycle has begun because of the heat transferred to the mould.

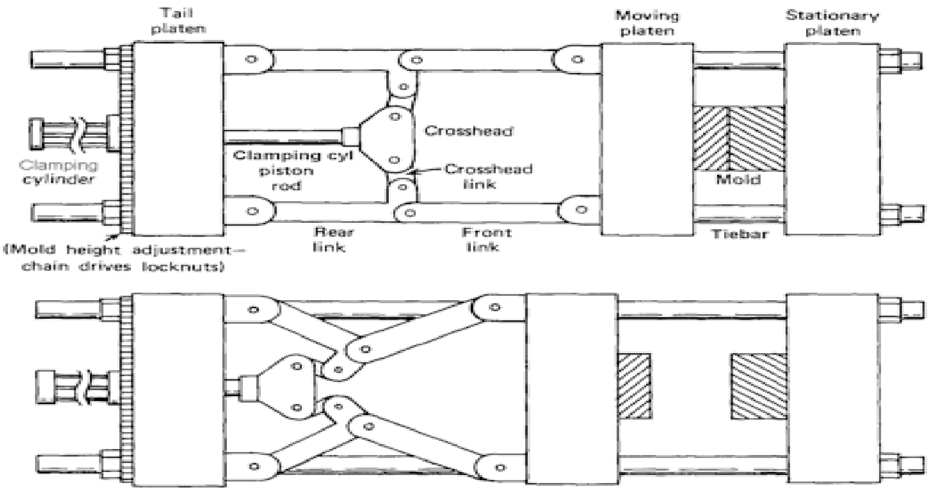

Figure 1.7: Opening and Closing Position for Toggle Mechanism [1]

Hydraulic Clamping Unit

Straight hydraulic clamping is relatively easy and trouble free. Most machines using hydraulic clamping are larger than those using toggles because of the larger cylinder and ram. The clamp force is easily adjustable.

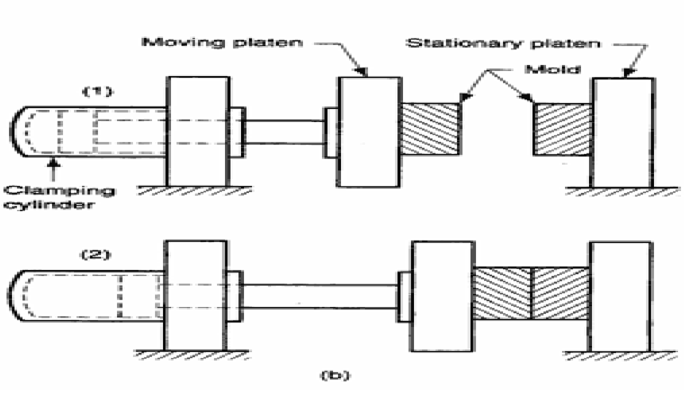

Figure 1.8: Opening and Closing Position for Hydraulic Clamp [1]

Hydro-Mechanical Clamping Unit

These types of clamps combine the best attributes of the previous two. After the toggles links have been fully extended, hydraulic force is exerted to build up clamp tonnage. As with the straight hydraulic, clamp force is easily adjustable.

1.4 Injection Moulding Cycle

The injection moulding cycle is an intermittent cycle. The injection moulding process is performed in cycle which is as follows:

- Mould Close
- Tonnage
- Injection
- Cooling and Refilling
- Mould Open
- Ejection

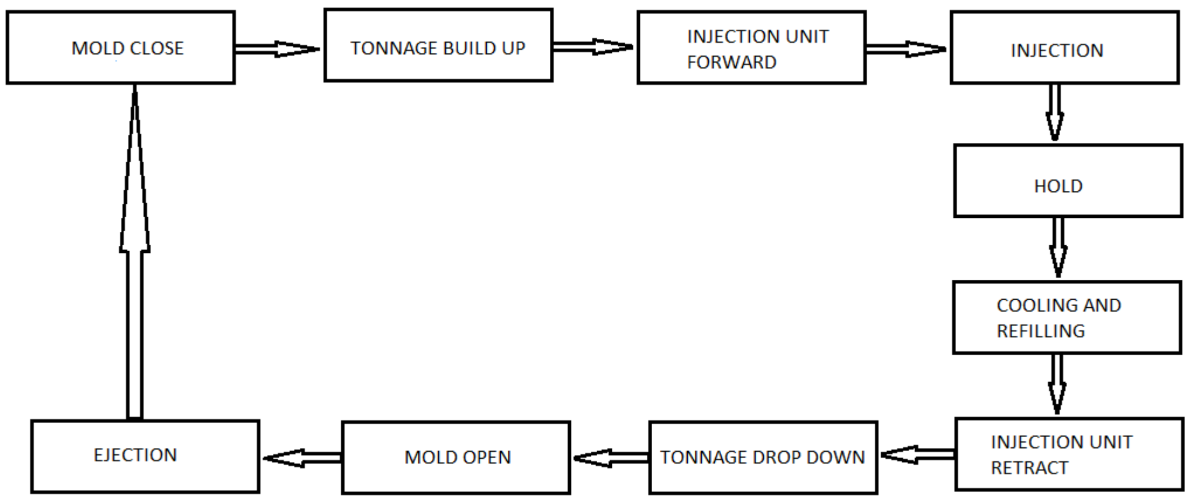

Figure 1.9: Injection Moulding Cycle [4]

1.5 Applications of Injection Moulding Machine [3]

Some applications of injection moulding machine products are given below:

- Aerospace components
- Automotive components
- Avionics components
- Cable assemblies
- Computer electronics
- Electronics components
- Engineering prototypes
- Geophysics
- Instrumentation
- Marketing samples
- Material quality testing
- Medical & dental products
- Medical laboratories
- Model shops, toys, hobby
- New product design & development
- Packaging containers
- R&D labs
- Test specimens

1.6 Objectives

- To develop parametric modelling of reciprocating screw of injection moulding machine.
- Static structural analysis of reciprocating screw of injection moulding machine for diameter 69.8 mm.
- Transient thermal analysis of reciprocating screw of injection moulding machine for diameter 69.8 mm.

1.7 Methodology

Following are the steps to follow in project:

1. Preparation of 3d model of reciprocating screw of diameter 69.8 mm.
2. To link the 3d model with excel sheet by the excel analysis.
3. Modify different dimensions as per required model and get the new model.
4. Pro/programming of reciprocating screw.
5. Identify material properties.
6. Identify boundary conditions.
7. Perform static structural analysis of reciprocating screw.
8. Perform transient thermal analysis of reciprocating screw.

Chapter 2

Literature Review

Some literature based on modelling and finite element analysis of reciprocating screw of injection moulding machine is discussed below:

Rajoria and Jadhao, 2013 [5] Presented reciprocating screw is a pivotal part of injection molding macine. A reciprocating screw the material forward by either hydraulic or electric motor. In this procedure material is melt by the heat which is given by the ceramic heater. Material is likewise dissolve by the devastating of reciprocating screw. Wearing of threads is principle issue of reciprocating screw in the injection moulding machine. Wearing of threads occurs because of the impacts of high temperature liquefied plastic material and pressure of mold materials. This diminishes strength and pressure of reciprocating screw. The material use for screw is SAE 52100 and other alternate materials used are SAE4340, SAE4040 and SAE 1040.So, transient thermal analysis is carried out on reciprocating screw. Among all steel grades SAE 4040 (EN8) is most suitable to the mould material. Because EN8 is minimum heat flux generated during the process.

For SAE 4340: $470*10^6$ Pa

For SAE 4040:$350*10^6$ Pa

So, SAE 4340 will resist more pressure compared to SAE 4040. So, SAE 4340 is suggested for the injection moulding machine.

Ganesh, 2015 [6] For reciprocating screw of injection moulding machine, Steady state thermal analysis & Static structural analysis carried out on screw by using finite element analysis applying temperature at various points and fixed support. The reciprocating screw material is EN41B, EN9, EN8 & EN 24.The flowing mould material is Nylon, Low density roly-poly prop, Flexible PVC & Polystyrene. The result is EN 24 most suitable material for injection moulding machine.

Charpe and Jaju, 2015 [7] from analysis some other alternatives one suggested for wear reduction is as surface coating, surface hardening, material change etc. By this wear of reciprocating screw can be reducing by the surface treatment of tungsten coating on the reciprocating screw. Wear also reduce by the hardening (Nitriding) process and by changing the appropriate material.

Stepan et al, 2017 [8] Presented fatigue failure analysis of reciprocating screw of injection moulding machine. By this analysis fatigue life of reciprocating screw can be determine. From the theoretical fatigue curve of number of cycle vs length of crack shows the initiation life is smaller than propagation life of crack. The complete fatigue life of reciprocating screw can be obtained by merging of *a-Ni* curve (number of cycles to length) and *a-Np* curve (number of cycles to rupture).

Bull and Zhou, 2001 [9] in this test developed can simulate the wear of inside the barrel of an injection moulding machine. This test indicated the effect of temperature on the wear of screw or barrel material. The wear rate of untreated steel and chrome-plated steel increase as the temperature rises but the wear rate of the nitrided steel is constant. We can calculate wear volume by equation, $V=LD\,(D\,(2R-D))^{1/2}$ where D is the maximum wear depth, L is the scar width (10 mm here) and R is the radius of steel wheel (101 mm here). Vickers hardness of materials has been given below,

Untreated steel=391 kg/mm^2

Chrome-plated steel=1125 kg/mm^2

Nitrided steel=1284 kg/mm^2

Venugopal, 2015 [10] by FEM analysis equivalent stress can be determining. From the result of FEM analysis the stresses induced in the coupling are more when we make the coupling of weaker material than that of reciprocating screw. In case of the failure of heaters, there is more chance of failure of the reciprocating screw. If material of coupling is weaker material suggested here mounted in the system, and then it can protect the reciprocating screw by failure of coupling. Maximum induced equivalent stress is

Reciprocating Screw = 18 Mpa

Coupling = 85.2 Mpa

Nagrale and Baxi, 2011 [11] presented static structural analysis of reciprocating screw of injection moulding machine. Wearing of threads occur due to effects of high temperature of mould materials. This analysis is used to identify the wearing of threads and provide the possible solutions. By this analysis found the total deformation, Von-mises stress, directional heat flux, total heat flux.

Amol and Somashekhar, 2014 [12] performed static structural analysis and steady state thermal analysis for reciprocating screw of materials EN24 (SAE4340) and EN-41B. Applying torque at the end of motor side and keeping full length of surface of screw as fixed support side, it is found that reciprocating screw has more chances of failure. In analysis of the coupling we observed that, coupling shows maximum chances of failure than reciprocating screw. And also maximum value of equivalent stress is obtained higher than the reciprocating screw. The coupling is weaker than the reciprocating screw and it will fail before the reciprocating screw. The coupling is better solution for reducing torsion failure of the reciprocating screw by making coupling in injection moulding machine. Equivalent stress has been found in analysis is,

Reciprocating screw = $1.6567*10^{-6}$ Mpa

Coupling = 0.026355 Mpa

Fantoni et al, 2012 [13] presents the analysis of an injection moulding machine using functional analysis to identify problems when machine is in working condition. The analysis performed to identify the design reasons behind the injection moulding machine feature and the related processing phases. Screw diameter reduction and increased position accuracy appeared to be the most critical factor both from the functional analysis and the experimental validation of the process in order to improve the micro moulding process performance and therefore the polymer-based micro part quality.

Yao et al, 2008 [14] experiments were performed on a reciprocating screw of injection moulding machine with the maximum shot weight of 128 g and clamping force of 88 tons. The barrel is divided into seven zones including one nozzle zone and six barrel zones. Each zone has one independent heater. The nozzle zone heater has a capacity of 600W. The other six heaters have 1080W capacities. Temperatures of different zones are measured by thermocouple. Zero-crossing solid state relay was used to actuate the heaters and the pulse width modulating control method was used for the manipulation of the heaters. The developed Strategy of temperature control can maintain the barrel temperatures.

2.1 Summary of Literature Review

In general, the researchers give different methods of FE analysis of reciprocating screw of injection moulding machine by changing different materials. Following are some points which show the researchers work.

- Static structural analysis of different materials of EN8, EN9, EN 24 and EN-41B to know the total deflection, von mises stress, etc.
- Transient thermal analysis of different materials of EN8, EN9, EN 24 and EN-41B to know the temperatures in different zones and total heat flux.
- Some researchers focus on failure analysis of reciprocating screw due to wearing of threads because of high temperature of mould material and it was found that performing nitriding process can reduce the wear of threads in reciprocating screw.

Chapter 3
Design and Analysis Criteria

3.1 Design Procedure of Reciprocating Screw (Feed Screw)

The reciprocating screw has three zones with a ring-plunger assembly. The Feed Zone, where the plastic first enters the screw and is conveyed along a constant root diameter; the Transition Zone, where the plastic is conveyed, compressed and melted along a root diameter that increases with a constant taper; and the Metering Zone, where the melting of the plastic is completed and the melt is conveyed forward along a constant root diameter reaching a temperature and viscosity to form parts.

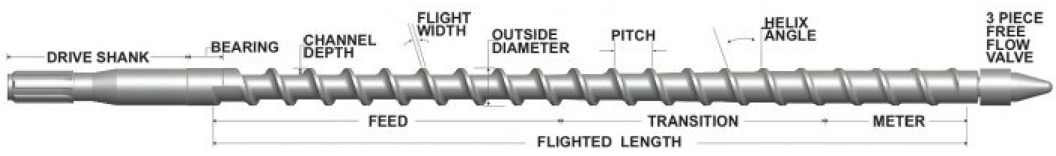

Figure 3.1: Nomenclature of Reciprocating Screw [15]

For a design of reciprocating screw different dimensions can be determine by following equations [16]

Total Length of Flighted Section of Screw = 20D

Length of Feed Section = 10D

Length of Transition Section = 5D

Length of Metering Section = 5D

Pitch of Screw = 1D

Width of Flight of Screw = 0.1D

Flight Depth in Feed Section = 0.16D to 0.18D

Flight Depth in Metering Section = 0.06D to 0.07D

Where,

D = Core Diameter of Reciprocating Screw

3.2 Acceptance Criteria

Mechanical properties of different materials for reciprocating screw listed below in Table 3.1

Table 3.1: Mechanical Properties of Different Materials [5]

Properties	SAE52100 (EN41B)	SAE4340 (EN24)	SAE4040 (EN8)	SAE1040
Young's Modulus (PA)	210×10^9	205×10^9	203×10^9	200×10^9
Poisson's Ratio	0.3	0.292	0.292	0.292
Density (kg/m³)	7810	7850	7810	7845
Thermal Expansion	11.9×10^{-6}	12.3×10^{-6}	10.7×10^{-6}	11.3×10^{-6}
Yield Tensile Strength (PA)	9.1×10^8	470×10^6	350×10^6	353.4×10^6
Ultimate Tensile Strength (PA)	672×10^6	689×10^6	632×10^6	585×10^6
Specific Heat (J/g-K)	0.475	0.475	0.473	0.486
Thermal Conductivity (W/m-K)	46.6	44.5	42.7	51.9

The above Table 3.1 will help to carry out the static structural analysis and transient thermal analysis of reciprocating screw of injection moulding machine. The above Table 3.1 shows the values of Young's modulus, Poison's ratio, Density, Thermal expansion, Yield tensile strength, Ultimate tensile strength, Specific heat and thermal conductivity.

Chapter 4
Parametric Modelling of Reciprocating Screw

Parametric is a term used to describe a dimension's ability to change the shape of model geometry as soon as the dimension value is modified.

Feature-based is a term used to describe the various components of a model. For example, a part can consists of various types of features such as holes, grooves, fillets, and chamfers. A 'feature' is the basic unit of a parametric solid model.

In a parametric model, each entity like line or arc in a wireframe, or a filleting operation has parameters connected with it. These parameters control the different geometric properties of the entity, like length, width and height of a model. They also control the locations of these entities within the model.

Parametric modelling uses the computer to design objects or systems that model part attributes with real world behaviour. Parametric models use feature-based, solid and surface modelling design tools to manage the system attributes.

One of the most main features of parametric modelling is that attributes that are interlinked automatically change their features. In other words, parametric modelling allows the designer to define entire classes of shapes, not just specific instances. Before the advent of parametric, editing the shape was not an easy task for designers. For example, to modify a 3D solid, the designer had to change the length, the breadth and the height. However, with parametric modelling, the designer need only alter one parameter; the other two parameters get adjusted automatically.

Parametric Modelling is an extremely fit for design tasks that involves exacting requirements and manufacturing criteria. For example, firm often turn to parametric when making families of parts that involve slight variations on a core design, because the designer will need to create design between dimensions, parts and assemblies. This supports designs that will need to be modified or iterated on a regular premise. It also creates models with single features that can be modified or changed — such as holes and chamfers — those are captured in a 'model tree.'

4.1 Modelling of Reciprocating Screw

Modelling of reciprocating screw is carried out using modelling software in creo parametric. Modelling of reciprocating screw has been done by the different parameters like Outer diameter, Total length of flighted section of screw, Length of feed section, Length of transition section, Length of metering section, Pitch of screw, Width of flight of screw, Flight depth in feed section, Flight depth in metering section, Flow side radius, Non flow side radius, Total shank length, Spline diameter, Spline length, Chamfer length and Chamfer angle of diameter 69.8 mm is given in below figure 4.1

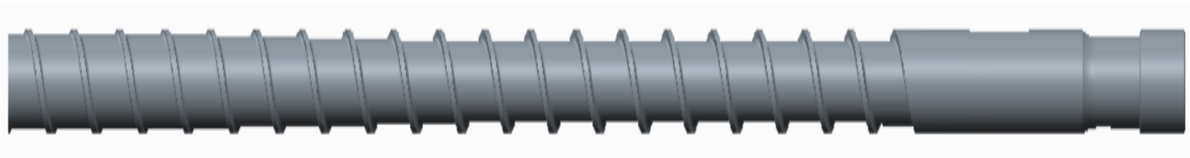

Figure 4.1:- Model of Reciprocating Screw of 69.8 mm

Drawing of reciprocating screw generated through modelling of reciprocating screw of diameter 69.8 mm to verify the different dimensions of model with the drawing of reciprocating screw which is given in below figure 4.2

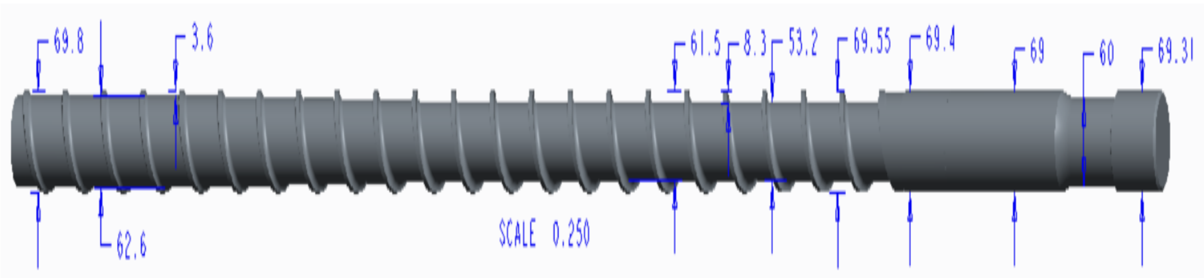

Figure 4.2:- Drawing of Reciprocating Screw of Diameter 69.8 mm

4.2 Parametric Modelling of Reciprocating Screw

Parameters of reciprocating screw of diameter 69.8 mm is linked with the excel spreadsheet which is shown below Table 4.1

Table 4.1:-Excel Spreadsheet of Reciprocating Screw of Diameter 69.8 mm

Main Dia.	70
L/D Ratio	22.9226361
Compression Ratio	2.305555556
Dia	69.8
Total Length (L)	1600
Feed Length (Lf)	800
Compression Length (Lc)	480
Metering Length (Lm)	320
Pitch (P)	70
Flight Width	7
Metering Flight Depth (Dm)	3.6
Feed Flight Depth (Df)	8.3
Under Cut Diameter	69.55
Under Cut Length	262.5
Under Cut Thickness	0.125
Shank Diameter1	69.4
Shank Diameter2	69
Shank Diameter3	60
Spline Diameter	69.31
Shank Length1	83
Shank Length2	199
Shank Length3	100
Spline Length	80
Leading Radius	7
Tailing Radius	3.5
Profile Length	63
Extention in Helical Profile	35

The Table 4.1 linked with the creo model of reciprocating screw of diameter 69.8 mm for the parametric modelling of diameter 79.8 mm.

Model of reciprocating screw of diameter 69.8 mm was modified by changing few parameters highlighted in table 4.2 and reciprocating screw of 79.8 mm was obtained.

Table 4.2:- Excel Spreadsheet of Reciprocating Screw of Diameter 79.8 mm

Main Dia.	80
L/D Ratio	20.05012531
Compression Ratio	2.289473684
Dia	79.8
Total Length (L)	1600
Feed Length (Lf)	800
Compression Length (Lc)	480
Metering Length (Lm)	320
Pitch (P)	80
Flight Width	8
Metering Flight Depth (Dm)	3.8
Feed Flight Depth (Df)	8.7
Under Cut Diameter	79.55
Under Cut Length	300.1074499
Under Cut Thickness	0.125
Shank Diameter1	79.4
Shank Diameter2	79
Shank Diameter3	70
Spline Diameter	79.31
Shank Length1	83
Shank Length2	199
Shank Length3	100
Spline Length	80
Leading Radius	7
Tailing Radius	3.5
Profile Length	72
Extention in Helical Profile	40

Parametric modelling is carried out by merging creo parametric and MS excel using excel analysis function. Excel analysis is used to carry out parametric modelling in that you change few specific parameters and get a new modified model. An excel spreadsheet file is made consisting of different relative dimension parameters of reciprocation screw and it is then linked with the Creo parametric model using excel analysis function. Once the spreadsheet file is linked with Creo parametric, any change in parameters given in spreadsheet will lead to change in parametric model as well.

Below figure 4.3 shows the reciprocating screw of diameter 79.8 mm and it is obtained after performing parametric modelling in MS excel on reciprocating screw of diameter 69.8 mm.

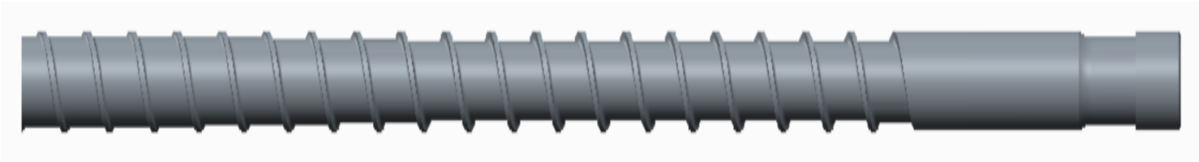

Figure 4.3:- Parametric Modelling of Reciprocating Screw of Diameter 79.8 mm

Drawing of reciprocating screw generated through parametric modelling of reciprocating screw of diameter 79.8 mm is given in below figure 4.4

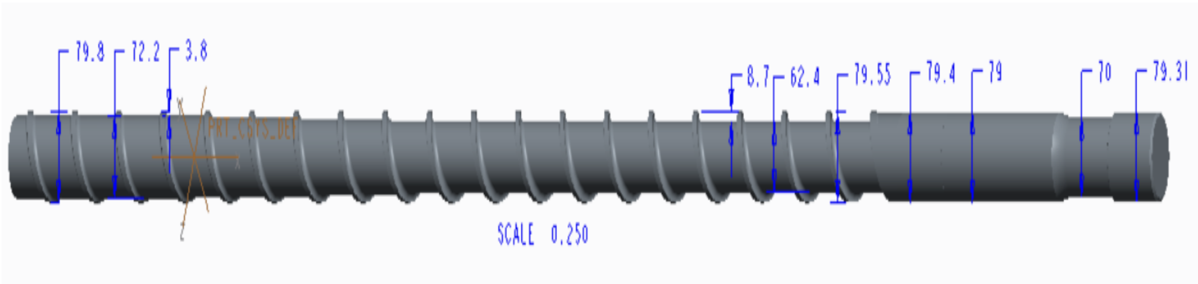

Figure 4.4:- Drawing of Reciprocating Screw of Diameter 79.8 mm

4.3 Pro/Programing of Reciprocating Screw

Pro/Program is a utility that lets you specify input variables (used for dimensions), setup relations, and modify or control the regeneration process for parts and assemblies. By running the program, the model can be change according to new design specifications. In pro/programming as per the requirement any parameter can be modified by selecting that particular parameter. And value of the parameter can be changed easily. Pro/Programming code of reciprocating screw as per the Appendix 1.

In Pro/Programming by selecting regenerate feature of the creo following box will open as shown in figure 4.5

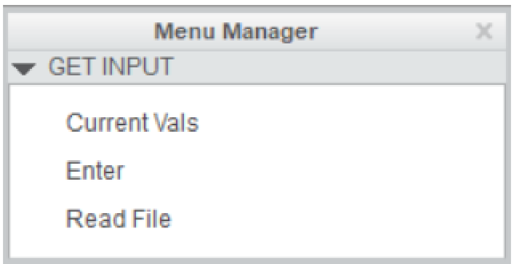

Figure 4.5: Inputs in Menu Manager

Then by selecting enter, following box of inputs of reciprocating screw will open, it consists of different dimensional parameters as shown in figure 4.6

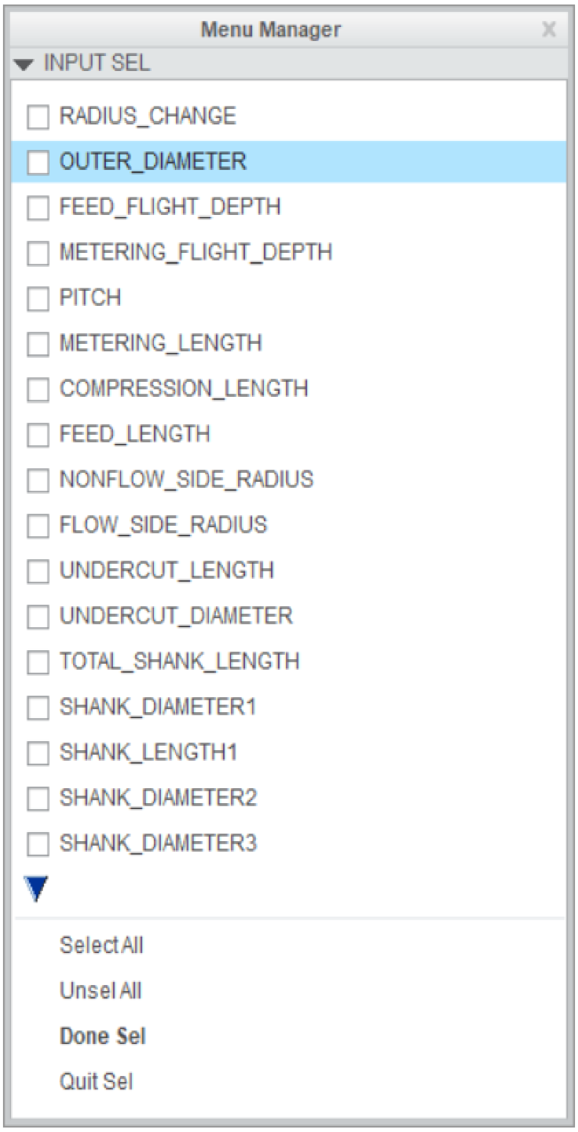

Figure 4.6: Input Parameters of Reciprocating Screw

By selecting any number of required parameters, the value of parameters can be set as shown figure 4.7

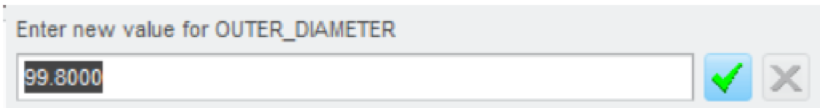

Figure 4.7: Modification of Parameter Value

The given required changes of input parameters will reflect in the model of reciprocating screw.

Chapter 5

Static Structural and Transient Thermal Analysis of Reciprocating Screw

5.1 Static Structural Analysis for 69.8 mm Diameter of Reciprocating Screw

A reciprocating screw in injection moulding machine is an important component held in barrel and subjected to forces. So, the static structural analysis is required to know which material has higher factor of safety.

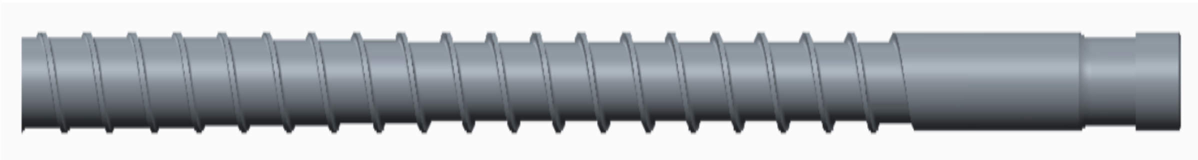

Figure 5.1: Model for Static Structural Analysis

5.1.1 Process of Static Structural Analysis for 69.8 mm Diameter of Reciprocating Screw [6]

1. The static structural analysis carried out in ANSYS workbench.
2. The different material properties applied to carry out this analysis are Density, Thermal expansion, Young's modulus, Poisson's ratio, Yield tensile strength, Ultimate tensile strength, Specific heat, Thermal conductivity.
3. The geometry of reciprocating screw was modelled in creo parametric and then imported into the ANSYS workbench.
4. The meshing of model was done.
5. Two boundary conditions are applied as following.
   i. One end of the reciprocating screw was kept fix which is near to the metering zone.
   ii. The injection pressure of 1184 bar was applied to the model of reciprocating screw near to the metering zone.

5.1.2 Boundary Conditions for Static Structural Analysis

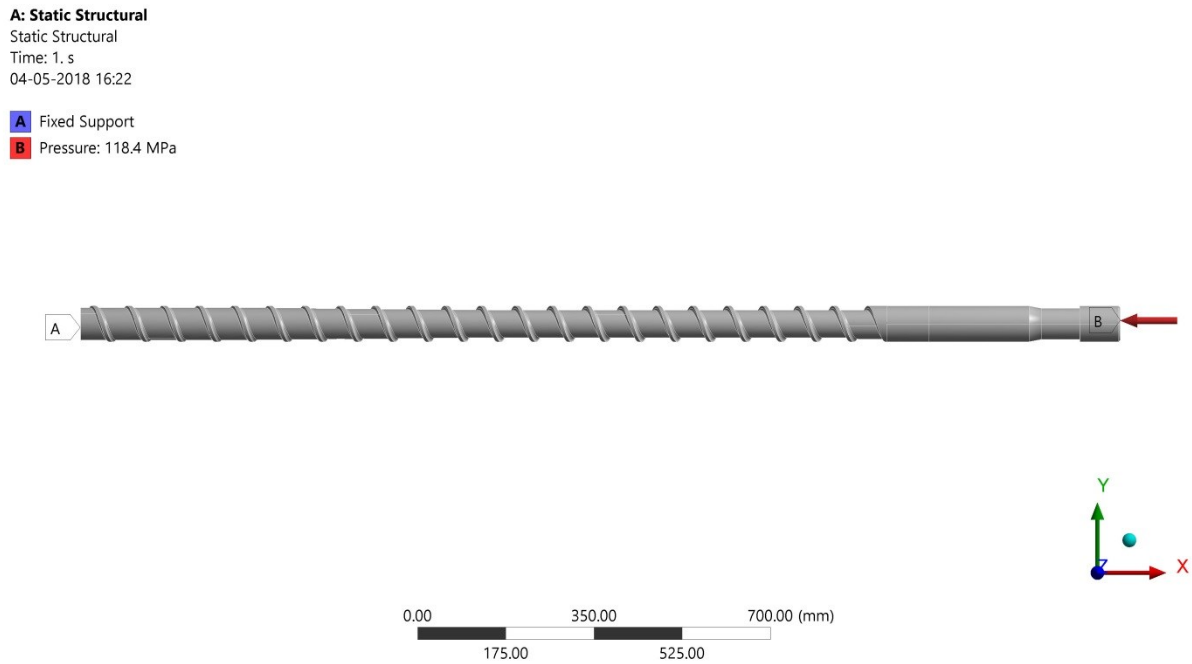

Figure 5.2: Boundary Conditions for Static Structural Analysis of Reciprocating Screw

Different boundary conditions are applied to carry out static structural analysis of reciprocating screw, which are as follows.

1. One end of the reciprocating screw was kept fix which is near to the metering zone

The reason of the fixing one end is that whenever the heater will fail and solidification will start. So, this end will act as fixed end.

2. The injection pressure of 1184 bar was applied near to the drive zone of reciprocating screw

The reciprocating screw is injecting 1184 bar of injection pressure during the injection of melting plastic in an injection moulding machine.

5.1.3 Mesh Generation of Reciprocating Screw for Static Structural Analysis

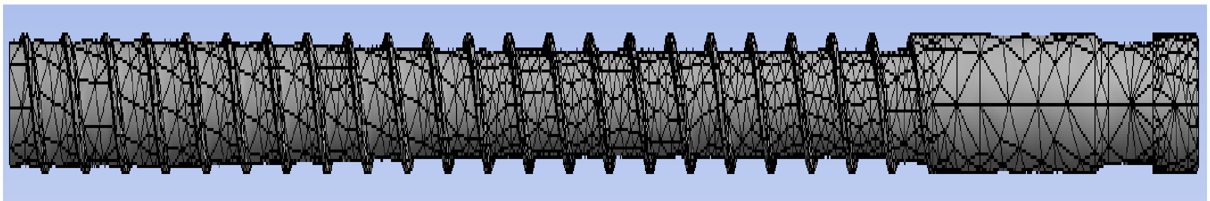

Figure 5.3: Mesh Distributions in Model for Static Structural Analysis

In order to carry out a finite element analysis, the model is divided into a number of small pieces known as finite elements. Since the model is divided into a number of discrete parts, FEA can be described as a discretization technique. In simple terms, a mathematical net or "mesh" is required to carry out a finite element analysis. For correct FEA solution, the mesh density should be chosen carefully. If mesh density is too fine than it require too much calculation time otherwise if it is too coarse than it will not give correct solution. Table 5.1 shows meshing data.

Table 5.1: Meshing Data of Reciprocating Screw for Static Structural Analysis

Object Name	**Mesh**
Physical Preference	Mechanical
Relevance	0
Relevance Center	Medium
Element Size	Default
Shape Checking	Standard Mechanical
Straight Sided Elements	No
Initial Size Speed	Active Assembly
Smoothing	Medium
Nodes	22706
Elements	12296

5.1.4 Results of Static Structural Analysis for 69.8 mm Diameter of Reciprocating Screw

The static structural analysis of reciprocating screw is carried out in software ANSYS. Following values of directional deformation, von-mises stress and shear stress are obtained as given below:

- **EN8 Material of Reciprocating Screw**

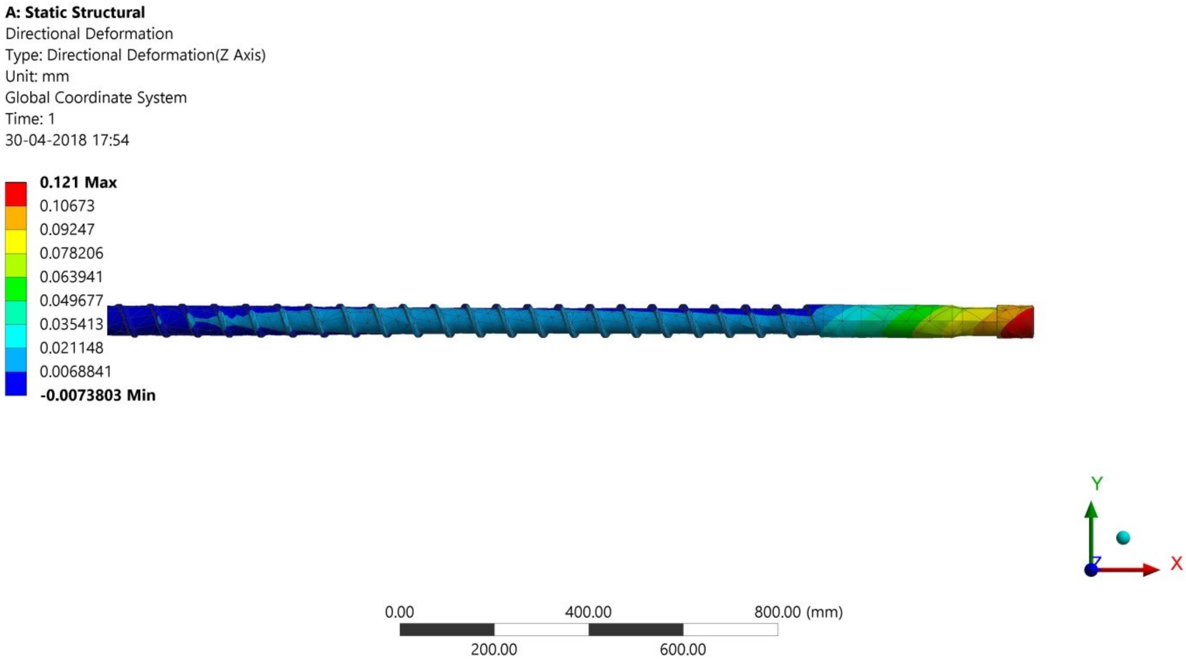

Figure 5.4: Directional Deformation of Reciprocating Screw of EN8 Material

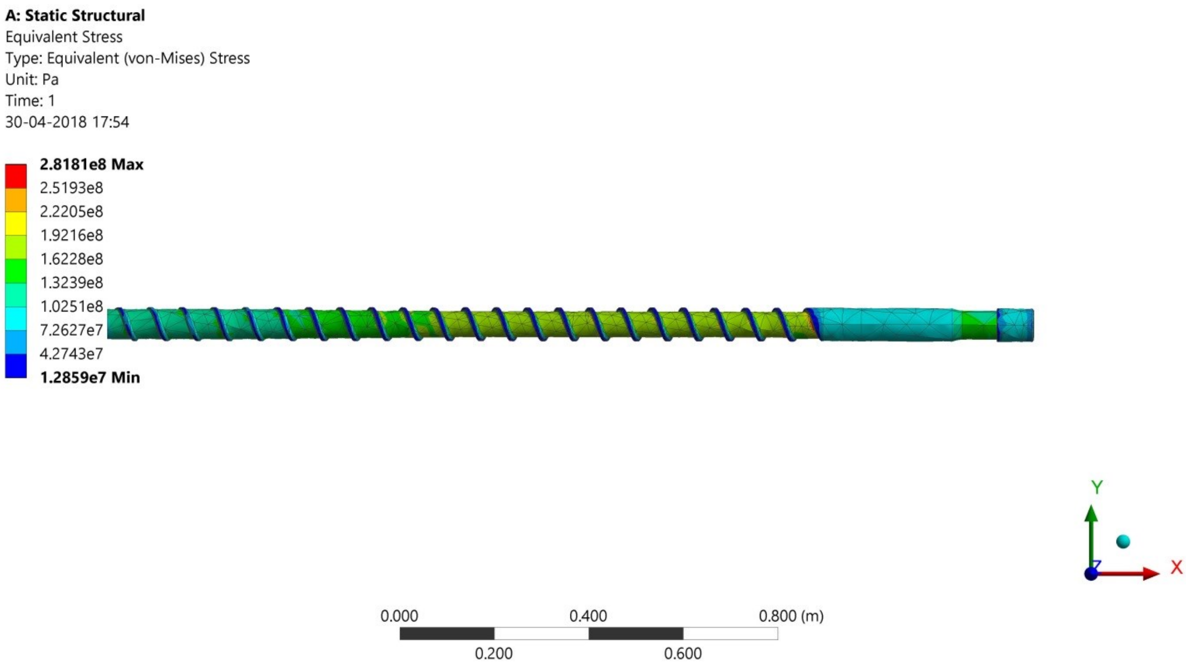

Figure 5.5: Von-Mises Stress of Reciprocating Screw of EN8 Material

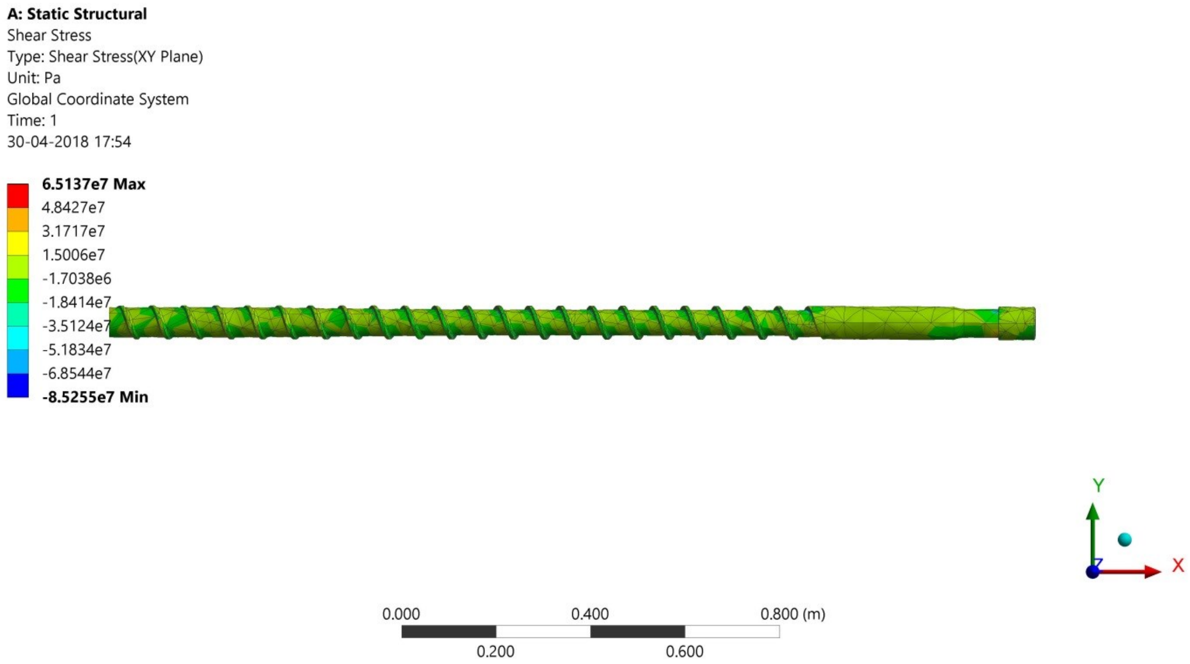

Figure 5.6: Shear Stress of Reciprocating Screw of EN8 Material

- **EN9 Material of Reciprocating Screw**

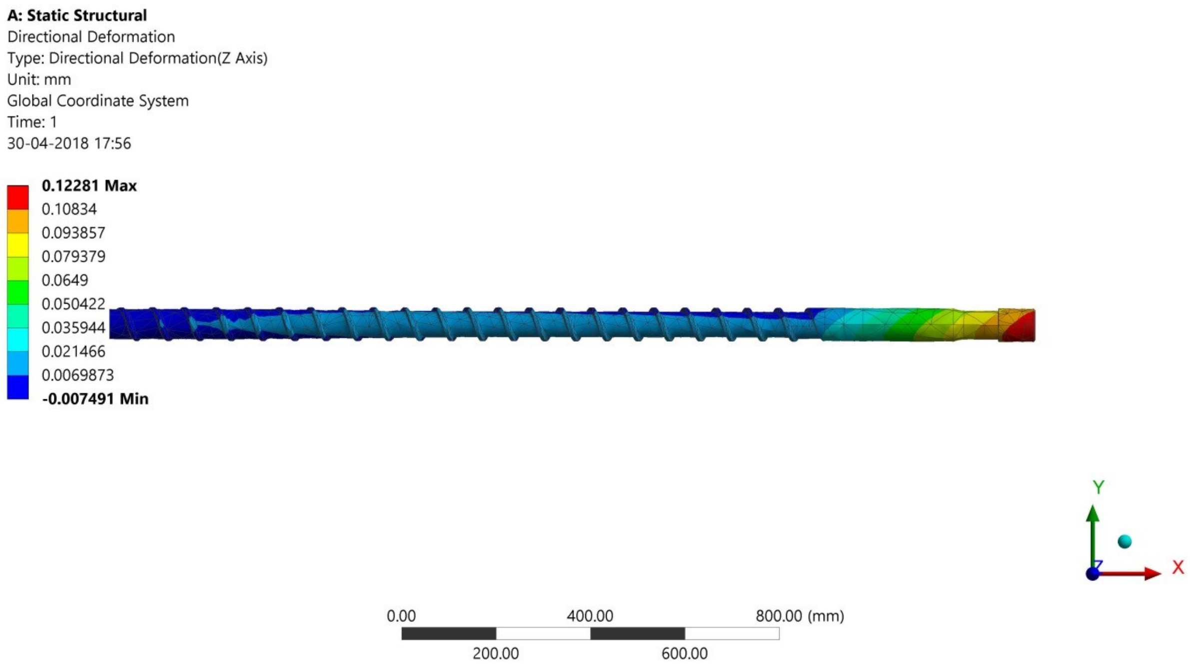

Figure 5.7: Directional Deformation of Reciprocating Screw of EN9 Material

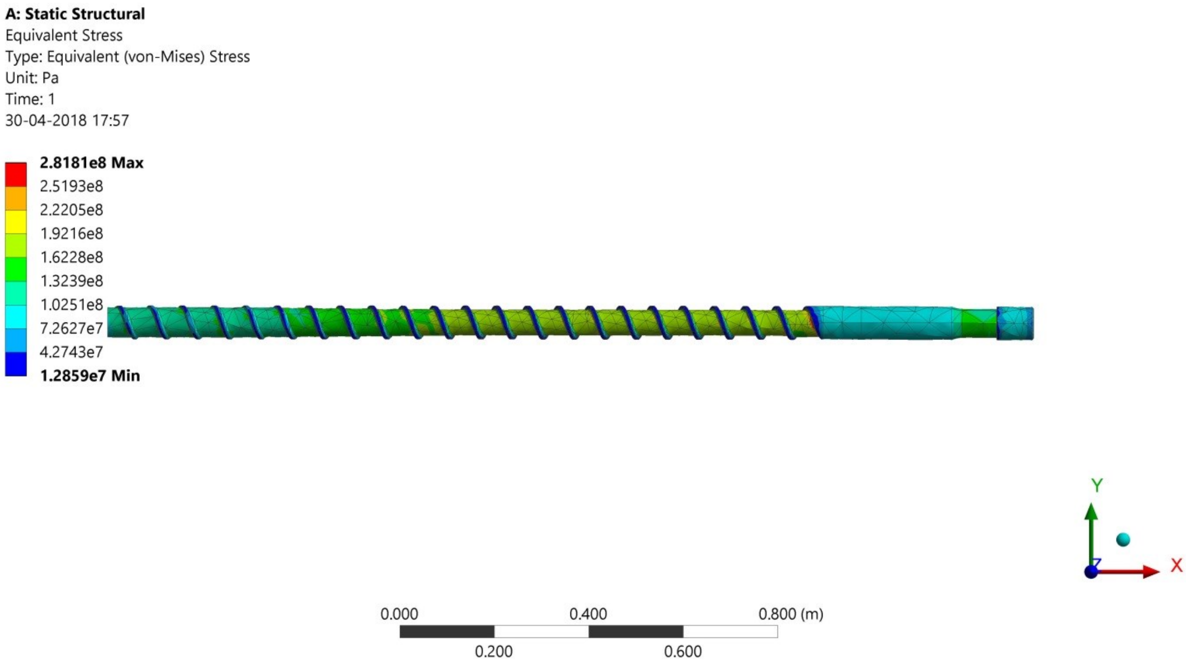

Figure 5.8: Von-Mises Stress of Reciprocating Screw of EN9 Material

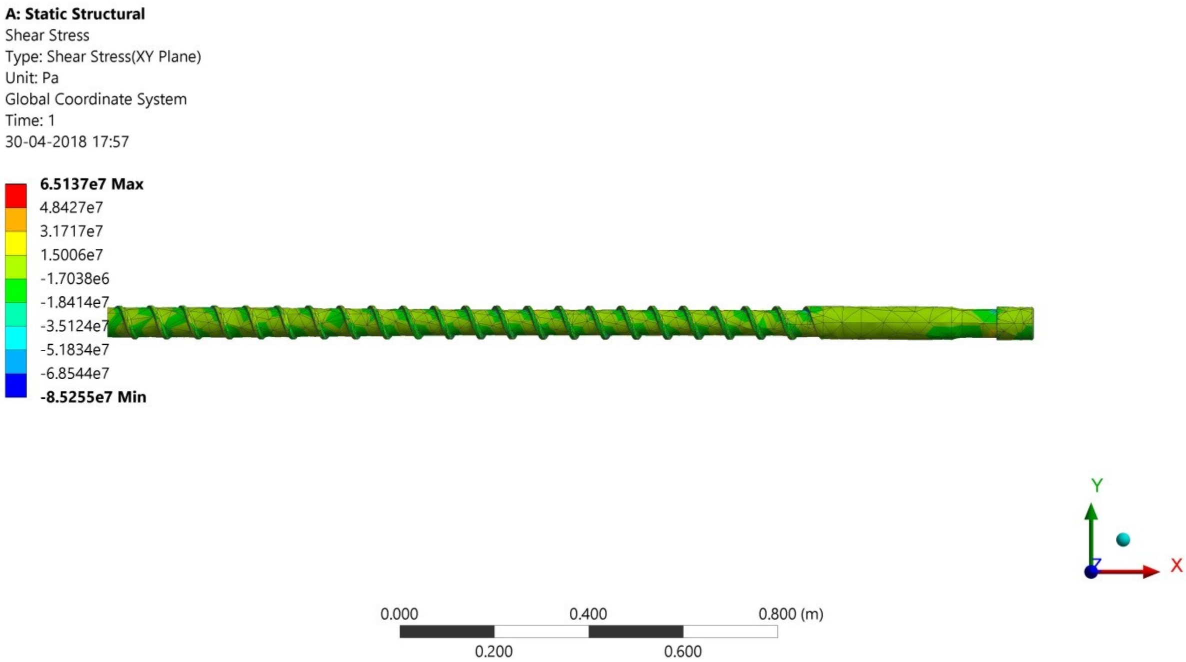

Figure 5.9: Shear Stress of Reciprocating Screw of EN9 Material

- **EN24 Material of Reciprocating Screw**

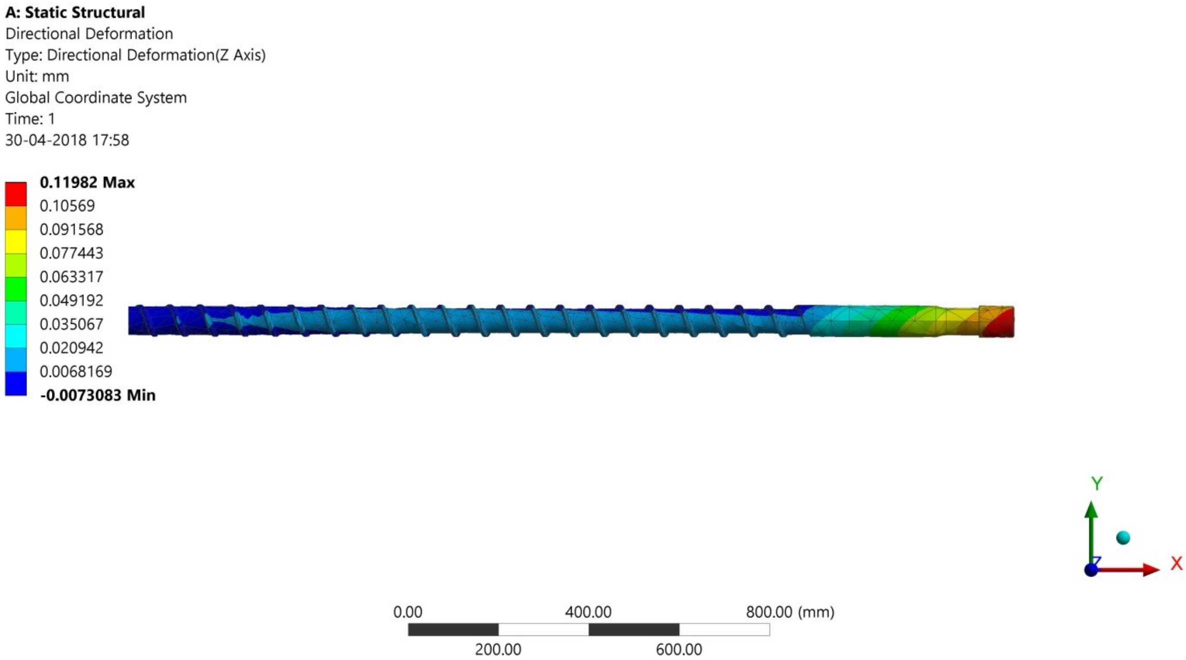

Figure 5.10: Directional Deformation of Reciprocating Screw of EN24 Material

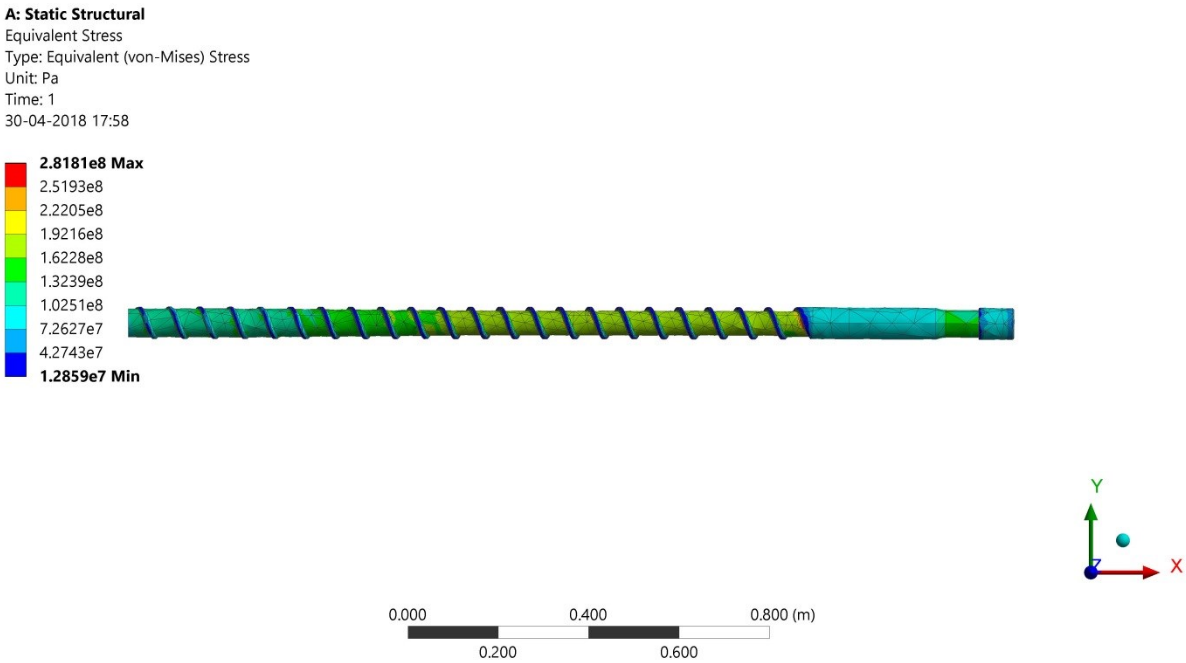

Figure 5.11: Von-Mises Stress of Reciprocating Screw of EN24 Material

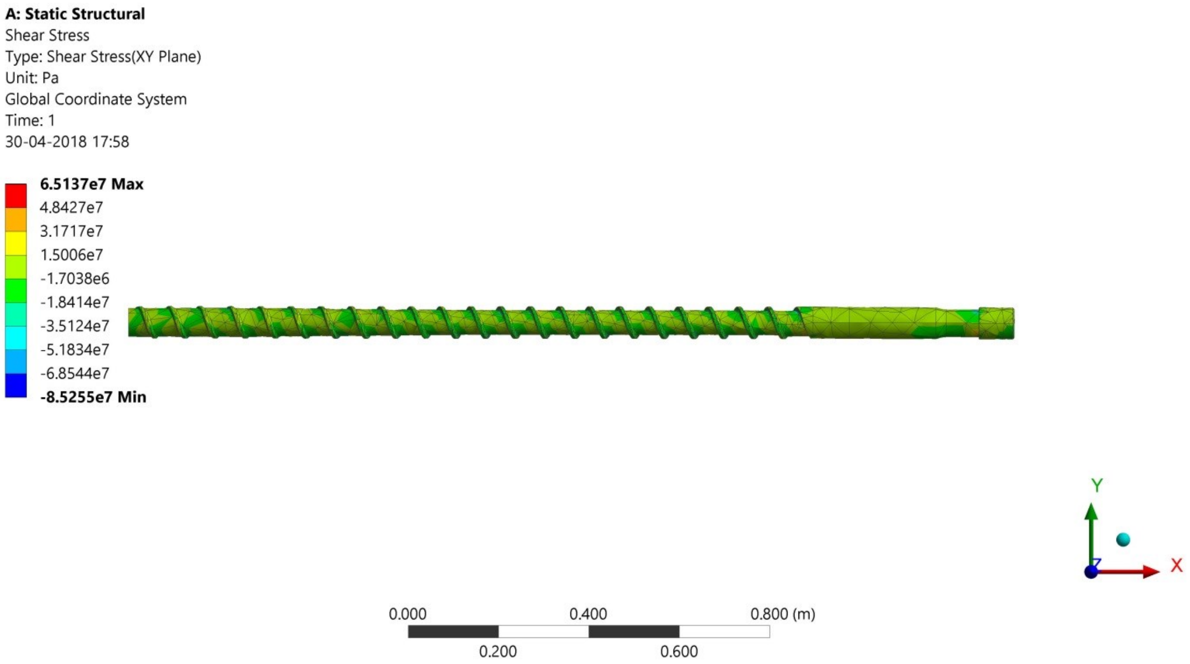

Figure 5.12: Shear Stress of Reciprocating Screw of EN24 Material

- **EN-41B Material of Reciprocating Screw**

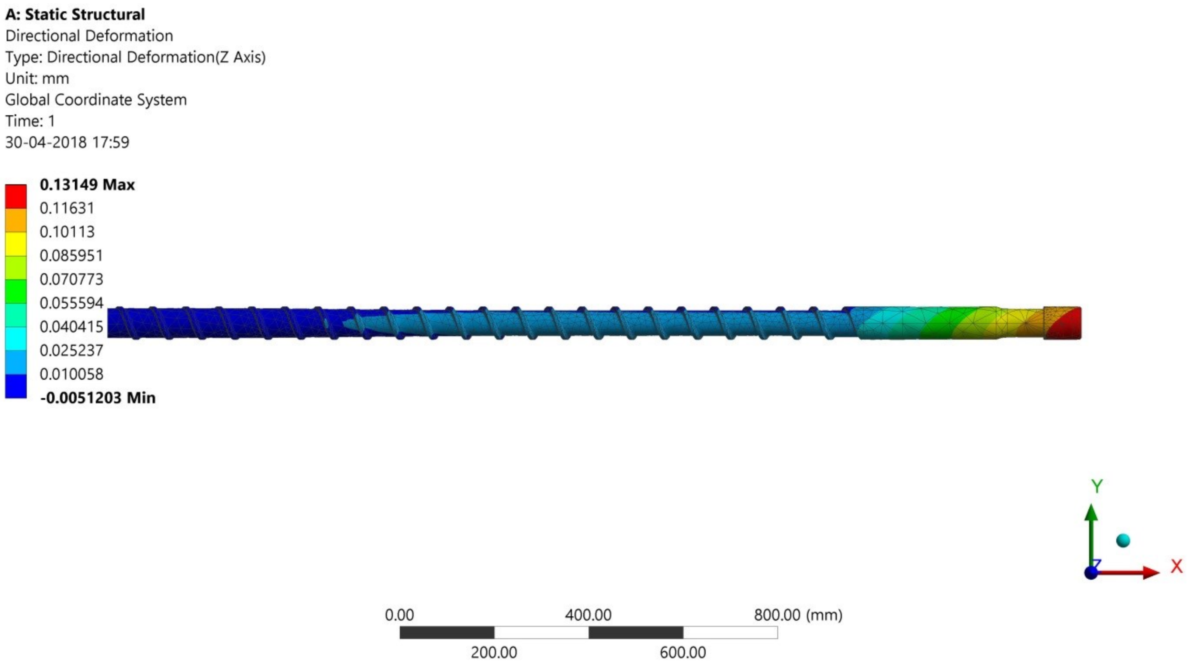

Figure 5.13: Directional Deformation of Reciprocating Screw of EN-41B Material

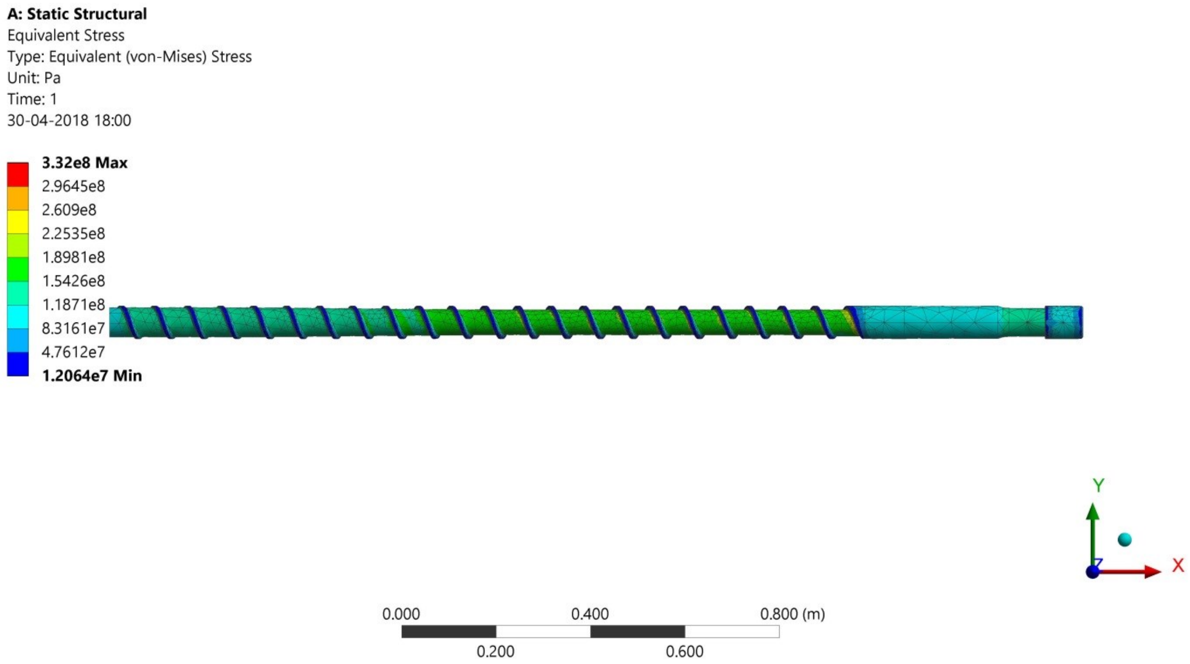

Figure 5.14: Von-Mises Stress of Reciprocating Screw of EN-41B Material

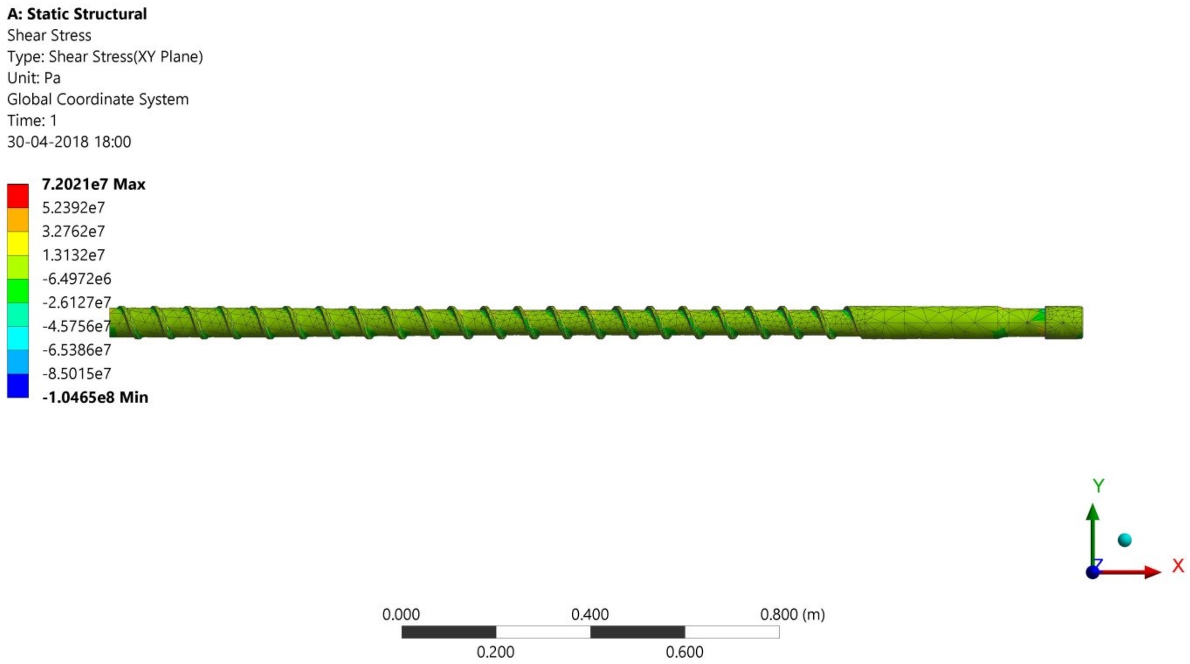

Figure 5.15: Shear Stress of Reciprocating Screw of EN-41B Material

5.1.5 Result Discussion of Static Structural Analysis for Diameter 69.8 mm of Reciprocating Screw

Results of total deformation, von-mises stress and shear stress for 69.8 mm reciprocating screw are shown in Table 5.2

Table 5.2: Results of Static Structural Analysis of Different Materials for 69.8 mm Reciprocating Screw

Property	EN8	EN9	EN24	EN-41B
Directional Deformation, mm	Max: 0.0068841 Min: -0.00738	Max: 0.0069873 Min: -0.007491	Max: 0.0068169 Min: -0.0073083	Max: 0.010058 Min: -0.0051203
Von-Mises Stress, Pa	Max: 2.8181e8 Min: 1.2859e7	Max: 2.8181e8 Min: 1.2859e7	Max: 2.8181e8 Min: 1.2859e7	Max: 3.32e8 Min: 1.2064e7
Shear Stress, Pa	Max: 6.5137e7 Min: -8.5255e7	Max: 6.5137e7 Min: -8.5255e7	Max: 6.5137e7 Min: -8.5255e7	Max: 7.2021e7 Min: -1.0465e8
Factor of Safety	1.24197	1.25403	1.66779	2.74096

From Table 5.2, it can be concluded that directional deformation of reciprocating screw of EN24 material is less compare to other materials. But, Factor of safety of reciprocating screw of EN-41B is more comparing to other materials. So, EN-41B material of the reciprocating screw is safer comparing to other materials.

5.1.6 Analytical Calculation of Static Structural Analysis for Reciprocating Screw Diameter of 69.8 mm

- **For EN-41B Material of Reciprocating Screw**

$$\sigma = \frac{F}{A} \tag{5.1}$$

$$= \frac{1184 \times 10^5}{\pi \times 0.0698 \times 1.6}$$

$$= 33.76 \times 10^7 \text{ N}/m^2$$

$$\varepsilon = \frac{\sigma}{E} \tag{5.2}$$

$$= \frac{33.76 \times 10^7}{210 \times 10^9}$$

$$= 0.001607$$

$$\delta l = \varepsilon \times l \tag{5.3}$$

$$= 0.001607 \times 1.6$$

= 2.57 microns

$$\text{F.O.S} = \frac{\text{Yield Tensile Strength}}{\text{Von−Mises Stress}} \tag{5.4}$$

$$= \frac{9.1}{3.32}$$

$$= 2.74096$$

Where, σ = Shear stress

F = Force

A = Area

ε = Strain

- **For EN 24 Material of Reciprocating Screw**

$$\varepsilon = \frac{\sigma}{E}$$

$$= \frac{33.76 \times 10^7}{205 \times 10^9}$$

$$= 0.001646$$

$$\delta l = \varepsilon \times l$$

$$= 0.001646 \times 1.6$$

= 2.63 microns

$$\text{F.O.S} = \frac{\text{Yield Tensile Strength}}{\text{Von} - \text{Mises Stress}}$$

$$= \frac{4.7}{2.8181}$$

$$= 1.66779$$

- **For EN 9 Material of Reciprocating Screw**

$$\varepsilon = \frac{\sigma}{E}$$

$$= \frac{33.76 \times 10^{7}}{200 \times 10^{9}}$$

$$= 0.001688$$

$$\delta l = \varepsilon \times l$$

$$= 0.001688 \times 1.6$$

= 2.7 microns

$$\mathrm{F.O.S} = \frac{\text{Yield Tensile Strength}}{\text{Von} - \text{Mises Stress}}$$

$$= \frac{3.534}{2.8181}$$

$$= 1.25403$$

- **For EN 8 Material of Reciprocating Screw**

$$\varepsilon = \frac{\sigma}{E}$$

$$= \frac{33.76 \times 10^{7}}{203 \times 10^{9}}$$

$$= 0.001663$$

$$\delta l = \varepsilon \times l$$

$$= 0.001663 \times 1.6$$

= 2.66 microns

$$\mathrm{F.O.S} = \frac{\text{Yield Tensile Strength}}{\text{Von} - \text{Mises Stress}}$$

$$= \frac{3.5}{2.8181}$$

$$= 1.24197$$

5.2 Transient Thermal Analysis for 69.8 mm Diameter of Reciprocating Screw

The reciprocating screw is deals with the heating. So, transient thermal analysis is required for the reciprocating screw to get idea of how the temperature varies at any point.

5.2.1 Process of Transient Thermal Analysis for 69.8 mm Diameter of Reciprocating Screw [5]

1. The transient thermal analysis carried out in ANSYS workbench.
2. The different material properties applied to carry out this analysis are Density, Thermal expansion, Young's modulus, Poisson's ratio, Yield tensile strength, Ultimate tensile strength, Specific heat, Thermal conductivity.
3. The geometry of reciprocating screw was modelled in creo parametric and then imported into the ANSYS workbench.
4. The meshing of model was done.
5. One boundary condition is applied as following.
    i. The different temperatures are applied in various zones of reciprocating screw.

5.2.2 Boundary Conditions for Transient Thermal Analysis

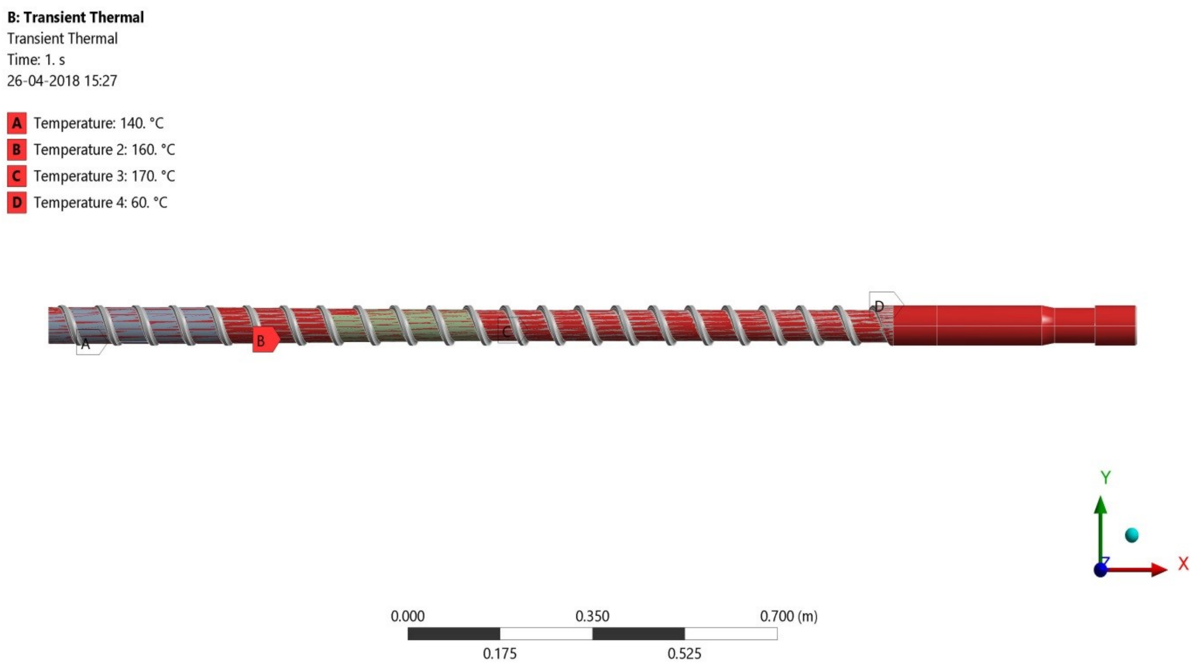

Figure 5.16: Boundary Condition for Transient Thermal Analysis of Reciprocating Screw

One boundary condition is applied to carry out transient thermal analysis of reciprocating screw, which is as following.

1. The different temperatures are applied in various zones of reciprocating screw

The reciprocating screw of injection moulding machine is used to melt the plastic granules. So, the different temperatures are applied in various zones of reciprocating screw for proper melting, which are given in Table 5.3

Table 5.3: Material Temperature Distribution for Various Zones [5]

	TEMPERATURES (° C)			
MATERIALS	**T1 (Metering Zone)**	**T2 (Compression Zone)**	**T3 (Feed Zone)**	**T4 (Drive Zone)**
NYLON	240	275	280	60
LOW DENSITY POLYETHYLENE	150	170	190	60
POLYPROPYLENE	200	230	240	60
PVC	140	160	170	60
POLYSTERENE	170	220	230	60

5.2.3 Mesh Generation of Reciprocating Screw for Transient Thermal Analysis

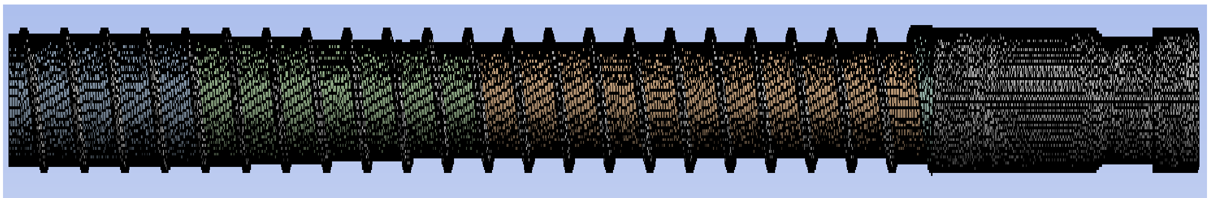

Figure 5.17: Mesh Distributions in Model for Transient Thermal Analysis

ANSYS Meshing is aware of the type of solutions that will be used in the project and has the appropriate criteria to create the best suited mesh. ANSYS Meshing chooses the most appropriate options based on the analysis type and the geometry of the model. If mesh density is too fine than it require too much calculation time otherwise if it is too coarse than it will not give correct solution. Table 5.4 shows meshing data.

Table 5.4: Meshing Data of Reciprocating Screw for Transient Thermal Analysis

Object Name	**Mesh**
Physical Preference	Mechanical
Relevance	0
Relevance Center	Medium
Element Size	5 mm
Shape Checking	Standard Mechanical
Straight Sided Elements	No
Initial Size Speed	Active Assembly
Smoothing	Medium
Nodes	153076
Elements	91525

5.2.4 Results of Transient Thermal Analysis for 69.8 mm Diameter of Reciprocating Screw

The transient thermal analysis of reciprocating screw is carried out in software ANSYS. Following values of temperature, total heat flux and total heat generation are obtained as given below:

- **Nylon Raw Input**

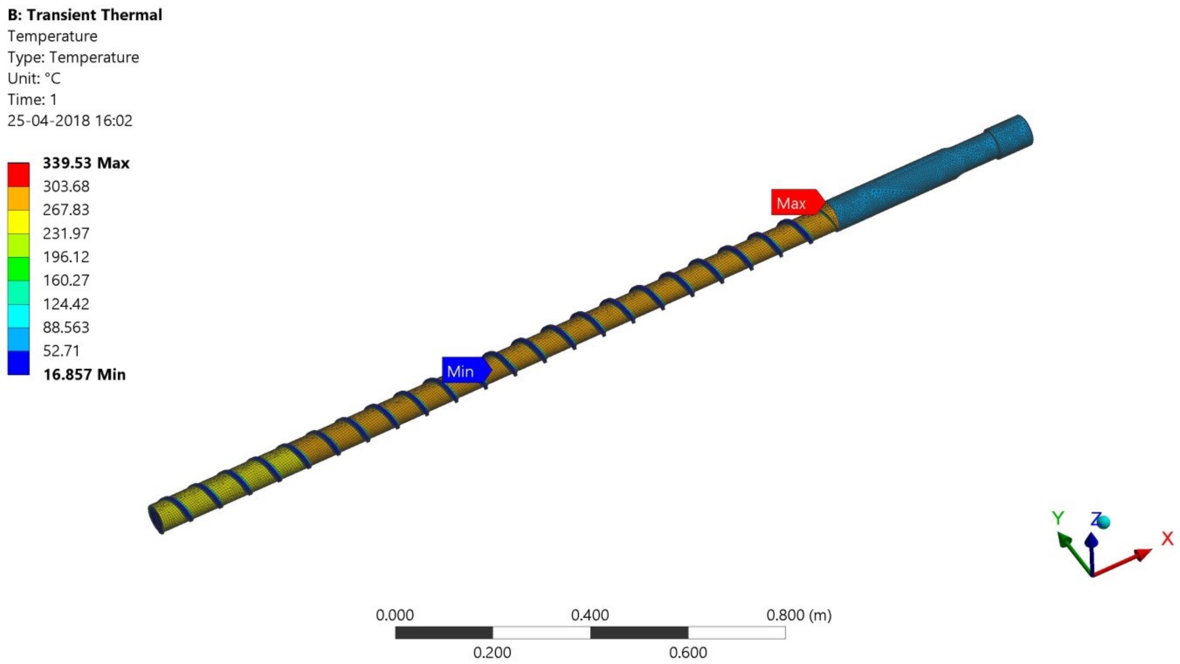

Figure 5.18: Temperature Profile of Nylon Raw Input using EN-41B Material of Reciprocating Screw

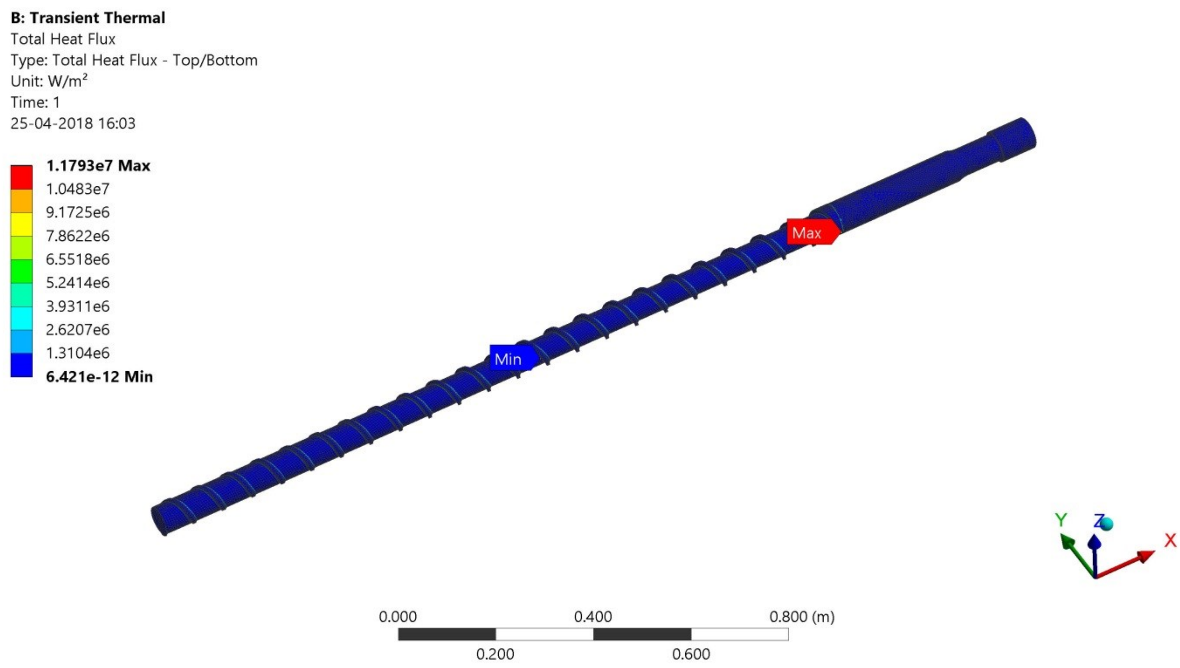

Figure 5.19: Total Heat Flux Profile of Nylon Raw Input using EN-41B Material of Reciprocating Screw

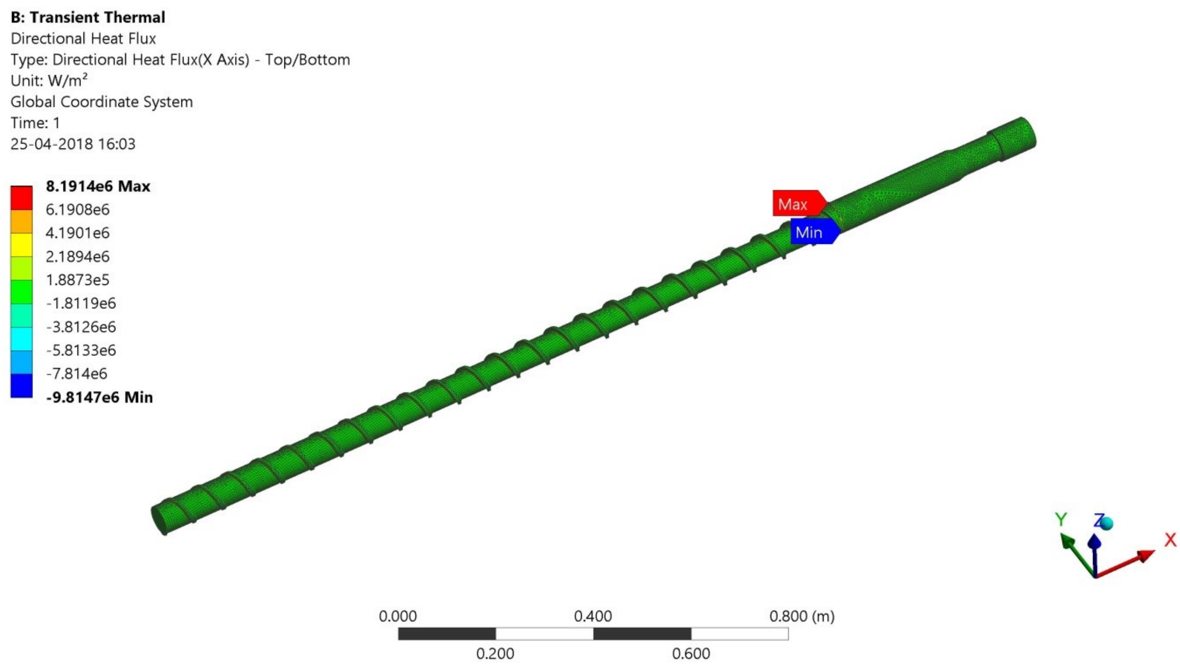

Figure 5.20: Directional Heat Flux Profile of Nylon Raw Input using EN-41B Material of Reciprocating Screw

- **LDPE Raw Input**

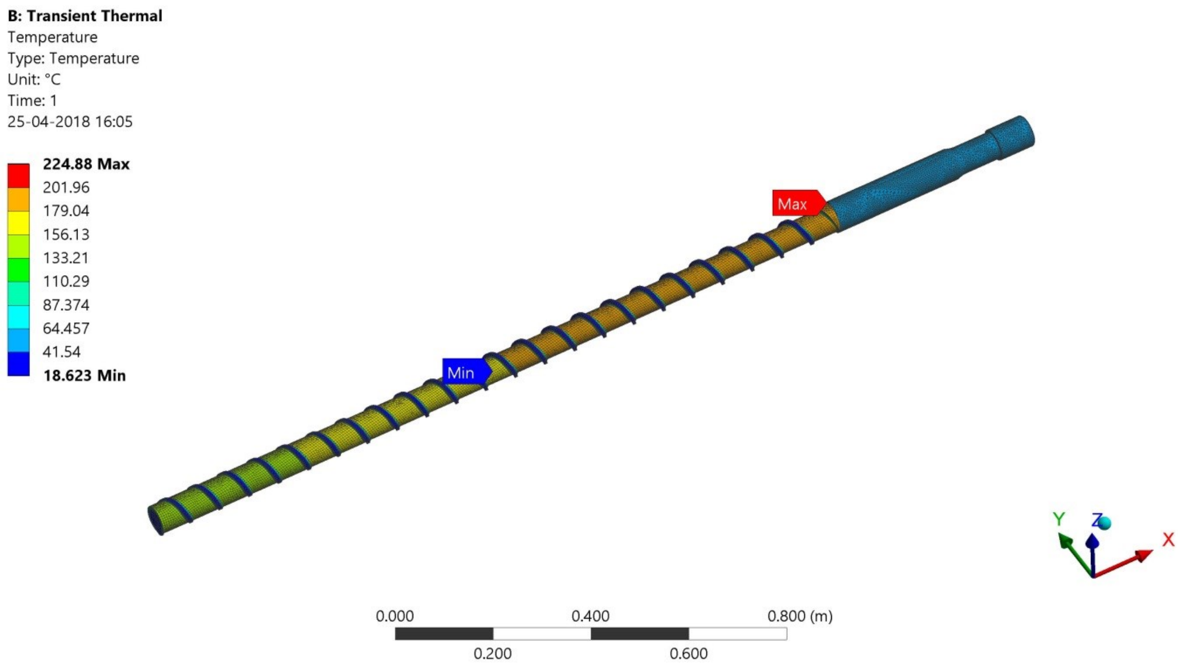

Figure 5.21: Temperature Profile of LDPE Raw Input using EN-41B Material of Reciprocating Screw

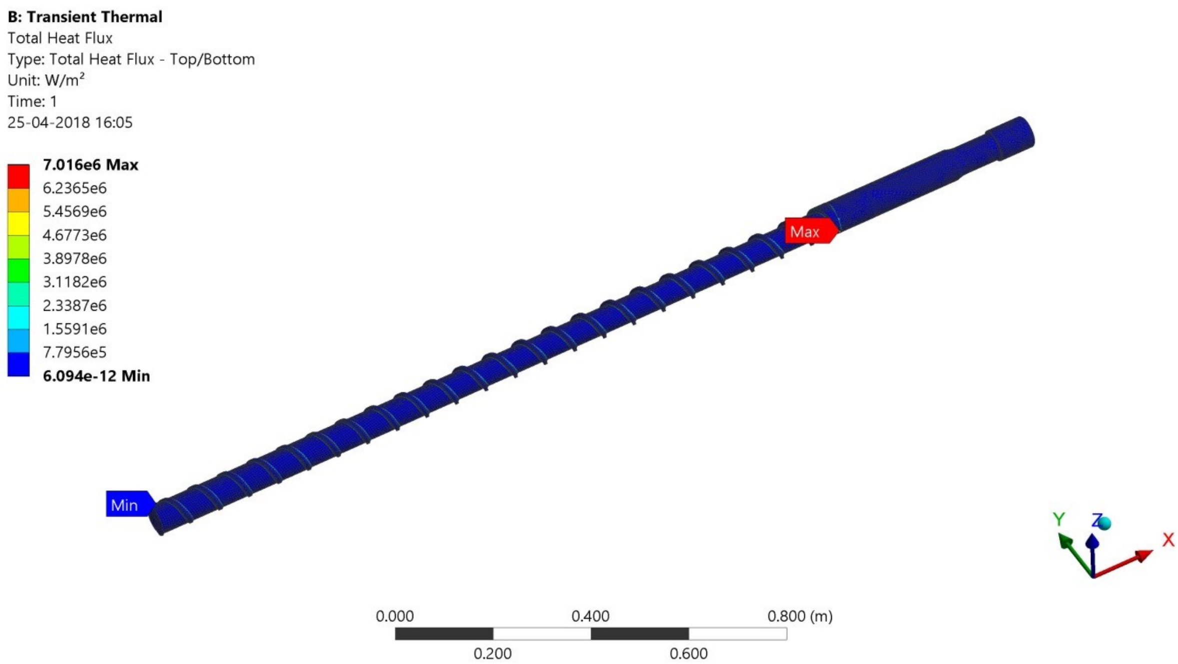

Figure 5.22: Total Heat Flux Profile of LDPE Raw Input using EN-41B Material of Reciprocating Screw

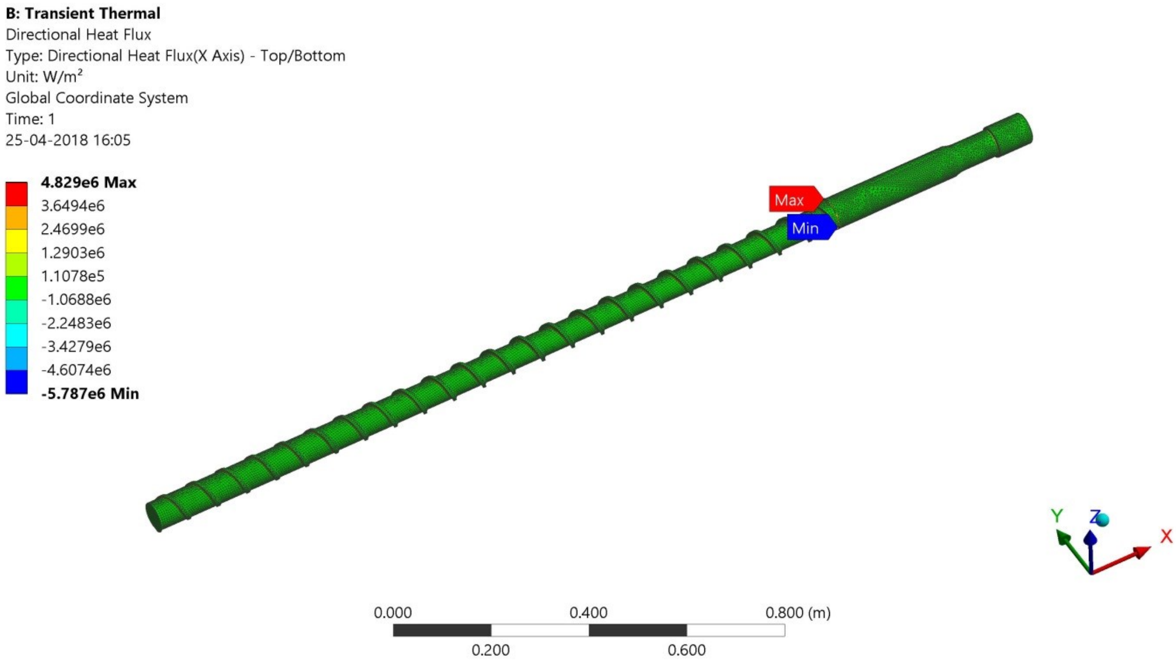

Figure 5.23: Directional Heat Flux Profile of LDPE Raw Input using EN-41B Material of Reciprocating Screw

- **Polypropylene Raw Input**

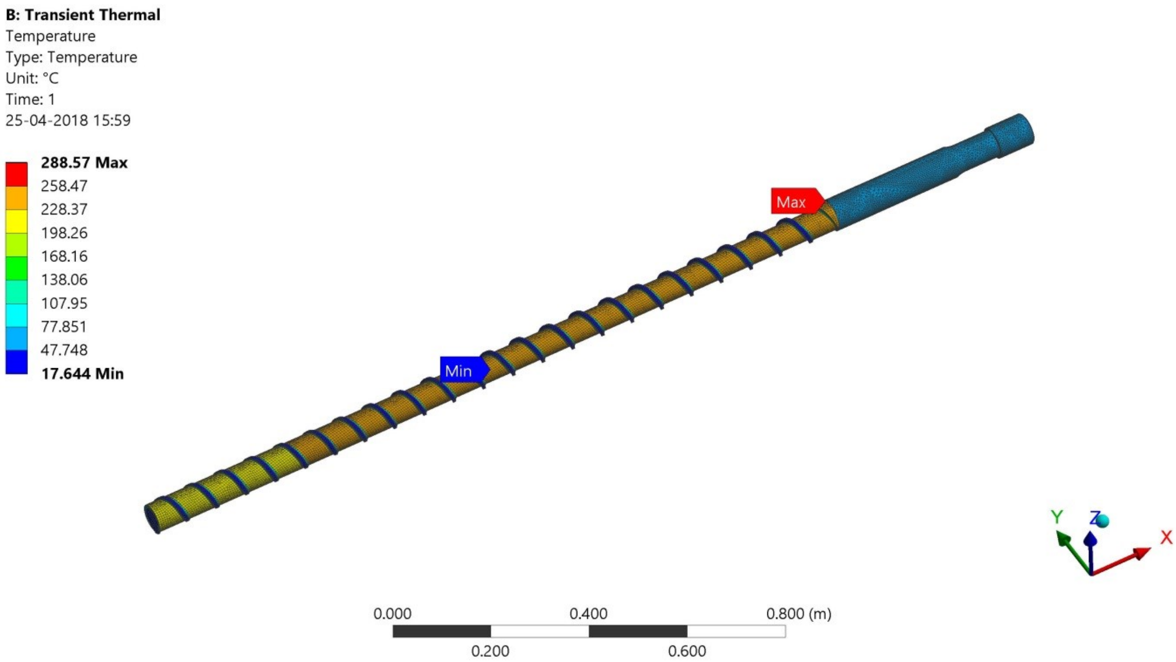

Figure 5.24: Temperature Profile of Polypropylene Raw Input using EN-41B Material of Reciprocating Screw

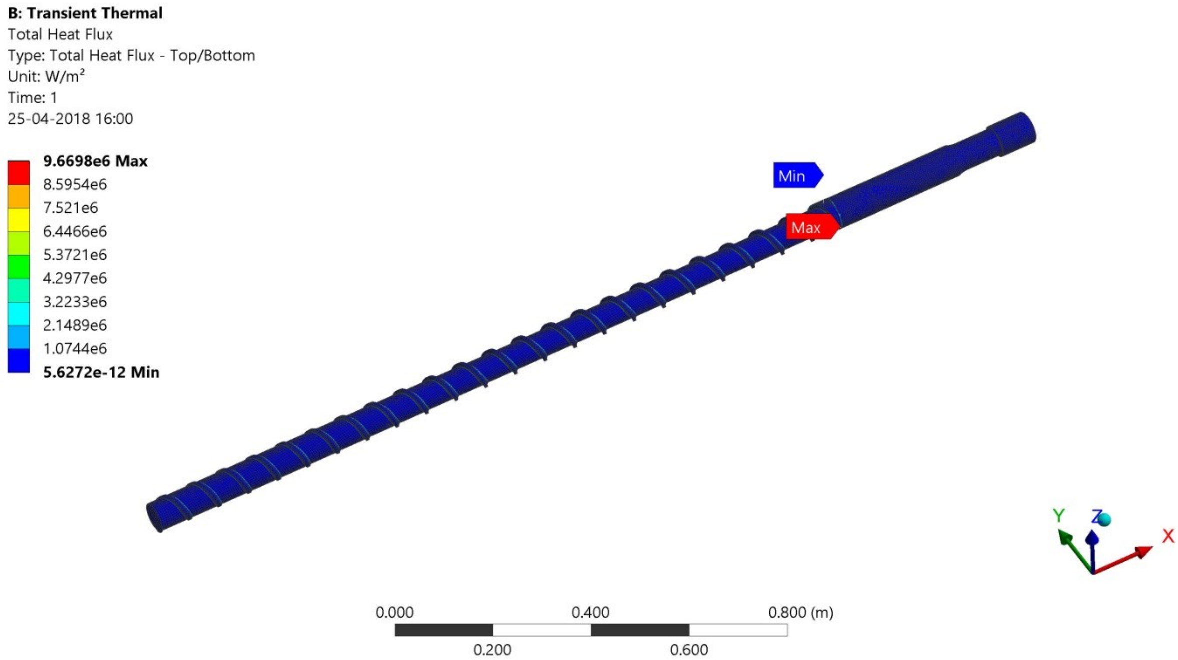

Figure 5.25: Total Heat Flux profile of Polypropylene Raw Input using EN-41B Material of Reciprocating Screw

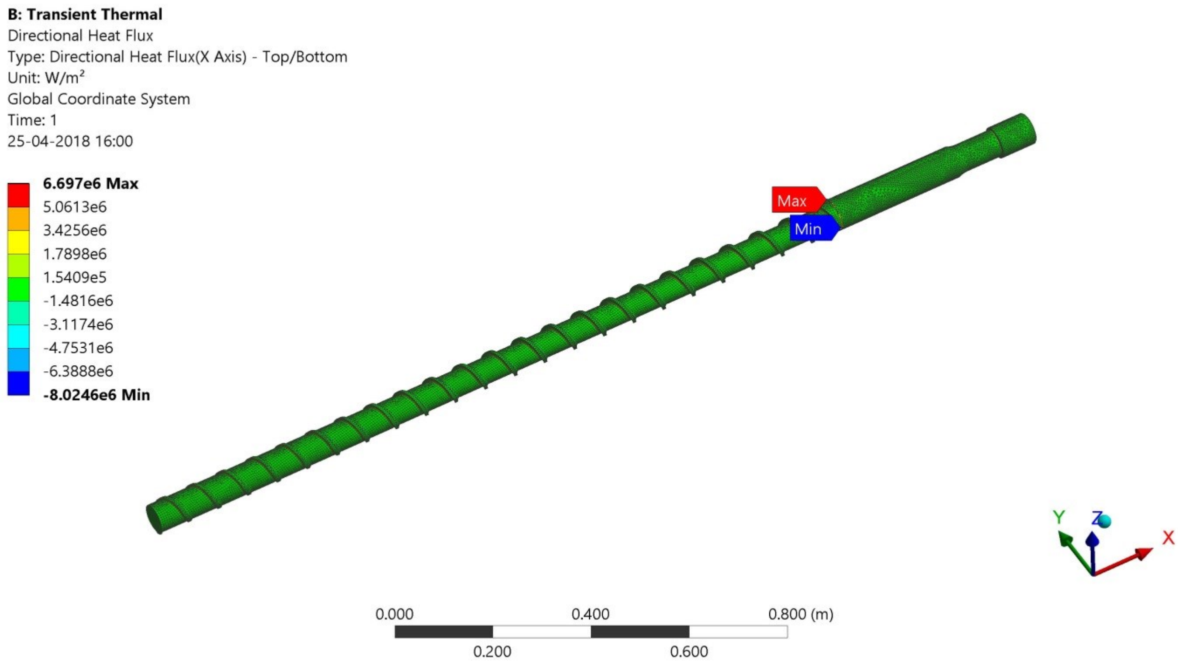

Figure 5.26: Directional Heat Flux Profile of Polypropylene Raw Input using EN-41B Material of Reciprocating Screw

- **PVC Raw Input**

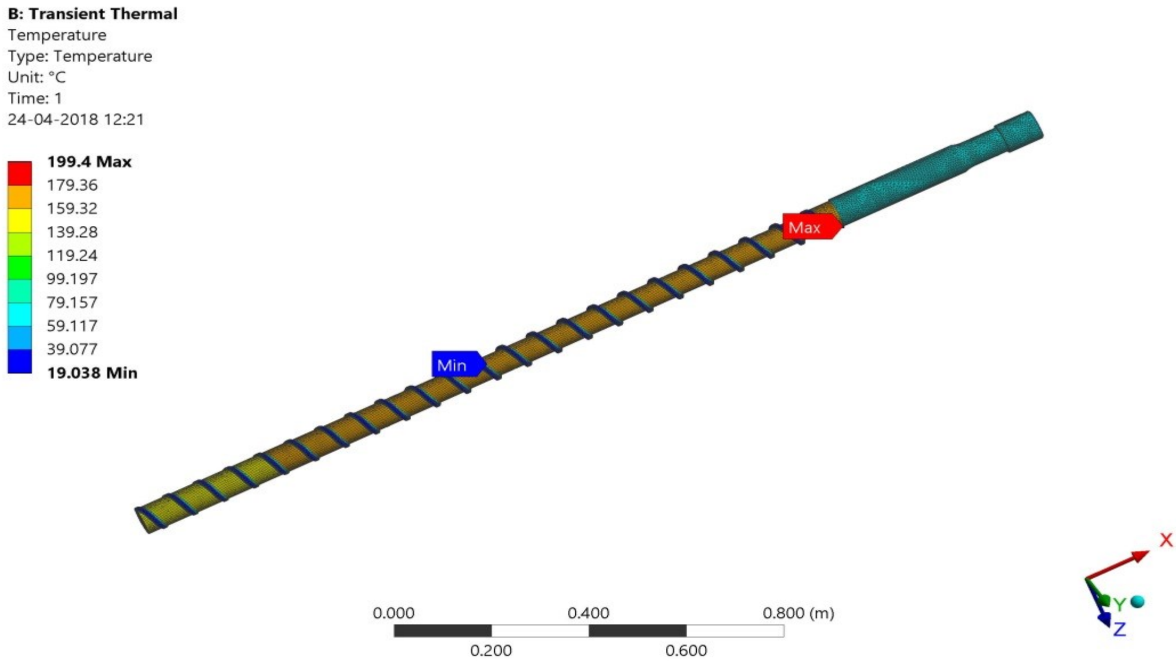

Figure 5.27: Temperature Profile of PVC Raw Input using EN-41B Material of Reciprocating Screw

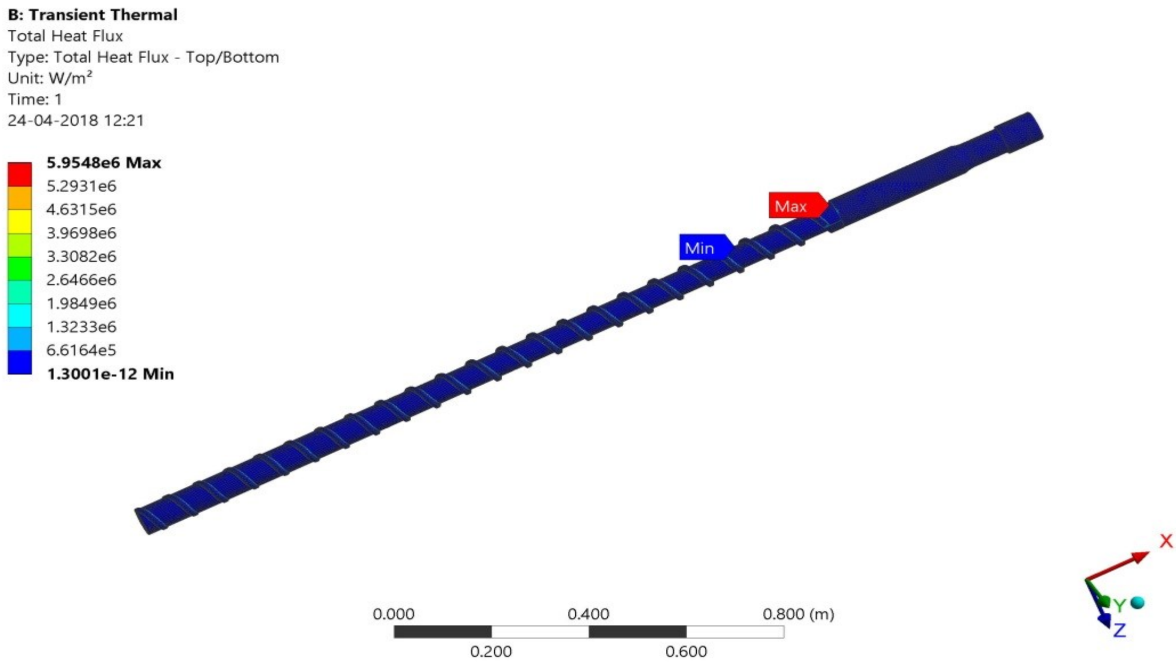

Figure 5.28: Total Heat Flux Profile of PVC Raw Input using EN-41B Material of Reciprocating Screw

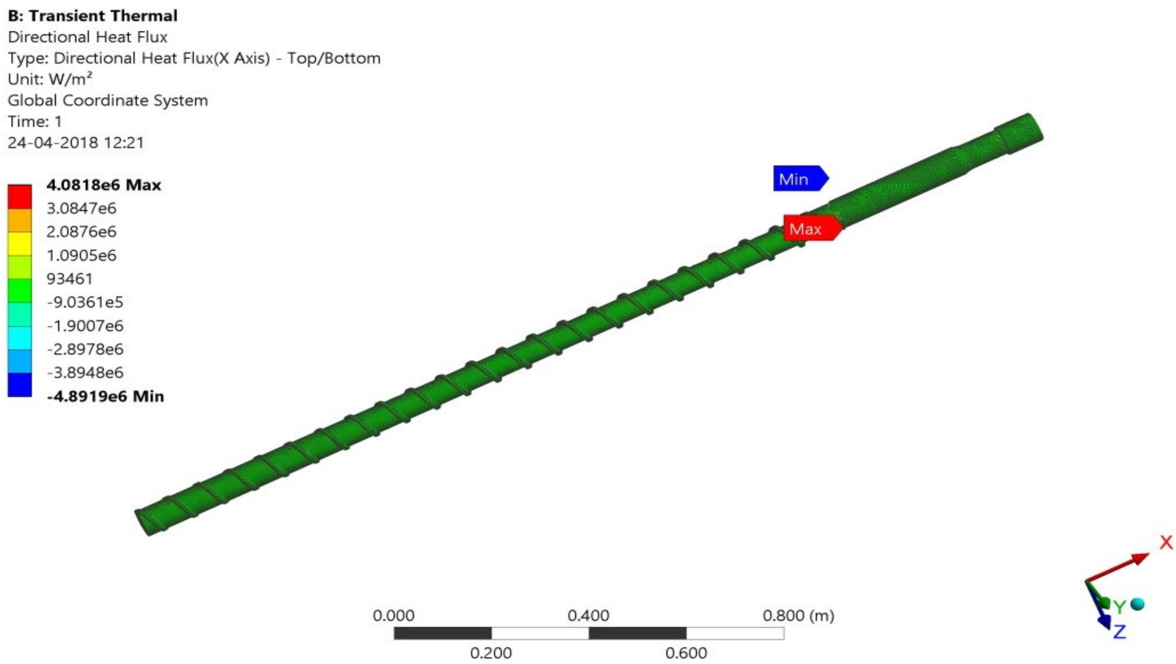

Figure 5.29: Directional Heat Flux Profile of PVC Raw Input using EN-41B Material of Reciprocating Screw

- **Polystyrene Raw Input**

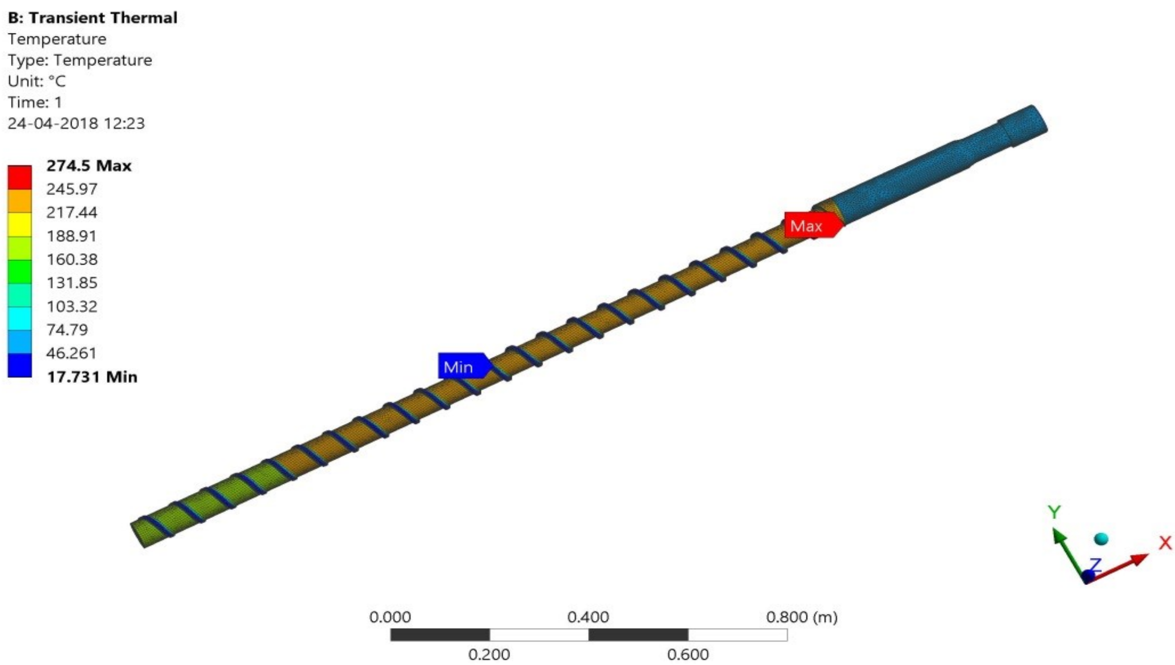

Figure 5.30: Temperature Profile of Polystyrene Raw Input using EN-41B Material of Reciprocating Screw

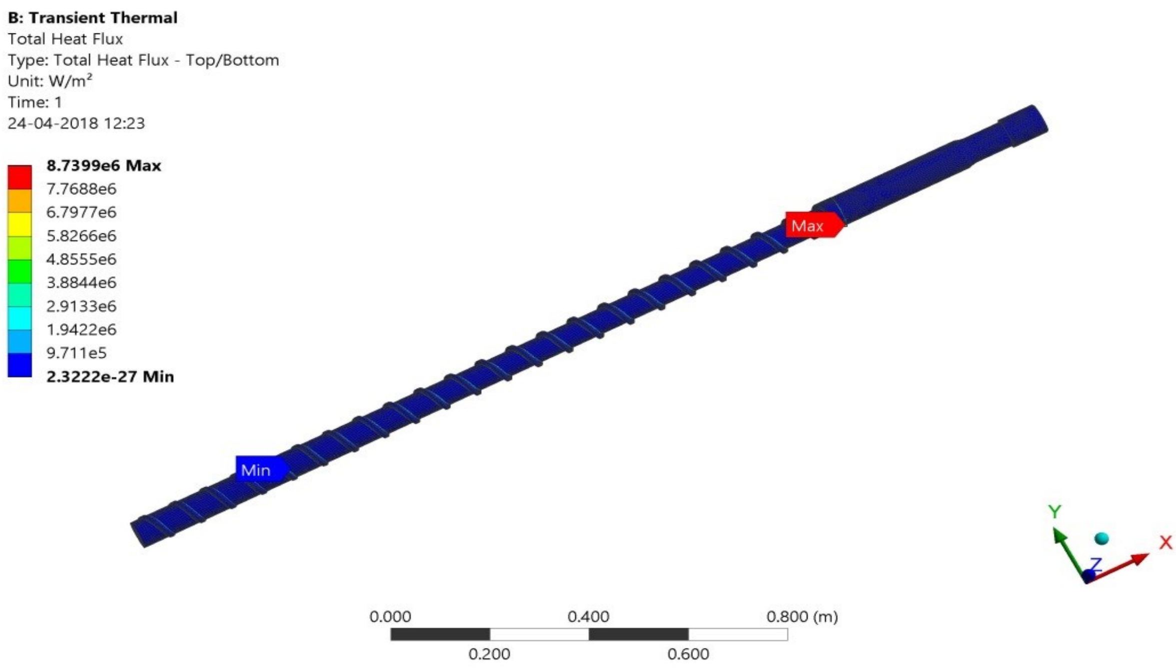

Figure 5.31: Total Heat Flux Profile of Polystyrene Raw Input using EN-41B Material of Reciprocating Screw

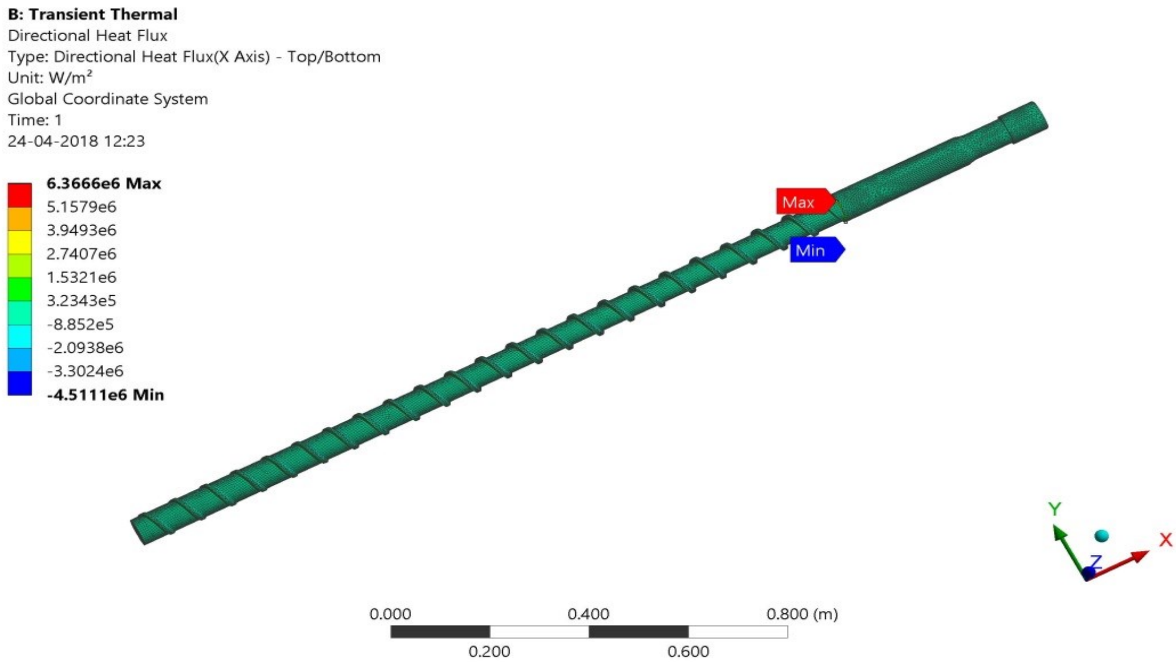

Figure 5.32: Directional Heat Flux Profile of Polystyrene Raw Input using EN-41B Material of Reciprocating Screw

5.2.5 Results of Transient Thermal Analysis for 69.8 mm Diameter of Reciprocating Screw

Results of temperature, total heat flux and directional heat flux of different raw material inputs using different material of reciprocating screw for 69.8 mm diameter of reciprocating screw are shown in following Tables.

Table 5.5: Results of Different Raw Material Inputs using EN 8 Material of Reciprocating Screw

Raw Materials	Temperature, °C	Total Heat Flux, W/m^2	Directional Heat Flux, W/m^2
Nylon	Max: 337.58 Min: 16.599	Max: 1.022e7 Min: 2.3045e-12	Max: 7.9687e6 Min: -5.3489e6
LDPE	Max: 224.99 Min: 18.593	Max: 6.4333e6 Min: 2.6481e-12	Max: 4.1501e6 Min: -5.3222e6
Polypropylene	Max: 291.3 Min: 17.651	Max: 8.8591e6 Min: 0	Max: 7.3752e6 Min: -7.398e6
PVC	Max: 198.79 Min: 19.6	Max: 7.3538e6 Min: 1.6879e-12	Max: 6.2821e6 Min: -3.7858e6
Polystyrene	Max: 274.5 Min: 17.117	Max: 8.0031e6 Min: 7.6174e-28	Max: 5.8313e6 Min: -4.135e6

Table 5.6: Results of Different Raw Material Inputs using EN 9 Material of Reciprocating Screw

Raw Materials	Temperature, °C	Total Heat Flux, W/m^2	Directional Heat Flux, W/m^2
Nylon	Max: 337.59 Min: 17.158	Max: 1.2247e7 Min: 2.801e-12	Max: 1.0729e7 Min: -6.4956e6
LDPE	Max: 224.03 Min: 18.996	Max: 7.4714e6 Min: 3.2187e-12	Max: 5.4253e6 Min: -3.8432e6
Polypropylene	Max: 287.12 Min: 18.617	Max: 1.0219e7 Min: 1.2954e-12	Max: 8.8553e6 Min: -5.315e6
PVC	Max: 198.79 Min: 18.548	Max: 6.3783e6 Min: 1.448e-12	Max: 5.277e6 Min: -3.2476e6
Polystyrene	Max: 274.5 Min: 17.254	Max: 9.6352e6 Min: 5.1103e-27	Max: 7.1071e6 Min: -5.0234e6

Table 5.7: Results of Different Raw Material Inputs using EN 24 Material of Reciprocating Screw

Raw Materials	Temperature, °C	Total Heat Flux, W/m^2	Directional Heat Flux, W/m^2
Nylon	Max: 337.59 Min: 17.533	Max: 1.0731e7 Min: 5.3798e-12	Max: 7.8873e6 Min: -5.5763e6
LDPE	Max: 224.03 Min: 18.58	Max: 6.4745e6 Min: 2.7597e-12	Max: 5.5262e6 Min: -3.2911e6
Polypropylene	Max: 289.98 Min: 17.887	Max: 9.2797e6 Min: 0	Max: 7.5498e6 Min: -7.6785e6
PVC	Max: 200.32 Min: 19.39	Max: 5.6734e6 Min: 1.2415e-12	Max: 4.5572e6 Min: -4.655e6
Polystyrene	Max: 274.5 Min: 18.334	Max: 8.3096e6 Min: 1.664e-27	Max: 6.0797e6 Min: -4.309e6

Table 5.8: Results of Different Raw Material Inputs using EN-41B Material of Reciprocating Screw

Raw Materials	Temperature, °C	Total Heat Flux, W/m^2	Directional Heat Flux, W/m^2
Nylon	Max: 339.53 Min: 16.857	Max: 1.1793e7 Min: 6.421e-12	Max: 8.1914e6 Min: -9.8147e6
LDPE	Max: 224.02 Min: 20.743	Max: 6.9454e6 Min: 3.2657e-12	Max: 4.9059e6 Min: -3.452e6
Polypropylene	Max: 289.26 Min: 19.668	Max: 9.7511e6 Min: 0	Max: 6.6906e6 Min: -7.975e6
PVC	Max: 199.4 Min: 19.038	Max: 5.9548e6 Min: 1.3001e-12	Max: 4.0818e6 Min: -4.8919e6
Polystyrene	Max: 274.5 Min: 17.731	Max: 8.7399e6 Min: 2.3222e-27	Max: 6.3666e6 Min: -4.5111e6

From tables, it can be conclude that among all the steel grade materials SAE 52100 (EN-41B) is the most suitable material to reduce wearing of threads for reciprocating screw because it exhibits the minimum heat flux generated while processing.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

- As per the requirement of the project a parametric modelling of reciprocating screw of injection moulding machine has been created of diameter 79.8 mm. The excel analysis function of creo (modelling software) has been used to generate parametric modelling of reciprocating screw of injection moulding machine. The other required sizes of the reciprocating screw also can be easily incorporate and model can be generated.
- Parametric modelling of reciprocating screw of injection moulding machine has been created of diameter 79.8 mm. The pro/programming function of creo (modelling software) has been used to obtain parametric modelling of reciprocating screw of injection moulding machine. Any parameter of the reciprocating screw also can be easily incorporate and model can be generated for further analysis.
- Static structural analysis showed the directional deformation of reciprocating screw of EN24 material is less compare to other materials. But, Factor of safety of reciprocating screw of EN-41B is 2.74096 more comparing to other materials. So, EN-41B material of the reciprocating screw is safer comparing to other materials.
- Transient thermal analysis showed the SAE 52100 (EN-41B) is the most suitable material comparing to other steel grade materials of reciprocating screw to reduce wearing of threads, because it exhibits the minimum heat flux generated while processing of plastic granules melting.

6.2 Future Work

- A simulation test for wear in the injection moulding machines. The simulation test can simulate the tribological conditions inside the barrel of an injection moulding machine. It has indicated the effect of temperature on the wear of screw or barrel material.
- To know the effects of design parameters on plasticizing.

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Appendix 1

```
INPUT
DIAMETER CHANGE STRING
"Do you want the change(y/n)?"
IF DIAMETER_CHANGE == "y"
    OUTER_DIAMETER NUMBER
    FEED_FLIGHT_DEPTH NUMBER
    METERING_FLIGHT_DEPTH NUMBER
    PITCH NUMBER
    METERING_LENGTH NUMBER
    COMPRESSION_LENGTH NUMBER
    FEED_LENGTH NUMBER
    NONFLOW_SIDE_RADIUS NUMBER
    FLOW_SIDE_RADIUS NUMBER
    UNDERCUT_LENGTH NUMBER
    UNDERCUT_DIAMETER NUMBER
    TOTAL_SHANK_LENGTH NUMBER
    SHANK_DIAMETER1 NUMBER
    SHANK_LENGTH1 NUMBER
    SHANK_DIAMETER2 NUMBER
    SHANK_DIAMETER3 NUMBER
    SHANK_LENGTH3 NUMBER
    SPLINE_DIAMETER NUMBER
    SPLINE_LENGTH NUMBER
    CHAMFER_LENGTH NUMBER
    CHAMFER_ANGLE NUMBER
END IF
END INPUT
```

```
RELATIONS
    D80=PITCH-(PITCH*0.1)
    D84=PITCH/2
    D134= ((2*OUTER_DIAMETER)-(2*UNDERCUT_DIAMETER))/2
    SHANK_LENGTH2=TOTAL_SHANK_LENGTH-SHANK_LENGTH1-
SHANK_LENGTH3-SPLINE_LENGTH
END RELATIONS

    ADD FEATURE (initial number 1)
    INTERNAL FEATURE ID 1
DATUM PLANE
NO. ELEMENT NAME INFO
---    -------------   -------------
1       Feature Name Defined
2       Constraints Defined
2.1     Constraint #1   Defined
2.1.1 Constr Type X Axis
3       Flip Datum Dir Defined
4       Fit Defined
4.1     Fit Type Default
NAME = PLANE2
  FEATURE IS IN LAYER(S):
     01___PRT_ALL_DTM_PLN - OPERATION = SHOWN
     01___PRT_DEF_DTM_PLN - OPERATION = SHOWN
END ADD
    ADD FEATURE (initial number 2)
    INTERNAL FEATURE ID 3
    DATUM PLANE
NO. ELEMENT NAME INFO
 ---   -------------   -------------
   1       Feature Name Defined
   2       Constraints Defined
```

2.1 Constraint #1 Defined

2.1.1 Constr Type Y Axis

3 Flip Datum Dir Defined

4 Fit Defined

4.1 Fit Type Default

NAME = TOP

FEATURE IS IN LAYER(S):

01___PRT_ALL_DTM_PLN - OPERATION = SHOWN

01___PRT_DEF_DTM_PLN - OPERATION = SHOWN

END ADD

ADD FEATURE (initial number 3)

INTERNAL FEATURE ID 5

DATUM PLANE

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Constraints Defined

2.1 Constraint #1 Defined

2.1.1 Constr Type Z Axis

3 Flip Datum Dir Defined

4 Fit Defined

4.1 Fit Type Default

NAME = FRONT

FEATURE IS IN LAYER(S):

01___PRT_ALL_DTM_PLN - OPERATION = SHOWN

01___PRT_DEF_DTM_PLN - OPERATION = SHOWN

END ADD

ADD FEATURE (initial number 4)

INTERNAL FEATURE ID 7

TYPE = COORDINATE SYSTEM

NAME = PRT_CSYS_DEF

FEATURE IS IN LAYER(S):

05___PRT_ALL_DTM_CSYS - OPERATION = SHOWN

05___PRT_DEF_DTM_CSYS - OPERATION = SHOWN

END ADD

ADD FEATURE (initial number 5)

INTERNAL FEATURE ID 40

PARENTS = 1(#1)

DATUM PLANE

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Constraints Defined

2.1 Constraint #1 Defined

2.1.1 Constr Type Offset

2.1.2 Constr References Surface PLANE2 of feat #1 (DATUM PLANE)

2.1.3 Constr Ref Offset Value = -444.0000

3 Flip Datum Dir Defined

4 Fit Defined

4.1 Fit Type Default

NAME = PLANE1

FEATURE IS IN LAYER(S):

01___PRT_ALL_DTM_PLN - OPERATION = SHOWN

FEATURE'S DIMENSIONS:

Metering_Length = (Displayed :) 444

(Stored :) -444.0 (0.01, -0.01)

END ADD

ADD FEATURE (initial number 6)

INTERNAL FEATURE ID 42

PARENTS = 1(#1)

DATUM PLANE

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Constraints Defined

2.1 Constraint #1 Defined

2.1.1 Constr Type Offset

2.1.2 Constr References Surface PLANE2 of feat #1 (DATUM PLANE)

2.1.3 Constr Ref Offset Value = 667.0000

3 Flip Datum Dir Defined

4 Fit Defined

4.1 Fit Type Default

NAME = PLANE3

FEATURE IS IN LAYER(S):

01___PRT_ALL_DTM_PLN - OPERATION = SHOWN

FEATURE'S DIMENSIONS:

Compression_Length = (Displayed :) 667

(Stored :) 667.0 (0.01, -0.01)

END ADD

ADD FEATURE (initial number 7)

INTERNAL FEATURE ID 44

PARENTS = 42(#6)

DATUM PLANE

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Constraints Defined

2.1 Constraint #1 Defined

2.1.1 Constr Type Offset

2.1.2 Constr References Surface PLANE3 of feat #6 (DATUM PLANE)

2.1.3 Constr Ref Offset Value = 1112.0000

3 Flip Datum Dir Defined

4 Fit Defined

4.1 Fit Type Default

NAME = PLANE4

FEATURE IS IN LAYER(S):

01___PRT_ALL_DTM_PLN - OPERATION = SHOWN

FEATURE'S DIMENSIONS:

Feed_Length = (Displayed :) 1112

(Stored :) 1112.0 (0.01, -0.01)

END ADD

IF RADIUS_CHANGE == "y"

ADD FEATURE (initial number 8)

INTERNAL FEATURE ID 46

PARENTS = 3(#2) 40(#5) 44(#7) 1(#1) 5(#3)

Sketch

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Section Defined

2.1 Setup Plane Defined

2.1.1 Sketching Plane FRONT: F3 (DATUM PLANE)

2.1.2 View Direction Side 1

2.1.3 Orientation Right

2.1.4 Reference PLANE2:F1 (DATUM PLANE)

2.2 Sketch Defined

3 X-hatching Closed curve sections will NOT be cross hatched

3.1 Display NO

SECTION NAME = Sketch 1

FEATURE IS IN LAYER(S):

03___PRT_ALL_CURVES - OPERATION = SHOWN

FEATURE'S DIMENSIONS:

d162 = (Displayed :) 0 (weak)

(Stored :) 0.0 (0.01, -0.01)

d167 = (Displayed :) 90 (weak)

(Stored :) 90.0 (0.5, -0.5)

Outer_Diameter = (Displayed :) 99.8 Dia

(Stored :) 99.8 (0.01, -0.01)

END ADD

ADD FEATURE (initial number 9)

INTERNAL FEATURE ID 154

PARENTS = 46(#8)

PROTRUSION: Revolve

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Extrude Feat type Solid

3 Material Add

4 Section Defined

4.1 Reference Sketch F8 (SKETCH_1)

5 Feature Form Solid

6 Revolve Axis Defined

7 Revolve Axis Option Internal Centreline

8 Direction Side 2

9 Angle Defined

9.1 Side One Defined

9.1.1 Side One Angle None

9.2 Side Two Defined

9.2.1 Side Two Angle Variable

9.2.2 Value 360.0

SECTION NAME = Sketch 1

FEATURE IS IN LAYER(S):

02___PRT_ALL_AXES - OPERATION = SHOWN

FEATURE'S DIMENSIONS:

d21 = (Displayed :) 360

(Stored :) 360.0 (0.5, -0.5)

END ADD

ADD FEATURE (initial number 10)

INTERNAL FEATURE ID 213

PARENTS = 1(#1) 40(#5) 42(#6) 44(#7) 154(#9) 5(#3)

CUT: Helical Sweep

NO. ELEMENT NAME INFO

---	-------------	-------------
1	Feature Name	Defined
2	Section	Defined
2.1	Sketch	Defined
3	Extrude Feat type	Solid
4	Material	Remove
5	Feature Form	Solid
6	Material Side	Two
7	Profile section	Defined
7.1	Setup Plane	Defined
7.1.1	Sketching Plane	FRONT: F3(DATUM PLANE)
7.1.2	View Direction	Side 1
7.1.3	Reference	PLANE2:F1 (DATUM PLANE)
7.2	Sketch	Defined
8	Sketch plane orientation	through axis of revolution
9	Section Flip	through axis of revolution
10	Revolve Axis	A_4 (AXIS):F9 (REVOLVE_1)
11	Revolve Axis Option	External Ref
12	Pitch array	Defined
12.1	Pitch Compounds	Defined
12.1.1	Pitch reference	Defined
12.1.2	Pitch value	100.0000
12.1.3	Pitch reference option	Start Point
12.1.4	Pitch location parameter	0.0000
12.1.5	Pitch location parameter	0.0000
13	Section cost/variable option	Keep constant section
14	Pitch reference option	Use left handed rule.

SECTION NAME = Profile Section

SECTION NAME = Sweep Section

OPEN SECTION

FEATURE'S DIMENSIONS:

Pitch = (Displayed :) 100PITCH

(Stored :) 100.0 (0.01, -0.01)

Non-flow_side_Radius = (Displayed :) 3.5R

(Stored :) 3.5 (0.01, -0.01)

d78 = (Displayed :) 0

(Stored :) 0.0 (0.01, -0.01)

d79 = (Displayed :) 31.5

(Stored :) 31.5 (0.01, -0.01)

d80 = (Displayed :) 90

(Stored :) 90.0 (0.01, -0.01)

d84 = (Displayed :) 50

(Stored :) 50.0 (0.01, -0.01)

d85 = (Displayed :) 51.04

(Stored :) 51.04 (0.01, -0.01)

d86 = (Displayed :) 25

(Stored :) 25.0 (0.01, -0.01)

Feed Flight Depth = (Displayed :) 9.7

(Stored :) 9.7 (0.01, -0.01)

Metering_Flight_Depth = (Displayed :) 4.2

(Stored :) 4.2 (0.01, -0.01)

Flow_side_Radius = (Displayed :) 7R

(Stored :) 7.0 (0.01, -0.01)

END ADD

ADD FEATURE (initial number 11)

INTERNAL FEATURE ID 2105

PARENTS = 3(#2) 154(#9) 1(#1) 5(#3)

Sketch

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Section Defined

2.1 Setup Plane Defined

2.1.1 Sketching Plane FRONT: F3 (DATUM PLANE)

2.1.2 View Direction Side 1

2.1.3 Orientation Right

2.1.4 Reference PLANE2:F1 (DATUM PLANE)

2.2 Sketch Defined

3 X-hatching Closed curve sections will NOT be cross hatched

3.1 Display NO

SECTION NAME = Sketch 6

FEATURE IS IN LAYER(S):

02___PRT_ALL_AXES - OPERATION = SHOWN

03___PRT_ALL_CURVES - OPERATION = SHOWN

FEATURE'S DIMENSIONS:

d134 = (Displayed :) 0.3

(Stored :) 0.3 (0.01, -0.01)

Undercut_Length = (Displayed :) 458

(Stored :) 458.0 (0.01, -0.01)

Undercut_Diameter = (Displayed :) 99.5 Dia

(Stored :) 99.5 (0.01, -0.01)

END ADD

ADD FEATURE (initial number 12)

INTERNAL FEATURE ID 2149

PARENTS = 2105(#11)

CUT: Revolve

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Extrude Feat type Solid

3 Material Remove

4 Section Defined

4.1 Reference Sketch F11 (SKETCH_6)

5 Feature Form Solid

6 Material Side Two

7 Revolve Axis Defined

8 Revolve Axis Option Internal Centreline

9 Direction Side 2

10 Angle Defined

10.1 Side One Defined

10.1.1 Side One Angle None

10.2 Side Two Defined

10.2.1 Side Two Angle Variable

10.2.2 Value 360.0

SECTION NAME = Sketch 6

FEATURE IS IN LAYER(S):

02___PRT_ALL_AXES - OPERATION = SHOWN

FEATURE'S DIMENSIONS:

d137 = (Displayed :) 360

(Stored :) 360.0 (0.5, -0.5)

END ADD

END IF

ADD FEATURE (initial number 13)

INTERNAL FEATURE ID 2749

PARENTS = 44(#7) DATUM PLANE

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Constraints Defined

2.1 Constraint #1 Defined

2.1.1 Constr Type Offset

2.1.2 Constr References Surface PLANE4 of feat #7 (DATUM PLANE)

2.1.3 Constr Ref Offset Value = 633.0000

3 Flip Datum Dir Defined

4 Fit Defined

4.1 Fit Type Default

NAME = DTM
FEATURE IS IN LAYER(S):
01___PRT_ALL_DTM_PLN - OPERATION = SHOWN
FEATURE'S DIMENSIONS:
Total_Shank_Length = (displayed :) 633
(Stored :) 633.0 (0.01, -0.01)
END ADD
IF DIAMETER_CHANGE == "y"
ADD FEATURE (initial number 14)
INTERNAL FEATURE ID 2049
PARENTS = 7(#4) 154(#9) 2749(#13)
Sketch
NO. ELEMENT NAME INFO
--- ------------- -------------
1 Feature Name Defined
2 Section Defined
2.1 Setup Plane Defined
2.1.1 Sketching Plane DTM1:F13 (DATUM PLANE)
2.1.2 View Direction Side 1
2.1.3 Orientation Right
2.1.4 Reference Surf: F9 (REVOLVE_1)
2.2 Sketch Defined
3 X-hatching Closed curve sections will NOT be cross hatched
3.1 Display NO
SECTION NAME = Sketch 5
FEATURE IS IN LAYER(S):
03_PRT_ALL_CURVES - OPERATION = SHOWN
FEATURE'S DIMENSIONS:
Spline_Diameter = (Displayed :) 99.29 Dia
(Stored :) 99.29 (0.01, -0.01)
END ADD
ADD FEATURE (initial number 15)

INTERNAL FEATURE ID 2055

PARENTS = 2049(#14)

PROTRUSION: Extrude

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Extrude Feat type Solid

3 Material Add

4 Section Defined

4.1 Reference Sketch F14 (SKETCH_5)

5 Feature Form Solid

6 Direction Side 1

7 Depth Defined

7.1 Side One Defined

7.1.1 Side One Depth None

7.2 Side Two Defined

7.2.1 Side Two Depth Variable

7.2.2 Value 98.00

SECTION NAME = Sketch 5

FEATURE IS IN LAYER(S):

02___PRT_ALL_AXES - OPERATION = SHOWN

FEATURE'S DIMENSIONS:

Spline_Length = (Displayed :) 98

(Stored :) 98.0 (0.01, -0.01)

END ADD

ADD FEATURE (initial number 16)

INTERNAL FEATURE ID 2012

PARENTS = 7(#4) 154(#9) 2055(#15)

Sketch

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Section Defined

2.1 Setup Plane Defined

2.1.1 Sketching Plane Surf: F15 (EXTRUDE_4)

2.1.2 View Direction Side 1

2.1.3 Orientation Right

2.1.4 Reference Surf: F9 (REVOLVE_1)

2.2 Sketch Defined

3 X-hatching Closed curve sections will NOT be cross hatched

3.1 Display NO

SECTION NAME = Sketch 4

FEATURE IS IN LAYER(S):

03___PRT_ALL_CURVES - OPERATION = SHOWN

FEATURE'S DIMENSIONS:

Shank_Diameter3 = (Displayed :) 90 Dia

(Stored :) 90.0 (0.01, -0.01)

END ADD

ADD FEATURE (initial number 17)

INTERNAL FEATURE ID 2018

PARENTS = 2012(#16)

PROTRUSION: Extrude

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Extrude Feat type Solid

3 Material Add

4 Section Defined

4.1 Reference Sketch F16 (SKETCH_4)

5 Feature Form Solid

6 Direction Side 2

7 Depth Defined

7.1 Side One Defined

7.1.1 Side One Depth None

7.2 Side Two Defined

7.2.1 Side Two Depth Variable

7.2.2 Value 100.00

SECTION NAME = Sketch 4

FEATURE IS IN LAYER(S):

02___PRT_ALL_AXES - OPERATION = SHOWN

FEATURE'S DIMENSIONS:

Shank_Length3 = (Displayed :) 100

(Stored :) 100.0 (0.01, -0.01)

END ADD

ADD FEATURE (initial number 18)

INTERNAL FEATURE ID 1939

PARENTS = 7(#4) 154(#9)

Sketch

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Section Defined

2.1 Setup Plane Defined

2.1.1 Sketching Plane Surf: F9 (REVOLVE_1)

2.1.2 View Direction Side 1

2.1.3 Orientation Right

2.1.4 Reference Surf: F9 (REVOLVE_1)

2.2 Sketch Defined

3 X-hatching Closed curve sections will NOT be cross hatched

3.1 Display NO

SECTION NAME = Sketch 2

FEATURE IS IN LAYER(S):

03___PRT_ALL_CURVES - OPERATION = SHOWN

FEATURE'S DIMENSIONS:

Shank_Diameter1 = (Displayed :) 99.5 Dia

(Stored :) 99.5 (0.01, -0.01)

END ADD

ADD FEATURE (initial number 19)

INTERNAL FEATURE ID 1945

PARENTS = 1939(#18)

PROTRUSION: Extrude

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Extrude Feat type Solid

3 Material Add

4 Section Defined

4.1 Reference Sketch F18 (SKETCH_2)

5 Feature Form Solid

6 Direction Side 2

7 Depth Defined

7.1 Side One Defined

7.1.1 Side One Depth None

7.2 Side Two Defined

7.2.1 Side Two Depth Variable

7.2.2 Value 83.00

SECTION NAME = Sketch 2

FEATURE IS IN LAYER(S):

02___PRT_ALL_AXES - OPERATION = SHOWN

FEATURE'S DIMENSIONS:

Shank_Length1 = (Displayed :) 83

(Stored :) 83.0 (0.01, -0.01)

END ADD

ADD FEATURE (initial number 20)

INTERNAL FEATURE ID 1980

PARENTS = 7(#4) 154(#9) 1945(#19)

Sketch

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Section Defined

2.1 Setup Plane Defined

2.1.1 Sketching Plane Surf: F19 (EXTRUDE_1)

2.1.2 View Direction Side 1

2.1.3 Orientation Right

2.1.4 Reference Surf: F9 (REVOLVE_1)

2.2 Sketch Defined

3 X-hatching Closed curve sections will NOT be cross hatched

3.1 Display NO

SECTION NAME = Sketch 3

FEATURE IS IN LAYER(S):

03___PRT_ALL_CURVES - OPERATION = SHOWN

FEATURE'S DIMENSIONS:

Shank_Diameter2 = (Displayed :) 99 Dia

(Stored :) 99.0 (0.01, -0.01)

END ADD

ADD FEATURE (initial number 21)

INTERNAL FEATURE ID 1986

PARENTS = 1980(#20)

PROTRUSION: Extrude

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Extrude Feat type Solid

3 Material Add

4 Section Defined

4.1 Reference Sketch F20 (SKETCH_3)

5 Feature Form Solid

6 Direction Side 2

7 Depth Defined

7.1 Side One Defined

7.1.1 Side One Depth None

7.2 Side Two Defined

7.2.1 Side Two Depth Variable

7.2.2 Value 352.00

SECTION NAME = Sketch 3

FEATURE IS IN LAYER(S):

02___PRT_ALL_AXES - OPERATION = SHOWN

FEATURE'S DIMENSIONS:

Shank_length2 = (Displayed :) 352

(Stored :) 352.0 (0.01, -0.01)

END ADD

ADD FEATURE (initial number 22)

INTERNAL FEATURE ID 2081

PARENTS = 2055(#15)

CHAMFER: Edge

NO. ELEMENT NAME INFO

--- ------------- -------------

1 Feature Name Defined

2 Sets 1 Set

2.1 Set0 Defined

2.1.1 Dimensional Schema Angle X D

2.1.2 Chamfer shape Offset Surfaces

2.1.3 Conic Defined

2.1.3.1 Conic Type Plain

2.1.4 References Defined

2.1.4.1 Reference type Edge Chain

2.1.4.2 Curve Collection 2 Selections

2.1.4.3 Reference Surface Defined
2.1.5 Radii1 Points
2.1.5.1 Rad 0 Defined
2.1.5.1.1 D1 Defined
2.1.5.1.1.1 Distance type Enter Value
2.1.5.1.1.2 Distance value 3.00
2.1.5.1.2 D2 Defined
2.1.5.1.2.1 Distance type Enter Value
2.1.5.1.2.2 Distance value 45.0
2.1.6 Pieces1 of 1 Included, 0 Trimmed, 0 Extended
3 Attach type Make Solid
4 Transitions Defined

FEATURE'S DIMENSIONS:

Chamfer_Length = (Displayed :) 3
(Stored :) 3.0 (0.01, -0.01)
Chamfer_Angle = (Displayed :) 45
(Stored :) 45.0 (0.5, -0.5)

END ADD

ADD FEATURE (initial number 23)
INTERNAL FEATURE ID 2244
PARENTS = 1986(#21) 2018(#17)

ROUND: General

NO. ELEMENT NAME INFO
--- ------------ -------------
1 Feature Name Defined
2 Sets 1 Set
2.1 Set 0 Defined
2.1.1 Shape options Constant
2.1.2 Conic Defined
2.1.2.1 Conic Type Plain
2.1.3 References Defined
2.1.3.1 Reference type Edge Chain

2.1.3.2 Curve Collection 2 Selections

2.1.4 Spine Defined

2.1.4.1 Ball/Spine Rolling Ball

2.1.5 Extend Surfaces Disable

2.1.6 Radii 1 Points

2.1.6.1 Rad 0 Defined

2.1.6.1.1 D1 Defined

2.1.6.1.1.1 Distance type Enter Value

2.1.6.1.1.2 Distance value 63.00

2.1.7 Pieces1 of 1 Included, 0 Trimmed, 0 Extended

3 Attach type Make Solid

4 Transitions Defined

FEATURE'S DIMENSIONS:

d158 = (Displayed :) 63R

(Stored :) 63.0 (0.01, -0.01)

END ADD

ADD FEATURE (initial number 24)

INTERNAL FEATURE ID 2267

PARENTS = 2018(#17) 2055(#15)

ROUND: General

NO. ELEMENT NAME INFO

--- ------------ -------------

1 Feature Name Defined

2 Sets1 Set

2.1 Set 0 Defined

2.1.1 Shape options Constant

2.1.2 Conic Defined

2.1.2.1 Conic Type Plain

2.1.3 References Defined

2.1.3.1 Reference type Edge Chain

2.1.3.2 Curve Collection 2 Selections

2.1.4 Spine Defined

2.1.4.1 Ball/Spine Rolling Ball

2.1.5 Extend Surfaces Disable

2.1.6 Radii 1 Points

2.1.6.1 Rad 0 Defined

2.1.6.1.1 D1 Defined

2.1.6.1.1.1 Distance type Enter Value

2.1.6.1.1.2 Distance value 1.00

2.1.7 Pieces1 of 1 Included, 0 Trimmed, 0 Extended

3 Attach type Make Solid

4 Transitions Defined

FEATURE'S DIMENSIONS:

d159 = (Displayed :) 1R

(Stored :) 1.0 (0.01, -0.01)

END ADD

END IF

MASSPROP

END MASSPROP