DESIGN AND ANALYSIS OF NEW COUPLING SYSTEM IN INJECTION MOLDING MACHINE TO IMPROVE SCREW LIFE

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ABSTRACT

Injection molding machine is the most commonly used manufacturing process for the fabrication of plastic parts. The plastic being melted in injection molding 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. This project deals with, the solution of problem occurred for reciprocating screw of Injection molding machine. It identifies and solves the problem by using the modeling and analysis techniques.
The problem occurred in the reciprocating screw of machine which is wearing of threads due to affect of temperature of mold materials (flow materials) i.e. Nylon, low density polypropylene, polystyrene, PVC etc., The main work was to model the components of machine with dimensions, and perform thermal analysis with modeled component.

KEYWORDS: - Reciprocating Screw, Barrel, and mould
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INTRODUCTION

The injection machine melts and plasticizes the molding material inside the heating cylinder. It further injects this into the mold tool to create the molded product by solidifying inside it. The injection machine is constructed of a mold clamping device that opens and closes the mold tool, and device that plasticize and inject the molding material.
Injection molding is the most commonly used manufacturing process for the fabrication of plastic parts. A wide variety of products are manufactured using injection molding machine, such as plastics housings, consumer electronics, and medical devices Including valves & syringes which vary greatly in their size, complexity and application. The injection molding process requires the use of an injection molding machine, raw plastic material, and a mold. The plastic is melted in the injection molding machine and then injected into the mold, where it cools and solidifies into the final part.
Barrel of the Injection molding machine is surrounded by number of heating elements. As this heating element fails, the temperature of the molten material will be decreased which turns to solidification. This increases the stresses on the reciprocating screw which results into the failure of the shaft. Sometimes it is observed that shaft fails though there is no failure of heating elements. This is frequent problem observed in the plastic industry. Cost of the reciprocating screw is high and also the time required replacing the shaft with newer one takes long time which is about 4 to 5 working days. This large loss of time and money leads to very

high economical loss for plastic industry due to struck of the production. FEM analysis of the reciprocating shaft will predict the stress distribution and its maximum value. Similarly FEM analysis of the existing and new coupling of lower strength than the shaft material will give the highest stress value at which coupling will break. Experiment of the coupling failure on torsion testing machine will give the breaking stress of value the coupling. Experimental results will be verified with the FEM analysis of the coupling.

OBJECTIVES

1. Main objective of the project is to use the optimization of overload protection degree to minimize the losses. This means making some component (like coupling which has lower cost comparatively) of the system weaker than the reciprocating shaft so that the component will fail before the shaft.
2. Making the analysis of different materials for reciprocating shaft and suggesting the better material.

SCOPE

Scope of the project includes following steps.

1. Calculate the torque transferred by motor.
2. Analyze the stresses in the reciprocating screw considering the torque transferred by motor and different temperature zones for reciprocating screw.
3. Consider the temperature zones for reciprocating screw as metering zone, compression zone, feed zone and drive zone. Consider the production of low density polyethylene. Hence select the temperatures for these zones selected as 150ºC, 170ºC, 190ºC and 60ºC respectively.
4. Design and make the modeling of coupling based on the motor torque value.
   i. Make the coupling stress analysis considering the same torque value transferred by motor.
   ii. Manufacturing of the coupling as per design.
   iii. Test the coupling on torsion testing machine. Note the breaking stress value of the coupling.
   iv. Verify the experimental and FEM results.

METHODOLOGY

1. **Modeling**
   Modeling of the reciprocating screw and coupling is to be done with CATIA V5R20 as modeling software.
2. **FEM Analysis**
   Models are to be imported and stress analysis is to be done using analysis software ANSYS 14.5. In that the pre-processing is to be done using the material properties, load and boundary conditions. With this results to be noted are stress, strain and deflection.

3 Experimentation

Coupling to be manufactured as per design based on motor torque value. This coupling is to be tested on torsion testing machine for breaking stress value. If this stress value is found more than that of reciprocating screw breaking stress value, then the new designed coupling will be mounted in the system. Metering zone heater electric supply will be cut purposely and breakdown to be noted.

1. Modeling of the reciprocating screw

Actual dimensions of reciprocating screw at site are actually measured and the similar model is made in CATIA V5. Dimensions of the screw are as follows.

- Total length – 1430 mm
- Diameter of the shaft at drive end – 18.5 mm
- Root diameter of the shaft at the non-drive end – 43 mm
- Pitch of the helix- 45 mm
- Length of the helix part – 1262 mm

Steps for modeling of reciprocating screw:

- Start>Mechanical Design>Part Design
- Select Plane
- Shaft>Sketch
- Helix>Pitch>Height>Taper Angle>Starting Angle.
- Rib>Sketch.
- Chamfer>Length1>Length2.
- EdgeFillet>Radius.
- Make necessary pockets.

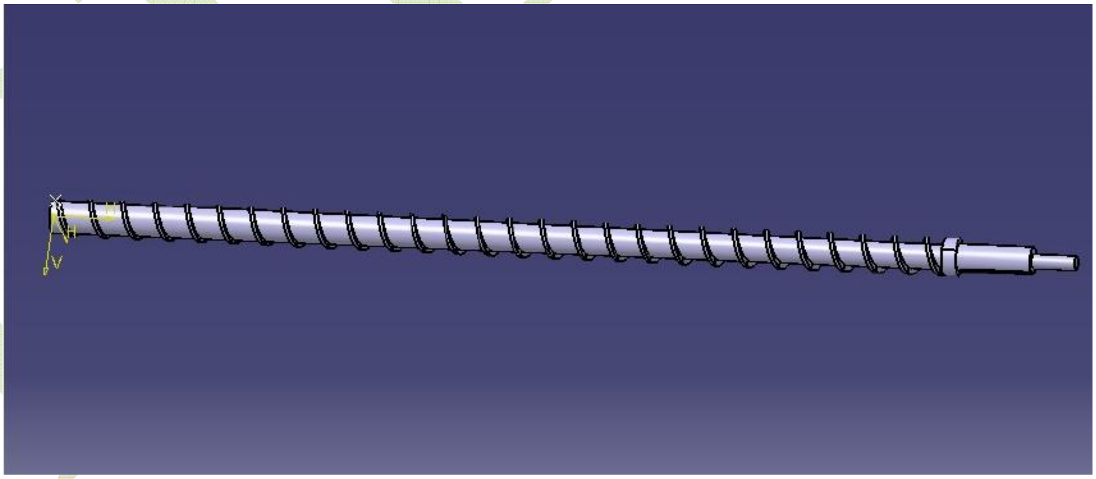

Figure: Modeling of reciprocating screw of existing Injection molding machine on site

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2 Design of the coupling

Step I- Shaft diameter (d)

The diameter of the shaft on which reciprocating screw is mounted is equal to 37mm.

$$d = 37\text{mm}$$

Step II- Flange dimensions

Outside diameter of the hub (d_h)

$$d_h = 1.75.d$$
$$= 1.75 \times 37\text{mm}$$
$$= 65\text{mm}$$

Length of the hub (l_h)

$$l_h = 1.5.d$$
$$= 1.5 \times 37\text{mm}$$
$$= 55.5\text{mm}$$

Pitch circle diameter for the bolts (D).

$$D = 3.d$$
$$= 3 \times 37\text{mm}$$
$$= 111\text{mm}$$

Thickness of the flange (t)

$$t = 0.5.d$$
$$= 0.5 \times 37\text{mm}$$
$$= 18.5\text{mm}$$

Thickness of the protecting rim (t_1)

$$t_1 = 0.5.d$$
$$= 0.25 \times 37\text{mm}$$
$$= 9.25\text{mm}$$

Diameter of spigot and recess (d_r)

$$d_r = 1.5.d$$
$$= 1.5 \times 37\text{mm}$$
$$= 55.7\text{mm}$$

Outside diameter of the flange (D_o)

$$D_o = (4d + 2t_1)$$
$$= (4 \times 37 + 2 \times 9.25)\text{mm}$$
$$= 166.5\text{mm}$$

Step III – Torsional shear stresses

Torque (T) transmitted.

Take the motor power P as 11.1855 KW and number of revolutions N of the reciprocating screw as 96 rpm.

$$T = \frac{P \times 60 \times 10^6}{2 \times \pi \times N}$$
$$= \frac{11.1855 \times 60 \times 10^6}{2 \times \pi \times 96}$$
$$= 1.112 \times 10^5 \ \text{Nmm}$$

Polar moment of inertia (J) for the coupling

$$J = \frac{\pi(d_h^4 - d^4)}{32}$$
$$= \frac{\pi(65^4 - 37^4)}{32}$$
$$= 1568485.685 \ \text{mm}^4$$

Min shear stress (τ) on reciprocating screw

$$\tau = \frac{T.r}{J} = \frac{T.\left(\frac{d_h}{2}\right)}{J}$$
$$= \frac{1.112\times10^5\times37}{2759929.889}$$
$$= 14.908 \ \text{N/mm}^2$$

Step IV- Diameter of bolts

For shaft diameter less than 40mm, the number of bolts N_b recommended are 3.

$$N_b = 3$$

Material of the bolt as C-45

Yield strength S_{yt} for this material is $380 \ \text{N/mm}^2$. Hence permissible shear stress τ_p of the bolts is equal to $\frac{S_{yt}}{3} = 126.67\text{N/mm}^2$.

Diameter of the bolt (d_b).

$$d_b^2 = \frac{8T}{\pi D N_b \tau_p}$$
$$= \frac{8\times1.112\times10^6}{\pi\times111\times3\times126.67}$$
$$d_b = 8.1934\text{mm}$$
$$= 9\text{mm}$$

Finite Element Analysis of reciprocating screw
Import the geometry

First go to ANSYS workbench. Import the geometry of reciprocating screw from the model created from CATA in igs format.

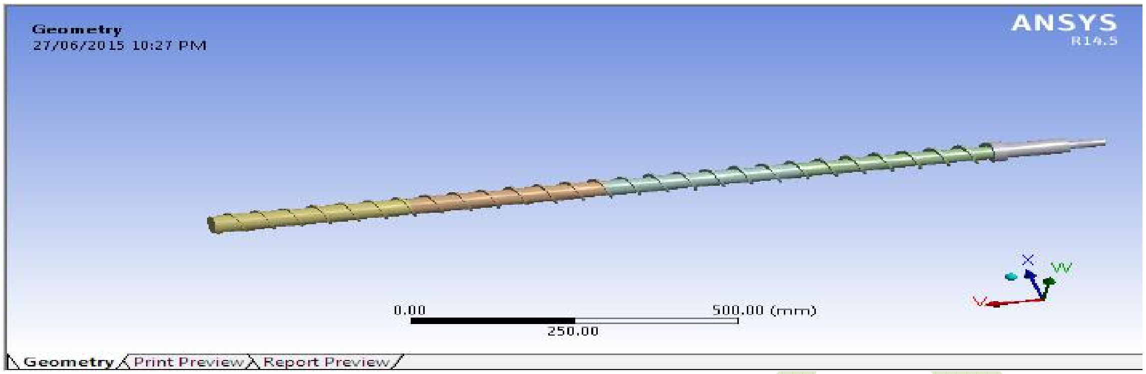

Figure1: Importing the reciprocating screw geometry into ANSYS workbench

3 Define the mechanical properties

After importing the geometry, go to the material properties. Select the physical properties. Since the material of the reciprocating screw is EN 41 B which comes under stainless steel category, select Linear elastic > Isotropic material.

Select the material properties as below.

Young's modulus- 210×10^{9} Pa

Poisson's ratio- 0.3

Density- 7850 kg/m^{3}

Coefficient of Thermal expansion-1.2×10^{-5}

Yield strength- 9.1×10^{8} Pa

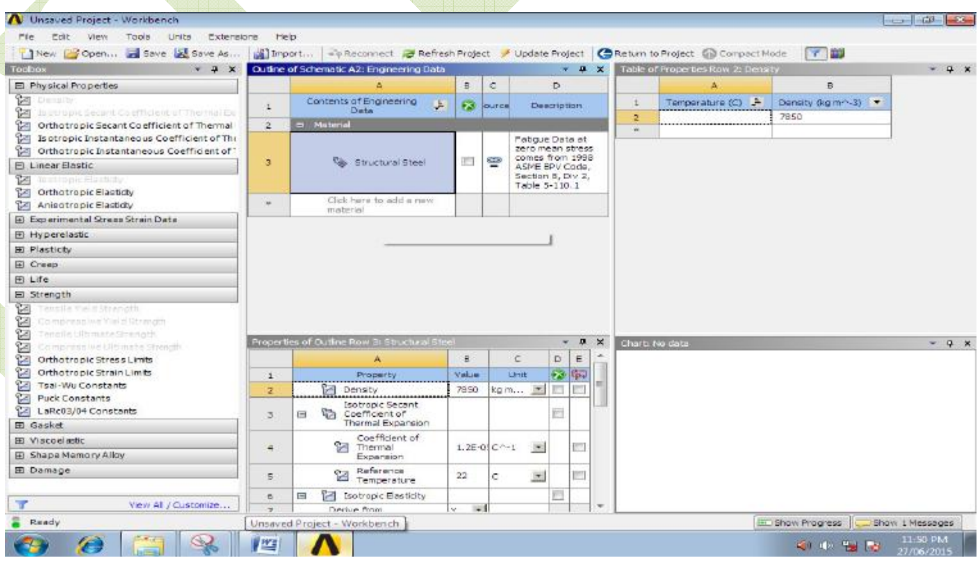

Figure2: Material and material properties selection

About existing material EN41B

EN41B is a 1.5% Chromium Aluminium Molybdenum Nitriding Steel.

Chemical analysis of EN41B

Element	C	Si	Mn	Cr	Mo	Al
Percentage	0.35/0.43	0.10/0.35	0.40/0.65	1.40/1.50	0.15/0.25	0.90/1.30

Table 1: Chemical analysis of EN41B

Mechanical properties of EN41B

Tensile Strength N/mm^2	Yield Strength N/mm^2	Elongation %	Impact Izod J	Hardness HB
775	585 min	15 min	40 min	223

Table 2: Mechanical properties of EN41B

APPLICATIONS

Die casting dies, Plungers and Cylinders, Abrasive Wheels, Plastic Mould Parts, Spindles, Extrusion Screws and Barrels

ANALYSIS

In this step, the geometry, constraints, loads are applied to generate matrix equations for each element, which are then assembled to generate a global matrix equation of the structure.

Fix the end of the reciprocating screw which is near the metering zone. The reason of fixing one end is that whenever the heater will fail and solidification will start, this end will act as fixed end.

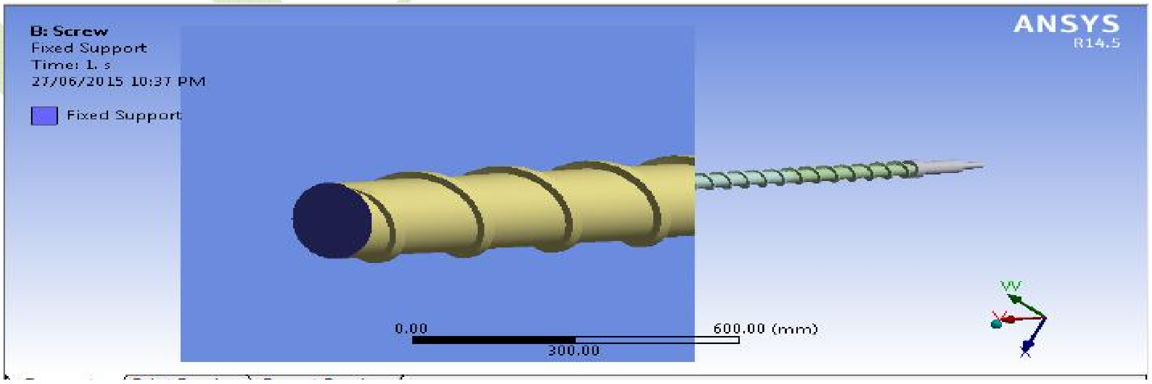

Figure3: Fixing of the reciprocating at non drive end

Apply torque at another end which is drive end. Select the torque value from machine manual.

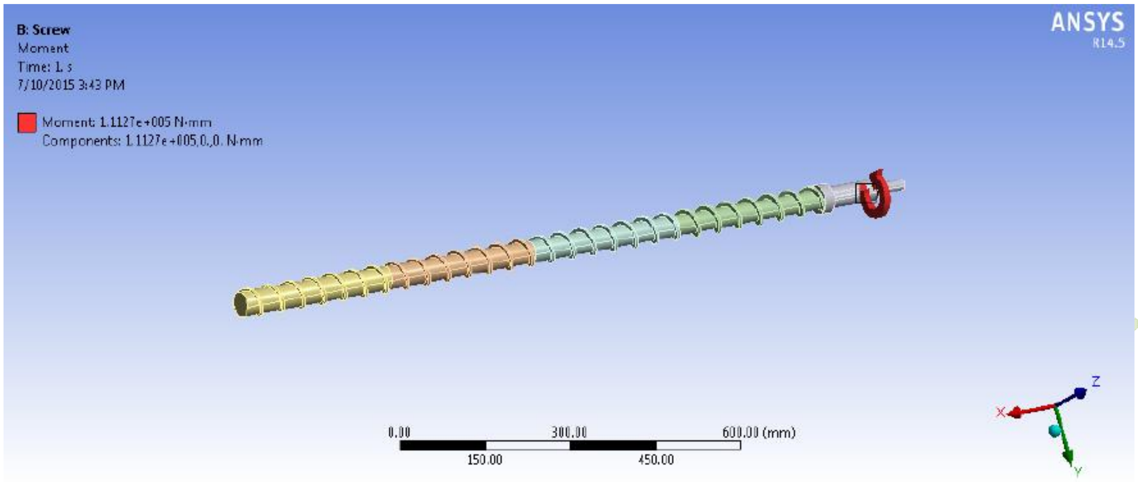

Figure 4: Applying the torque at drive end

In Design modeller, divide the reciprocating screw in four zones namely Metering zone at non drive end, Compression zone adjacent to metering zone, Feed zone next to compression zone and Drive zone near drive end.
Sponsoring organization produces the products of low density polyethylene.

4 Thermal Analyses

For this material EN 41B we have done thermal analysis also it gives clear idea of different temperature zones in reciprocating screw. By analysis we can get idea of how the temperature varies and temperature at any point.

Mould Temperature:

MATERIAL	T1(Metering Zone)	T2(Compression Zone)	T3(Feed Zone)	T4(Drive Zone)
EN41B	190	170	150	60

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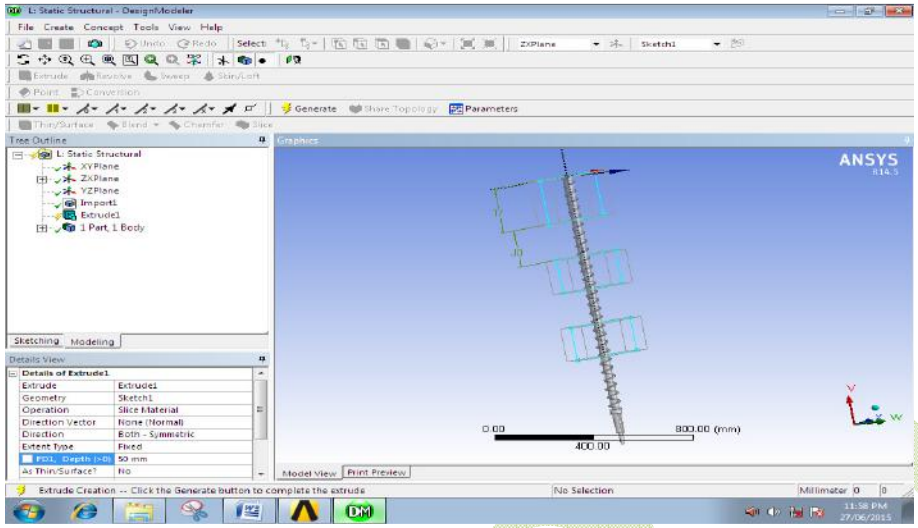

Figure5: Divide the reciprocating screw in four parts for four temperature zones

Analysis results for material EN 41B,EN24 And SAE1040

After analysis on software ANSYS R14.5 following values of total deformation and equivalent stress is obtained as given below:

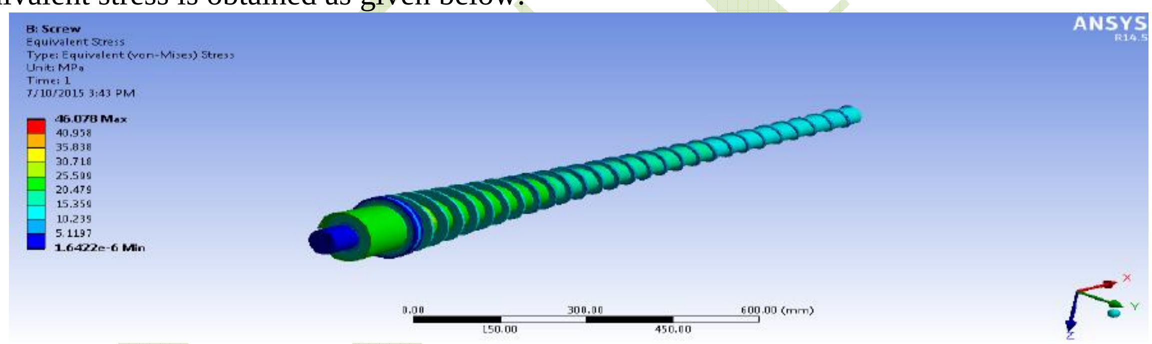

Figure6: Equivalent stress diagram of reciprocating screw for EN41B material

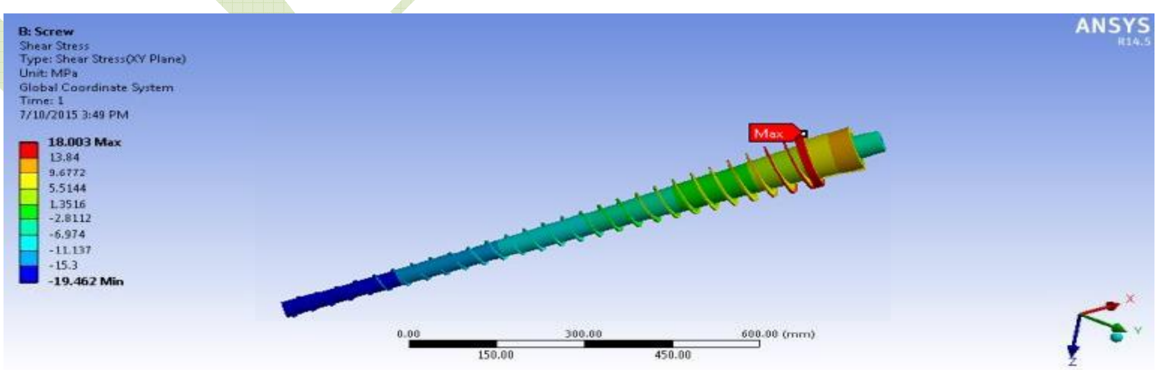

Figure7: Shear stress diagram of reciprocating screw for EN41B material

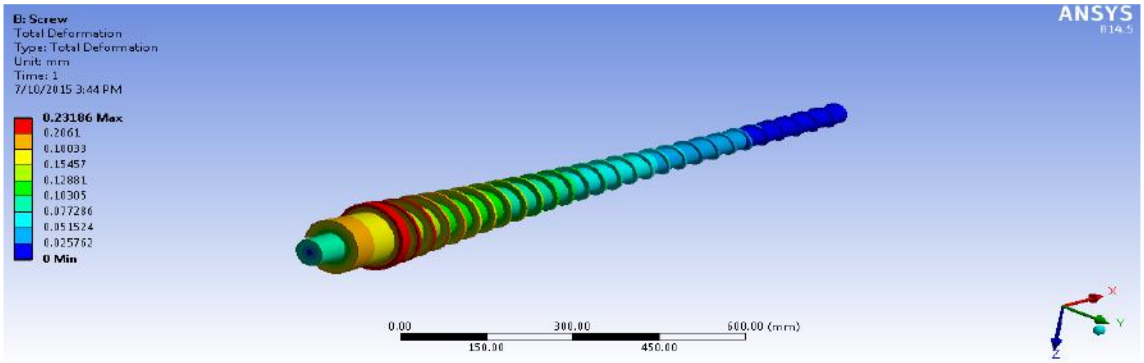

Figure8: Total deformation diagram of reciprocating screw for EN41B material

Similar steps are repeated and analysis is carried out for reciprocating screw for material EN24, EN8 and SAE 1040.
Equivalent stress diagram, shear stress diagram and total deformation diagram are as given below.

Material EN24:

EN24 is high tensile Alloy Steel.

Chemical analysis of EN24

Element	C	Si	Mn	Cr	Mo	Ni
Percentage	0.36/0.44	0.10/0.35	0.45/0.70	1.00/1.40	0.20/0.35	1.30/1.70

Table 4: Chemical analysis of EN24

Mechanical properties of EN24

Tensile Strength N/mm^2	Yield Strength N/mm^2	Elongation %	Impact Izod J	Hardness HB
850	650 min	13 min	40 min	248

Table5: Mechanical properties of EN24

Applications of EN24

Gears, Journals, Pinions, Spindles, Shafts and Rolls.

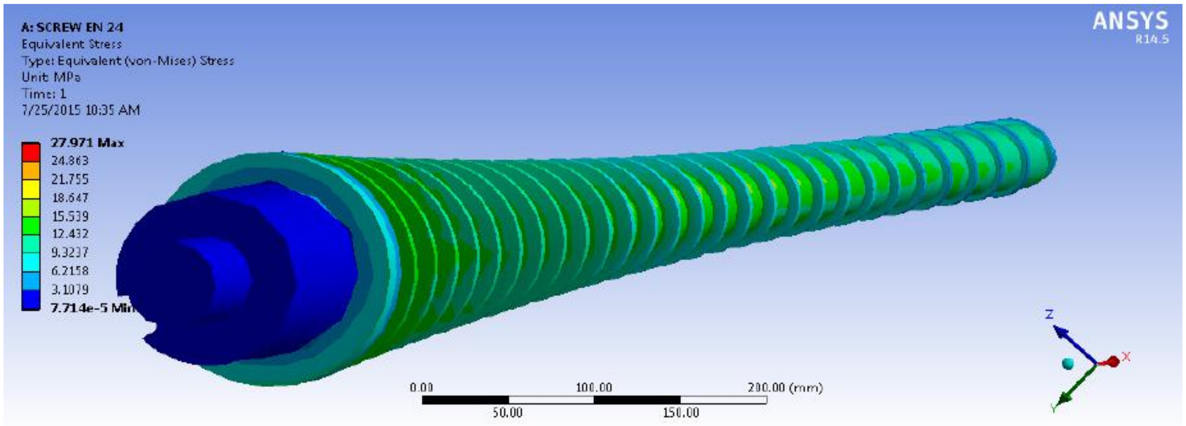

Figure9: Equivalent stress diagram of reciprocating screw for EN24 material

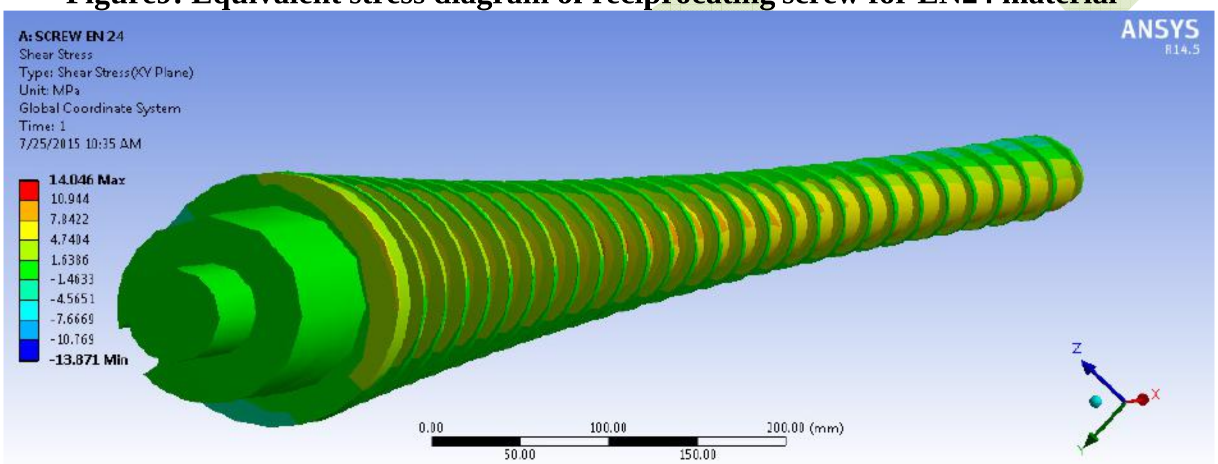

Figure10: Shear stress diagram of reciprocating screw for EN24 material

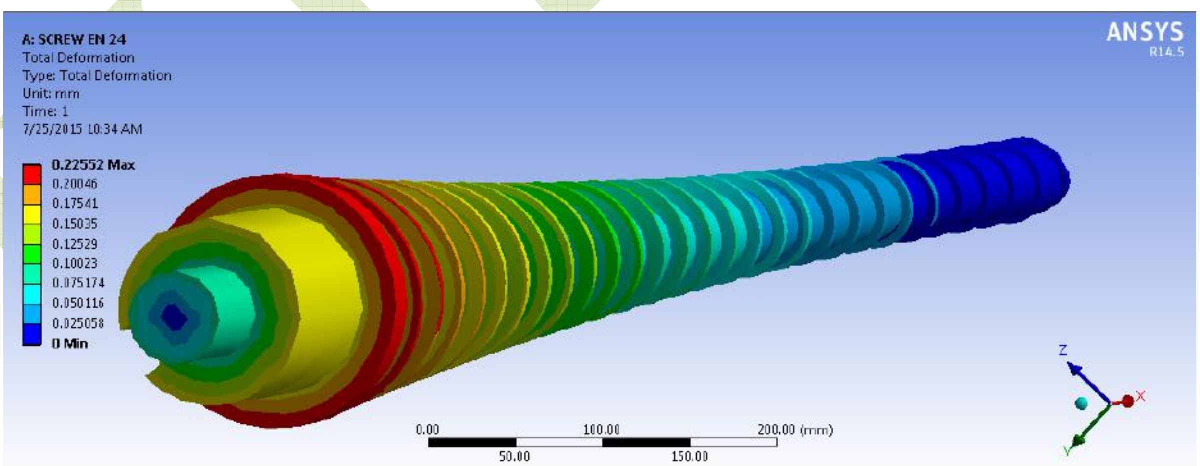

Figure11: Total deformation diagram of reciprocating screw for EN24 material

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Material SAE 1040:

Chemical analysis of SAE 1040

Element	C	Si	Mn	P	S
Percentage	0.37/0.44	0.07/0.6	0.6-0.9	0.03	0.05

Table 8: Chemical analysis of SAE 1040

Mechanical properties of SAE1040

Tensile Strength N/mm^2	Yield Strength N/mm^2	Elongation %	Impact Izod J	Hardness HB
520	415 min	16-18	40 min	264

Table 6: Mechanical properties of SAE1040

Applications

Step Shaft, steel plate/sheet,coil,round bar,flat bar,tube/pipe,profiled forgings.

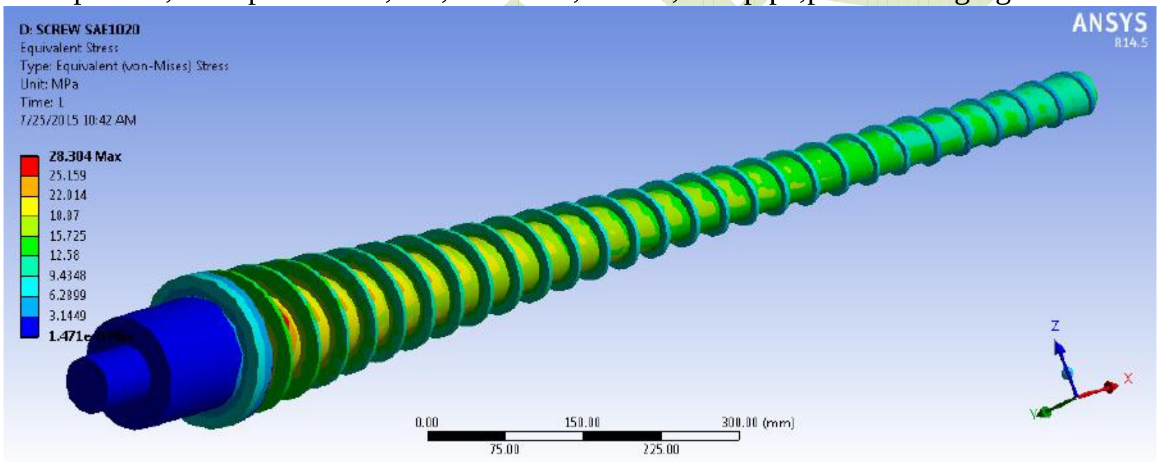


Figure12: Equivalent stress diagram of reciprocating screw for SAE1040 material

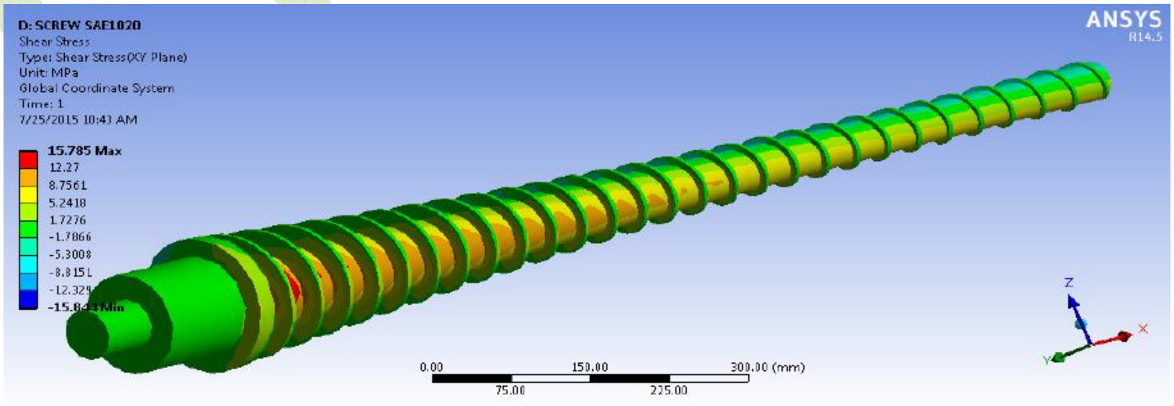


Figure13: Shear stress diagram of reciprocating screw for SAE 1040 material

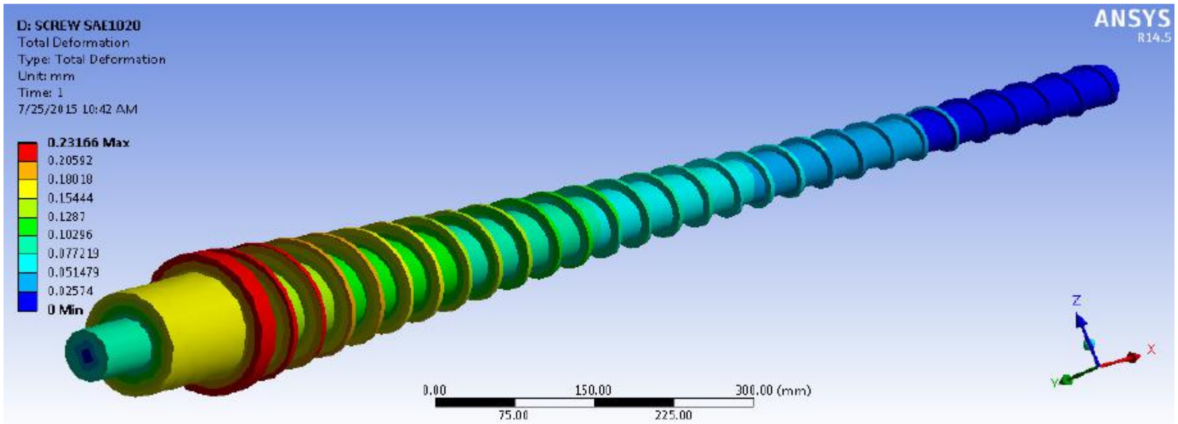


Figure14: Total deformation diagram of reciprocating screw for SAE1040material.
Comparison of the FEM results for different screw materials

Material	**Maximum Equivalent stress , (MPa)**	**Maximum shear stress, (MPa)**	**Maximum deformation, (mm)**
EN41B	46.07	18.03	0.23186
EN24	27.97	14.04	0.22552
EN8	27.97	14.04	0.22774
SAE1040	28.30	15.78	0.23166

Table7: Comparison of the FEM results for different screw materials

FEM ANALYSIS OF COUPLING

Import the coupling geometry to CATIA by converting it to igs file. Hide the shaft.

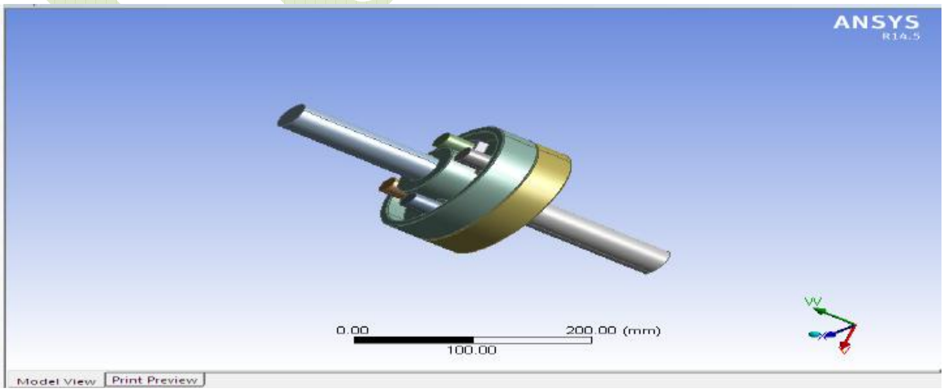
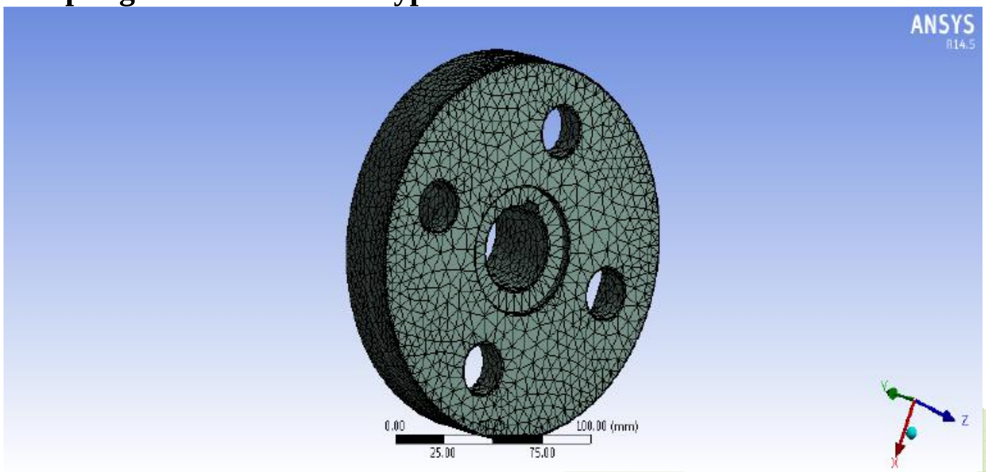


Figure15: Import the coupling geometry to ANSIS workbench

Mesh the coupling with tetrahedron types of elements.



Statistics	
Nodes	111223
Elements	61405
Mesh Metric	None

Figure16: Mesh the coupling with tetrahedron elements

Fix the coupling from non-drive end.

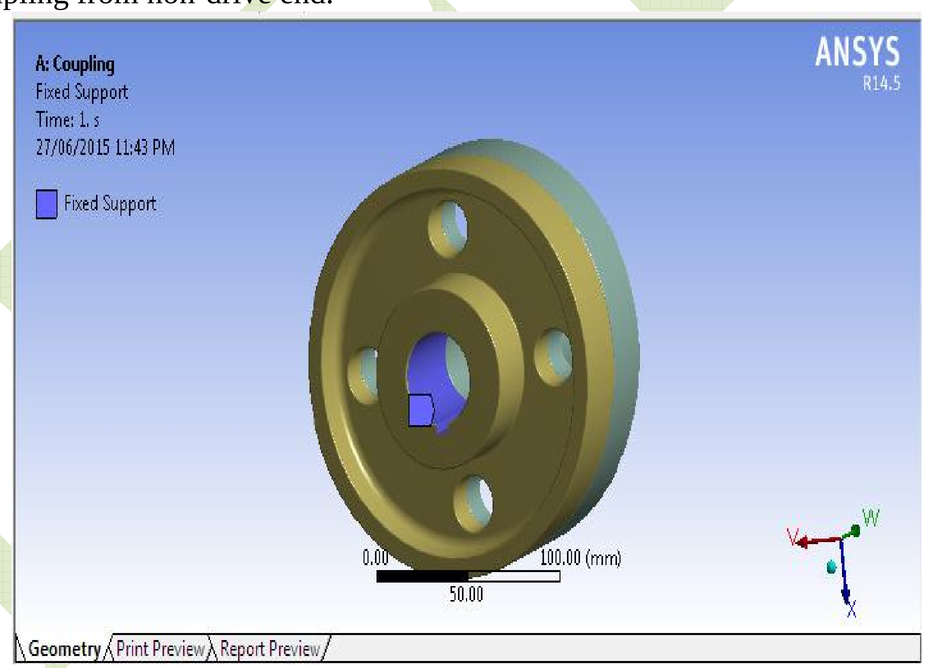


Figure35: Fixing the coupling at one end

Apply the moment (torque) from other end.

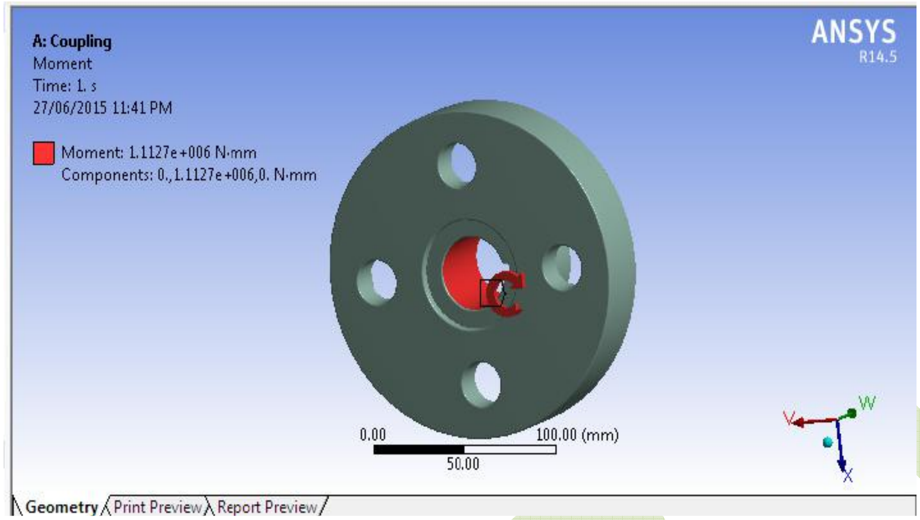


Figure 17: Applying the moment to the coupling at other end

Plot the results for shear stress.

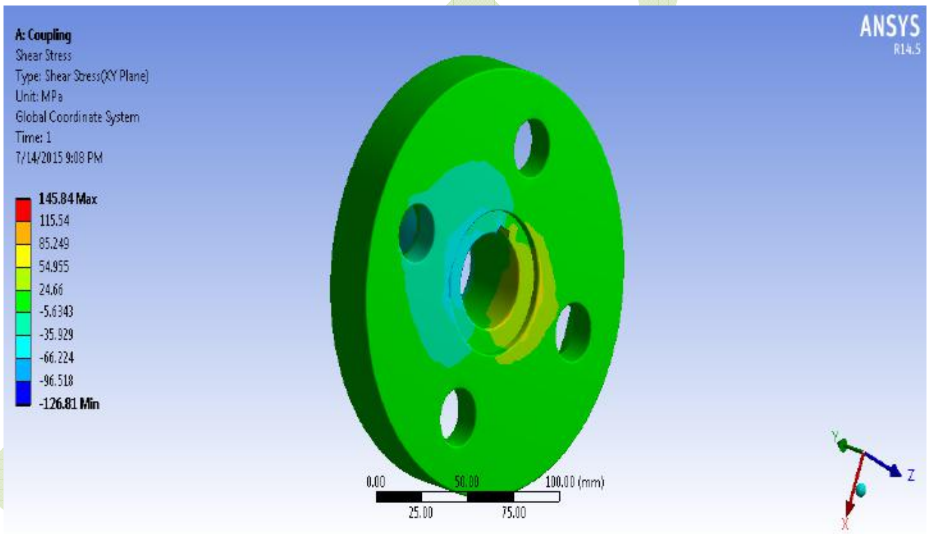


Figure18: shear stress distribution diagram of the coupling

EXPERIMENTAL CALCULATIONS

Write down the torsion equation.

$$\frac{T}{J} = \frac{\tau}{R} = \frac{G.\theta}{l}$$

T is the value of breaking torque of coupling in N.mm.

J is the polar moment of inertia in mm^4.

τ is the shear stress in N/mm^2.

R is the radius of the failure point of the coupling in mm.

G is the value of shear modulus in N/mm^2.

θ is the twist angle at failure in radians.

l is the length of coupling in mm.

From the experiment, note down the torque while coupling fails.
The value of the torque is 223.0 kg.m which is equal to 2187.63×10^3 N.mm
Calculate Polar moment of inertia J for the coupling.
Substitute 65 mm for the diameter of hub d_h and substitute 37 mm for the diameter of shaft d.

$$J=\frac{\pi(d_h^4-d^4)}{32}$$
$$=\frac{\pi(65^4-37^4)}{32}$$
$$=1568485.685\ \text{mm}^4$$

Measure the radius R where the coupling has failed.

Radius R where the coupling has failed is noted as 55 mm which is along PCD.

$$R=55\ \text{mm}$$

Substitute the values of torque T, polar moment of inertia J and radius R where in the torsion equation and calculate the shear stress τ value at failure.

$$\frac{T}{J}=\frac{\tau}{R}$$
$$\frac{2187.63\times10^3}{1569485.685}=\frac{\tau}{55}$$
$$\tau=76.66\ \text{N/mm}^2$$

Hence experimental value of the shear stress induced in the coupling is equal to $76.66\ \text{N/mm}^2$.

COMPARISON OF THE MAXIMUM SHEAR STRESS VALUE BY FEM AND BY EXPERIMENTAL METHOD

Component	Maximum shear stress on existing reciprocating screw	Maximum shear stress by FEM	Maximum shear stress by Experimental method
Coupling	18.03 N/mm^2	85.249 N/mm^2	76.66 N/mm^2

Table: Comparison of the maximum shear stress value by FEM and by experimental method
Comparison shows that shear stress induced in the coupling is much higher than that of the reciprocating screw.
Also the FEM and experimental results for the coupling shear stress varies slightly.

CONCLUSION AND SCOPE FOR FUTURE WORK

Maximum shear stresses in reciprocating screw as found by FE analysis is 18 MPa for material EN41B. As per FE analysis maximum shear stress in coupling is 85.2 MPa for material MS. Shear stress for failure of coupling on torsion testing machine is found as 77.12 MPa. Hence it is clear stress induced in the coupling is much higher than that of induced in the shaft. Also coupling being made of weaker material, it fail before reciprocating screw without causing any harm to it. Hence the theory of degree of overload protection is successfully implemented.
From the FE analysis of the materials EN41B, EN24, EN8 and SAE1040 it is clear that there is no considerable variation in stress values for same torque value of the reciprocating screw. Hence there is less possibility to substitute screw material by other metallic materials. If we go for some hard steel materials then chrome plating is not possible on hard steel materials which are must for not sticking of plastic material. Hence instead of change in material, research in change in geometry of screw material like helix angle, helix thickness is recommended.
Also changes recommended in the electric circuit. The problem arises due to failure of the heater. Hence there should be the solution to the root cause that is there should be alarm like system or circuit breaker so that whenever heater will fail, either it will blow alarm or it will switch off the machine. But this is possible for new machines coming in the market.
This project will help for all the existing machines in the market which are facing the problem breaking of the reciprocating shaft due to heater failure.

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