Design and analysis of mandrel use in cold pilger mill

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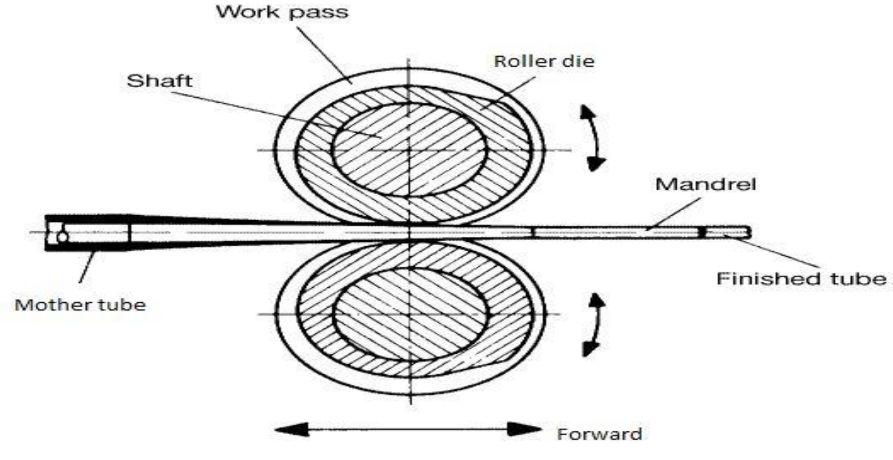
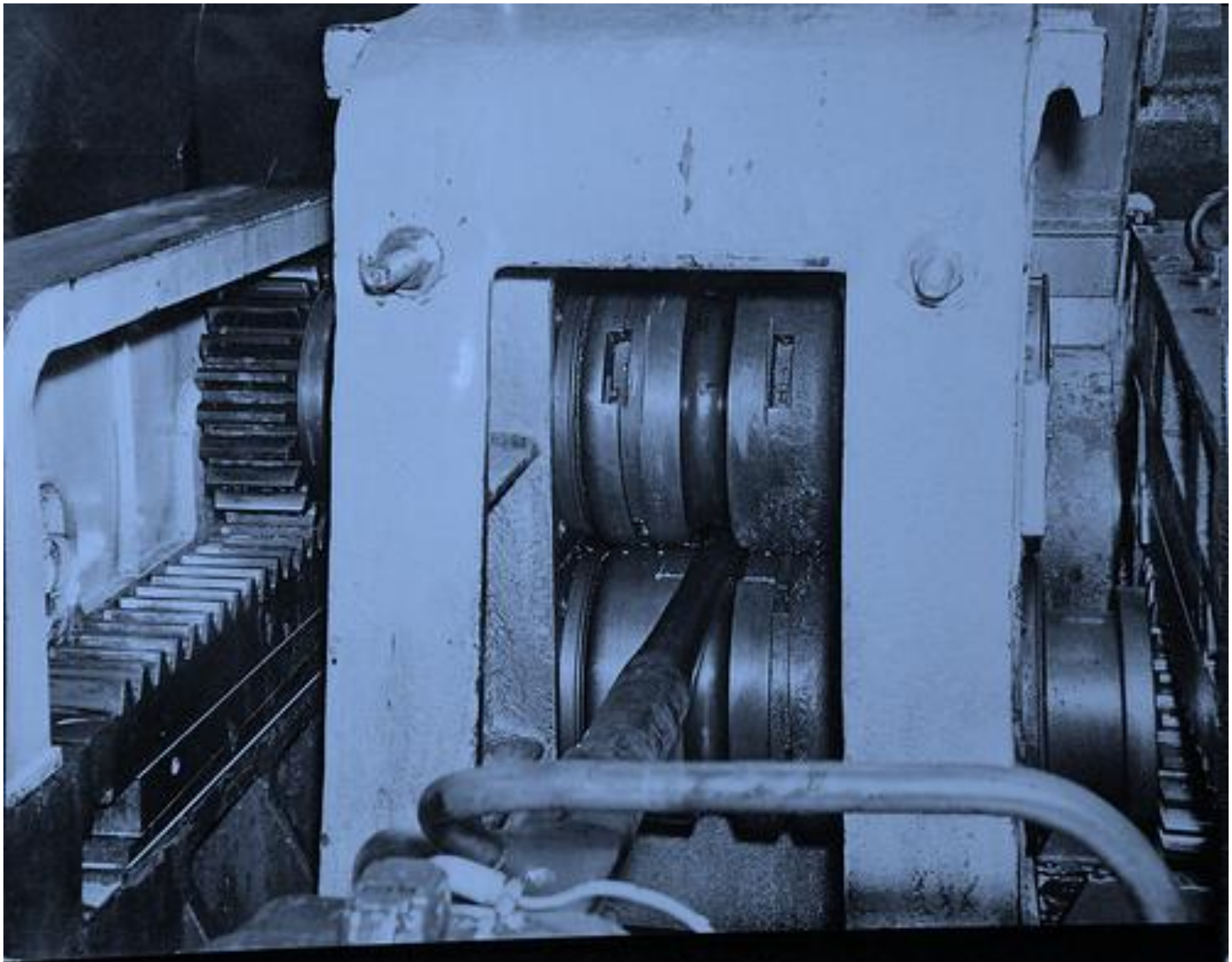
Contents

Introduction

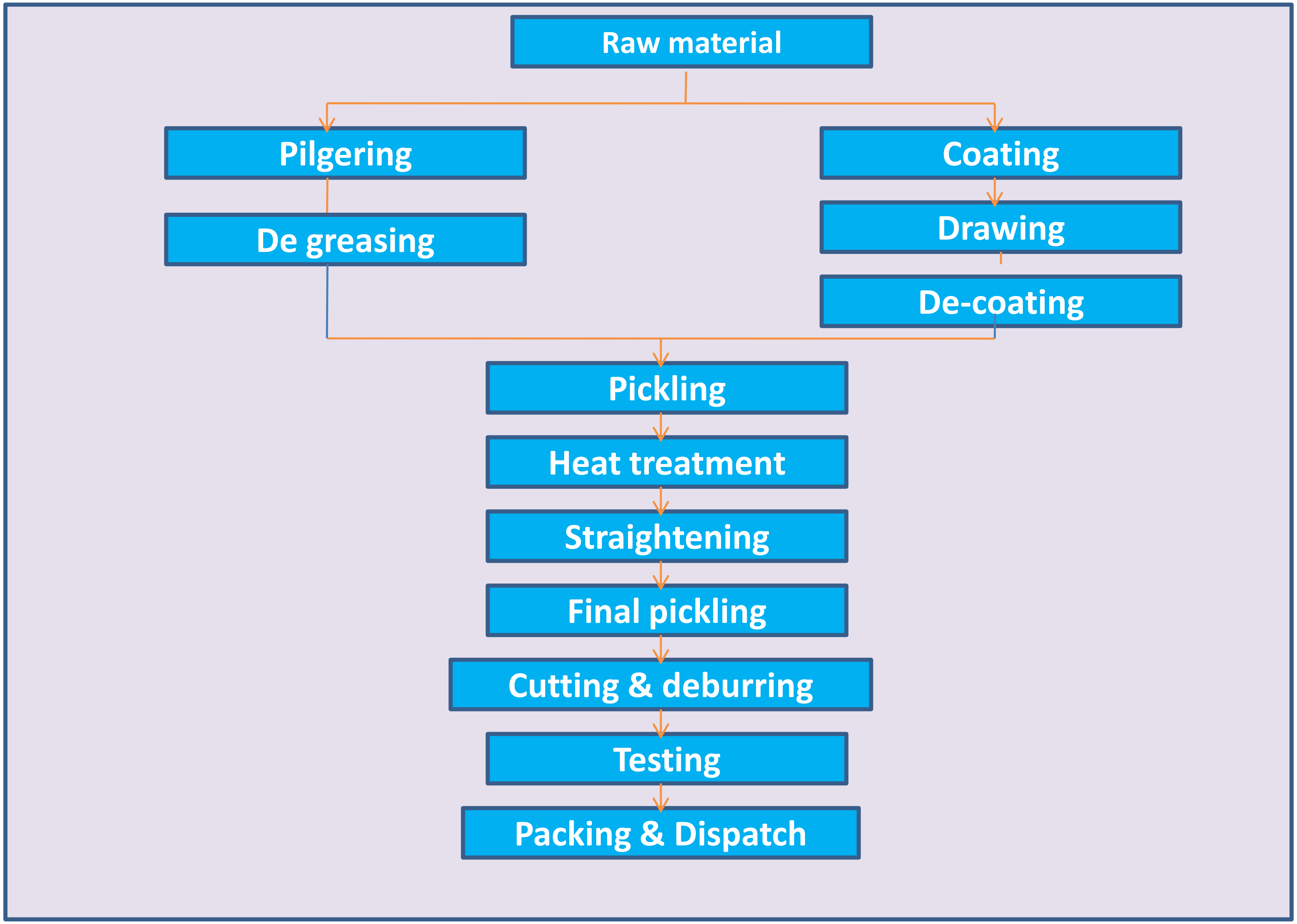
- Ratnadeep Metal & Tubes Ltd. manufactures stainless steel seamless tubes & pipes, stainless steel welded tubes & pipes.
- The pilgering process is one of the metals forming process to make high dimensional accuracy of tube.
- In pilger machine there is two roller die and a mandrel tangent to the two rollers. Outer diameter of tube depends upon the roller die and inner diameter depends upon the mandrel.
- Pilger machine can produce outer diameter up to 8mm to 230mm and thickness of tube up to 0.5mm to 30mm. Pilgering process can reduce the 90% of the cross section of copper material, 75% of stainless steel and 70% of high strength alloy like titanium alloys.



Pilger mill

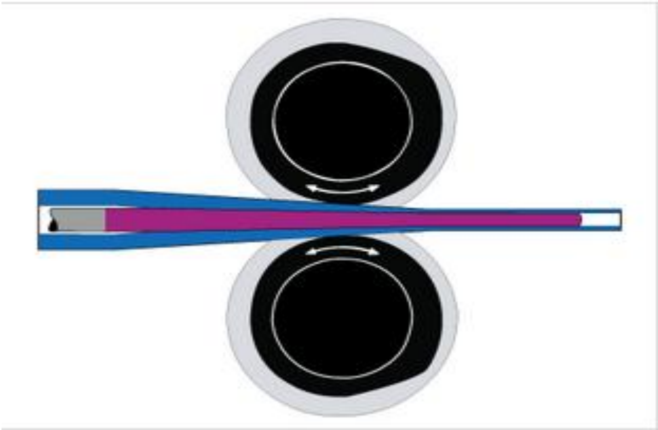


Flow chart for seamless tubes/pipes



Problem Definition

- During training we observed that company invests lots of money for mandrel due to its short life span and sudden failure.
- For better selection of availability of various material as well as various shapes of material i.e. Linear and parabolic so it should be clear decision for making selecting of mandrel. So design and analysis is required to do it.



Objectives

- To increase the span of life by designing different shape of mandrel for different material

  i.e. Parabolic as well as Linear shape
- To select the suitable material for mandrel from two tool steel material used to make the mandrel. i.e. H11 & M4
- To reduced the undesirable cost which is occurring due to the failure of mandrel and short life span.

Work-Flow Of The Project

Problem Definition

↓

Find out the factors affecting on the failure of mandrel and short life span

↓

Collection of data related to mandrel

↓

Load calculation

↓

Material Selection(H11 & M4) to compare

↓

Design of mandrel

↓

Structural analysis using FEA for material M4 and H11 tool steel

↓

Result analysis and comparison

↓

Conclusion

Literature Review

1. **S,Muot, a.Hacquin, p.Montmitonnerin** had 3D finite element simulation of cold pilgering for zircaloy cladding tubes for nuclear industry. For that following criteria are considered:

Billet dimensions: (1) Material –Alloy Zr-2.5%Nb (2) Initial diameter = 9.5mm (3) Final diameter = 1.9 mm (4) Initial thickness = 1.2mm (5) Angle of rotation = 50 (6) Feed rate = 5 m/s

By considering the above parameter the author made model and analyze and simulated for one forward stroke with FEM. In the paper above all criteria are considered and also the author considered the following three caseds for checking the effect of friction.

μ=0.075 at the die/tube interface

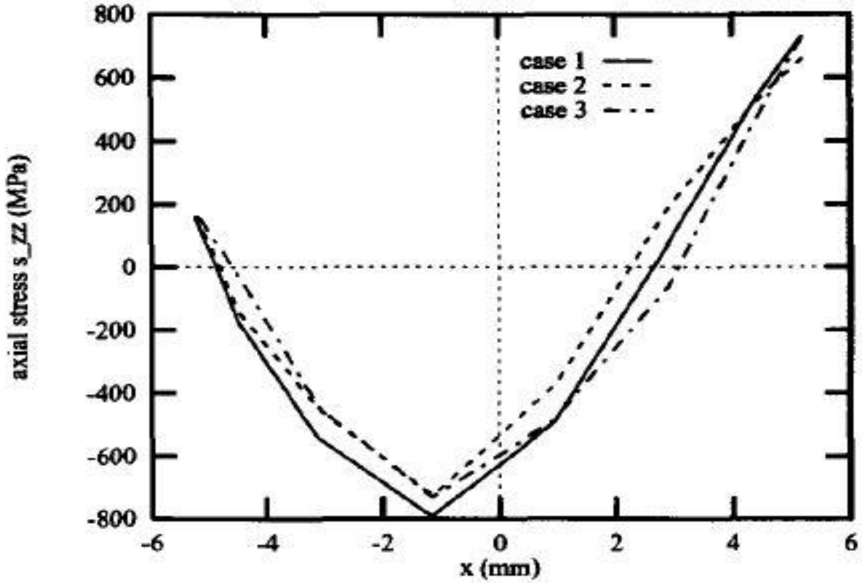
μ=0.075 at the mandrel/tube interface

μ=0.05 at the die/tube interface

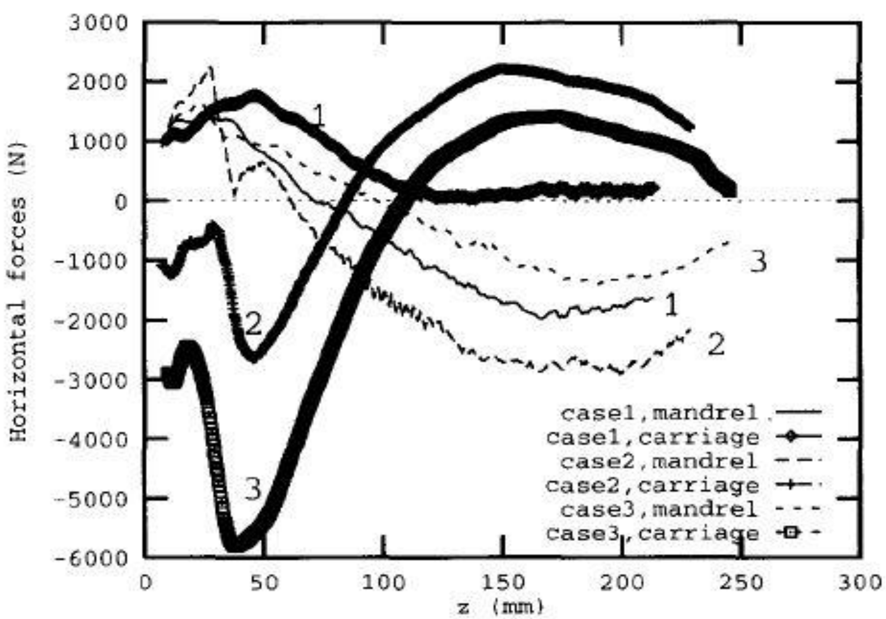
μ=0.10 at the mandrel/tube interface

μ=0.05 at the die/tube interface

μ=0.10 at the mandrel/tube interface



axial stress s_zz (MPa)
x (mm)
case 1
case 2
case 3



Horizontal forces (N)
z (mm)
case1,mandrel
case1,carriage
case2,mandrel
case2,carriage
case3,mandrel
case3,carriage

2. **Igor Matsegorin, Alexander Semenov, Eugeny Rivkin, Boris Rochenkov** had optimized the procedure for manufacturing tubular cladding and pressure tubes for nuclear industry. Pilgering process is used for manufacturing this type of tubes. For optimization following parameters are considered.

Types of pilger mill- KPW18

Billet dimensions: (1) Material-Alloy Zr-2.5%Nb (2) Initial Diameter=14mm (3) Final Diameter=8mm (4) Initial Thickness=0.9mm (5) Final Thickness=0.45 (6) Tube treatment Factor Q=1.3

Steps are considered:

Optimizing the deformation procedure in cold tube rolling.

Optimizing of basic rolling tool profiles.

Optimized feed and rotation angle of billet.

By considering the above criteria the author developed the an algorithm and program for optimizing procedure, tool profile, feed rate and rotation angle and from that plot different graphs and occluded that the optimal intervals of billet rotation angles were determined so as to reduce the asymmetry of transverse strain. Based on the identified criteria and using the developed program rolling mill were designed, produced an tested. The old and new pilger die selected, tested, measured and compared. The use of new tool calibration resulted in a higher tube rolling rate and lower spoilage levels, as well as in more uniform metal structure and longer service life.

3. **J.Park, S.S.Kim** had optimized design of a die shape for pilger mill process was carried out using FEM analyses considering the important design parameters of pilger mill machine feed rate and profile of grooved die and investigate effects on forming load and the deformed shape of a material depending on the surface profiles.

Design of pilger mill roll:

In this paper authors considered three of die profile (1) Linear (2) Cosine (3) Quadratic curves

In this paper optimum design of a die shape for pilger mill process was carried out using FEM analyses considering the important design parameters of the pilger mill machine feed rate and profile of the grooved die and investigate effects on forming load and the deformed shape of a material depending on the die surface profiles. Mass flow is almost linear in radial direction for quadratic modeling. It is also predicted in Fig 4 (b) that for linear modeling much load is exerted on the billet at the end of the forming due to significant difference in slope between the initial and end forming states.

He concluded that for the quadratic profile a steady state reached after 28 round trips to form 20 mm radius of a final billet and for the cosine and the linear profile the steady state reached after 48 and 38 round trips, respectively. The forming load for the cosine profile would be smaller than for the linear profile. Among three suggested models the roll design by quadratic profile offered better results in terms of total applied load and amount of forming.

4. **V.M.Prajapati, B.D.Patel** had fatigue analysis of h11 tool steel material and different geometric shape and used of ansys software the following conclusion of paper below.

	parabolic shape	linear shape
Factor of safety	6.0261e-002	3.4481e-002
No of cycles	5000 cycles	4000 cycles

5. **V.M.Prajapati** had stress analysis of h11 tool steel material and different geometric shape and used Ansys software for the same .The result he obtained is given below.

	parabolic shape	**linear shape**
Minimum Stress	5.852e+005 Pa	3.9292e+005 Pa
Maximum Stress	2.5e+009 Pa	1.4305e+009 Pa

6. **S.Nantha Gopan, M.GowthamJ.Kirubakaran Vivek, R.Rajesh, S.Ramakrishnan** had research and compare to conventional and adjustable mandrel used in pipe bending.

The main objective of the project is to analyze the pipe bending process using mandrels and to minimize the difficulties faced during the bending process. The work level is reduced as much as possible by creating a design followed by analysis of the mandrel used presently and the newly designed mandrel.

Parameters	Conventional mandrel	Adjustable mandrel
Stress	55.486 Mpa	265.3 Mpa
Strain	2.8 * e-4	1.4 * e-3
Displacement	0.2817	0.38452

Adjustable Mandrel

7) **S.Z.Qamar** , Effect of heat treatment on mechanical properties of h11 tool steel the paper conclusion below

AISI H11 is special alloy steel categorized as chromium tool steel because of its high toughness, hardness, it is well suited for hot work applications involving very high load.

Mechanical testing of H11 samples revealed that increasing temperature (a) hardness first increase to a maximum then gradually decrease, (b) Impact toughness first decrease to a minimum and then increase, (c) yield strength first decrease then increase, (d) ultimate strength fist increase to a maximum and then steadily decrease, (e) Ductility gradually decreases till 600°C,then increase rather sharply.

Design of mandrel

- **Load calculation**
- **Design of mandrel dimension using C Program**
- **Material Selection**

Load calculation of mandrel

$$\sigma_d = \sigma_0 \frac{1+\beta}{\beta}\left[1 - \left\{\frac{h_1}{h_2}\right\}^{\beta}\right] + \sigma_b \left\{\frac{h_1}{h_2}\right\}^{\beta} + \sigma_s$$

σ_d = Drawing stress

$\sigma_b = Back\ tension$

$h_1 = Final\ thickness\ tube$

$h_2 = Intial\ thickness\ tube$

$\mu_1 = Coefficint\ of\ friction\ between\ ring\ die\ and\ tube$

$\mu_2 = Coefficint\ of\ friction\ between\ ring\ tube\ and\ mandrel$

$\sigma_s = \sigma_b, For\ paltering\ process$

$$Take\ \sigma_0 = 210 \frac{N}{mm^2}, for\ steel$$

$$\beta = \frac{\mu_1 + \mu_2}{tan\alpha} = \frac{0.01 + 0.006}{tan1.5} = 0.6110$$

$$\sigma_b = \frac{1.5 * \sigma_0}{2\sqrt{3}} = \frac{1.5 * 210}{2\sqrt{3}} = 90.9326 \frac{N}{mm^2}$$

$$\frac{1+\beta}{\beta} = \frac{1+0.6110}{0.6110} = 2.6367$$

$$\left\{\frac{h_1}{h_2}\right\}^{\beta} = \left\{\frac{1.78}{4.00}\right\}^{0.6110} = 0.6097$$

$$\sigma_d = \sigma_0 \frac{1+\beta}{\beta}\left[1-\left\{\frac{h_1}{h_2}\right\}^{\beta}\right] + \sigma_b \left\{\frac{h_1}{h_2}\right\}^{\beta} + \sigma_s$$

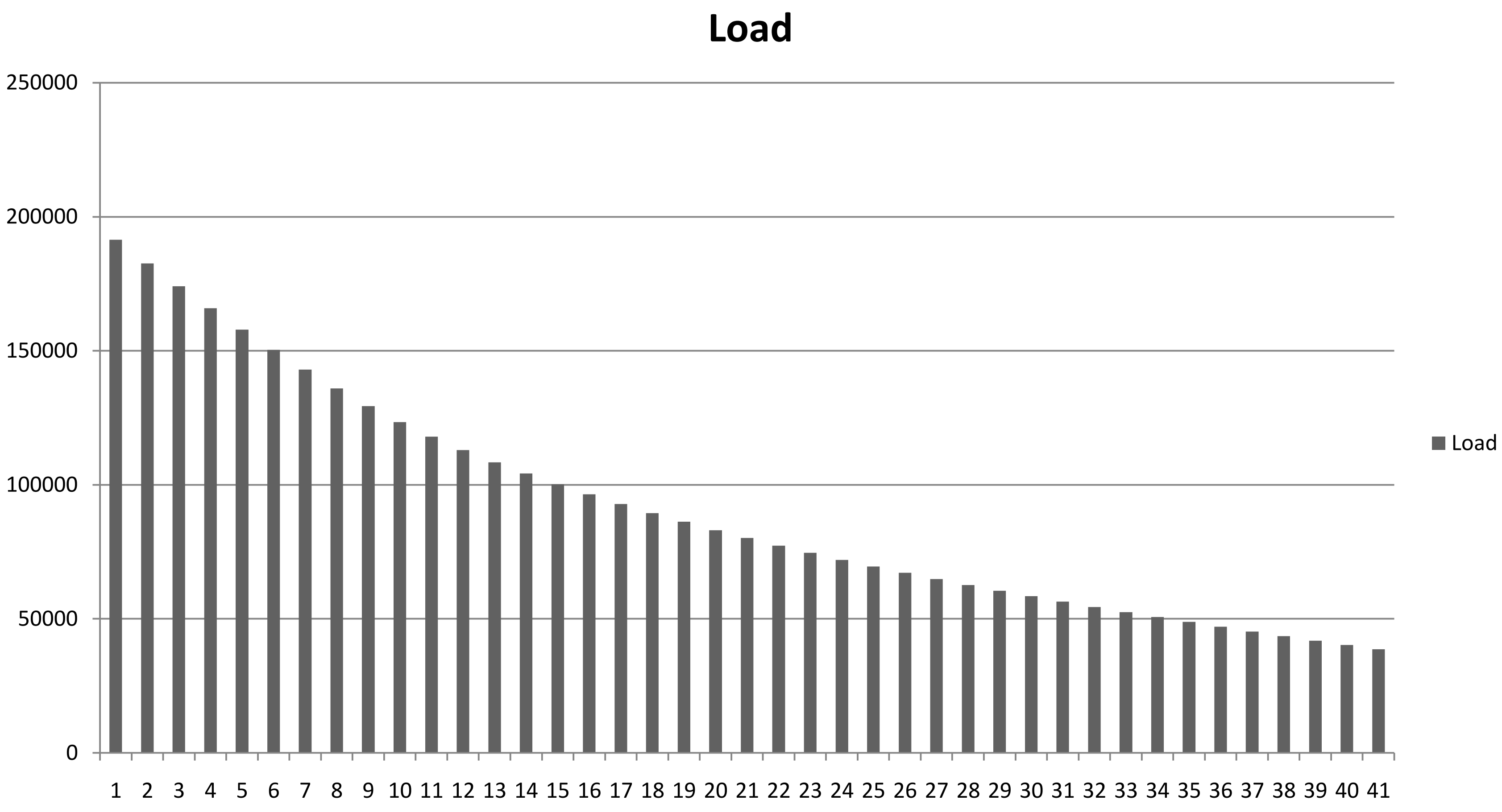
$$\sigma_d = [(210 * 2.6367)(1-0.6110)] + [90.9326 * 0.6110] + 90.9326$$

$$\sigma_d = 362.48 \frac{N}{mm^2}$$

$$Area\ of\ cross\ section\ at\ exit = \pi \mathrm{dt}$$
$$= \pi * 19.05 * 1.78$$
$$= 106.52 mm^2$$

$$Drawing\ load = Drawing\ stress * Area\ of\ exit$$
$$= 362.48 * 106.52$$

$$= 38611.3696\ \ N$$



Load
250000
200000
150000
100000
50000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41
Load

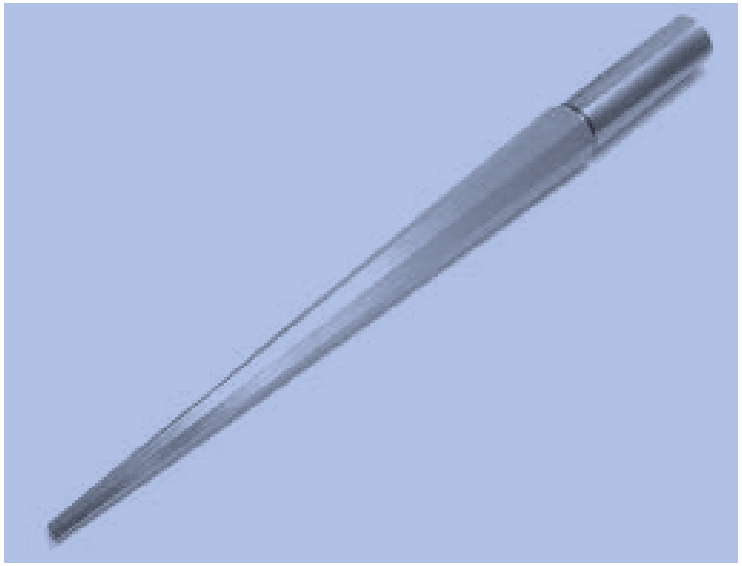
➢Design of mandrel dimension using C Program

```
#include<stdio.h>
#include<conio.h>
void main()
{
	float xen,xout,vi;
	int n,i;
	float di[100];
	clrscr();
	printf("Enetr Mandrel Bigger Diameter value :-");
	scanf("%f",&xen);
	printf("Enter Mandreal Smaller Diameter Value : -");
	scanf("%f",&xout);
	printf("Enter Division Of Mendreal Length :-");
	scanf("%d",&n);
	vi=(xen-xout)/(n-1);
	di[1]=xen;
	for(i=2;i<=n;i++)
	{
	    di[i]=di[i-1]-vi;
	}
	di[n]=xout;
	printf("\n\n Diameter are as following....\n");
	for(i=1;i<=n;i++)
	{
			printf("\t d%d=%f",i,di[i]);
	}
getch();
}
```

•Dimensions of Mandrel for each division

Sr.No	Dia (mm)	Sr.No	Dia (mm)	Sr.No	Dia (mm)
1	19.050	15	22.279	29	28.563
2	19.255	16	22.572	30	29.261
3	19.459	17	22.890	31	30.064
4	19.664	18	23.221	32	30.968
5	19.868	19	23.577	33	31.954
6	20.085	20	23.958	34	33.057
7	20.302	21	24.352	35	34.248
8	20.520	22	24.771	36	35.469
9	20.737	23	25.228	37	36.720
10	20.966	24	25.698	38	38.002
11	21.209	25	26.205	39	39.313
12	21.464	26	26.738	40	40.654
13	21.719	27	27.308	41	42.025
14	21.986	28	27.917		

- # PROCESS CYCLE OF MANDREL PREPARATION:-



1. Raw material cut on Hacksaw cutting machine
2. Side facing & Cut center drilling on both face of raw material on lathe
3. Storage of raw material
4. Preprofile turning (soft) on copying lathe
5. Profile Inspection on Surface table
6. Storage of Material
7. Heat Treatment of pilger mandrel
8. Hardness Checking of mandrel on Hardness Tester
9. Profile turning on copying lathe if require
10. Profile Grinding on AGC-125 CNC grinding m/c
11. Final inspection of mandrel profile
12. Identification & marking of mandrel
13. Mandrel profile polishing
14. Storage of finish mandrel

➢Material Selection

• Hot-work Tool Steels: Hot-work tool steels include all chromium, tungsten, and molybdenum class H alloys. They are typically used for forging, die-casting, heading, piercing, trim, extrusion and hot-shear and punching blades.

• Cold-work Tool Steels: Cold-work tool steels include all high-chromium class D, medium-alloy air-hardening class a alloys, water hardening W alloys, and oil hardening O alloys. Typical applications include cold working operations such as stamping dies, draw dies, burnishing tools, coining tools, and shear blades.

- H11 tool steel

Element	C	CU	CR	MN	MO	NI	P	S	SI	V
Mass%	0.33-0.43	0.25	4.75-5.50	0.20-0.50	0.95	0.3	0.3	0.3	0.80-1.20	0.30-0.60

Cutting tool	Rolls	Shear bladders
Cold pilger mandrels	Cold stamping tools	Moulds foot plastic processing

Density(kg/m3))	Yield strength(Mpa)	Ultimate Strength(Mpa)	Poisson's Ratio
7800	1650	1900	0.3

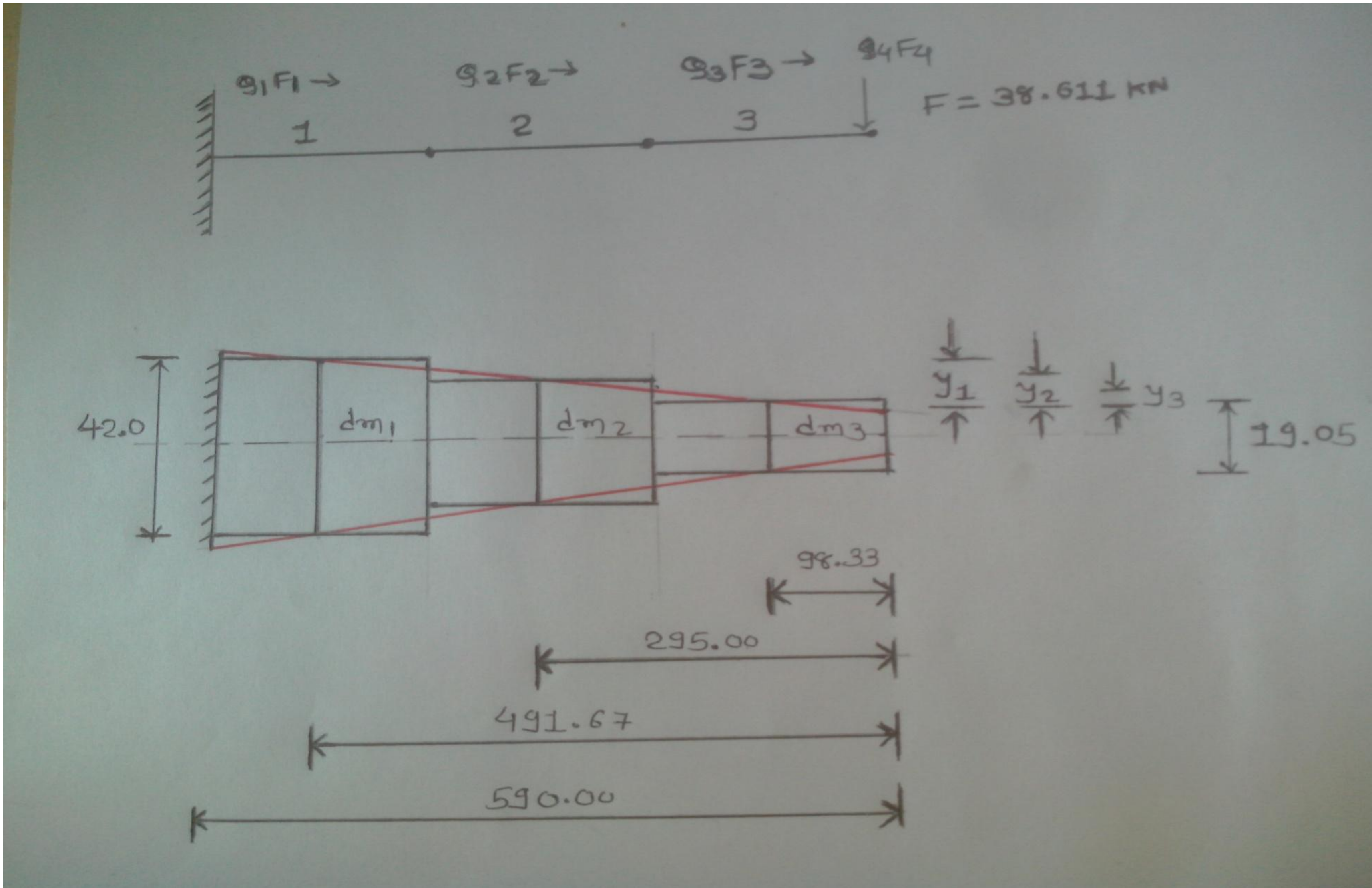
- M4 tool steel

Element	C	CU	CR	MN	MO	NI	P	S	SI	V	W
Mass%	1.25-1.40	0.25	3.75-4.25	0.15-0.40	4.25-5.25	0.3	0.3	0.3	0.20-0.45	4.00	5.50

Density(kg/m3))	Yield strength(Mpa)	Ultimate Strength(Mpa)	Poisson's Ratio
7979	4000	5129	0.3

Application: Used for cutting tools of all types for machining operation.

FEA Analysis



- From this figure

$$\frac{11.475}{590} = \frac{y_1}{491.67}$$

$$y_1 = 9.562\ mm$$

$$d_1 = 19.05 + (2y_1)$$

$$= 38.175\ mm$$

$$A_1 = \frac{\pi}{4} {d_1}^2$$

$$=1144.584\ mm^2$$

$$\frac{11.475}{590} = \frac{y_2}{295}$$

$$y_2 = 5.735$$

$$d_2 = 19.05 + (2y_2)$$

$$A_2 = 731.811\ mm^2$$

$$\frac{11.475}{590} = \frac{y_3}{98.33}$$

$$y_3 = 1.912$$

$$d_3 = 19.05 + (2y_3)$$

$$A_3 = 410.79\ mm^2$$

$$E_1 = E_2 = E_3 = 2 * 10^5\ \frac{N}{mm^2}$$

$$l_1 = l_2 = l_3 = 196.67\, mm$$

$$k_1 = \frac{A_1 E_1}{l_1}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

$$= \frac{1144.592 * 2 * 10^5}{196.67}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

$$k_1 = 10^3\begin{bmatrix} 1163.972 & -1163.972 \\ -1163.972 & 1163.972 \end{bmatrix}$$

$$k_2 = \frac{731.184 * 2 * 10^5}{196.67}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

$$k_2 = 10^3\begin{bmatrix} 743.564 & -743.564 \\ -743.564 & 743.564 \end{bmatrix}$$

$$k_3 = \frac{410.967 * 2 * 10^5}{196.67}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

$$k_3 = 10^3 \begin{bmatrix} 417.925 & -417.925 \\ -417.925 & 417.925 \end{bmatrix}$$

$$k = k_1 + k_2 + k_3$$

$$k = 10^3 \begin{bmatrix} 1163.972 & -1163.972 & 0 & 0 \\ -1163.972 & 1907.536 & -743.564 & 0 \\ 0 & -743.564 & 1161.489 & -417.925 \\ 0 & 0 & -417.925 & 417.925 \end{bmatrix}$$

$$Q = \begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \end{bmatrix} = \begin{bmatrix} 0 \\ Q_2 \\ Q_3 \\ Q_4 \end{bmatrix} \qquad F = \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \end{bmatrix} = \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ -38611.3696 \end{bmatrix}$$

Now the, KQ=F

$$10^3 \begin{bmatrix} 1163.972 & -1163.972 & 0 & 0 \\ -1163.972 & 1907.536 & -743.564 & 0 \\ 0 & -743.564 & 1161.489 & -417.925 \\ 0 & 0 & -417.925 & 417.925 \end{bmatrix} \begin{bmatrix} 0 \\ Q_2 \\ Q_3 \\ Q_4 \end{bmatrix} = \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ -38611.3696 \end{bmatrix}$$

Use the ellimation approach

$$10^3\begin{bmatrix}1907.536 & -743.564 & 0\\ -743.564 & 1161.484 & -417.925\\ 0 & -417.925 & 417.925\end{bmatrix}\begin{bmatrix}Q_2\\ Q_3\\ Q_4\end{bmatrix} = \begin{bmatrix}F_2\\ F_3\\ -38611.3696\end{bmatrix}$$

Take the f2 and f3 zero and solve the matrix

$$Q_2 = -0.0327\, mm$$

$$Q_3 = -0.0839\, mm$$

$$Q_4 = -0.1762\, mm$$

Reaction force

$$R = 10^3[\ 1163.972 \quad -1163.972 \quad 0 \quad 0]\begin{bmatrix}0\\ -0.0327\\ -0.0839\\ -0.1762\end{bmatrix}$$

$$= 38.06 * 10^3 N$$

Stress of each element

$$\sigma_1 = E\frac{1}{l_1}[-1 \quad 1]\begin{bmatrix}Q_1\\Q_2\end{bmatrix}$$

$$= 2*10^5*\frac{1}{196.67}[-1 \quad 1]\begin{bmatrix}0\\-0.0327\end{bmatrix}$$

$$= -33.253 \, {}^{N}/_{mm^2}$$

$$\sigma_2 = \frac{2*10^5}{196.67}[-1 \quad 1]\begin{bmatrix}-0.0327\\-0.0839\end{bmatrix} = -52.066 \text{ N/mm2}$$

$$\sigma_3 = \frac{2*10^5}{196.67}[-1 \quad 1]\begin{bmatrix}-0.0839\\-0.1762\end{bmatrix} = -93.86 \text{ N/mm2}$$

Analysis of mandrel using ANSYS

- ANSYS have the capabilities to make the analysis on following types:-
  - Static structural analysis
  - Dynamic structural analysis
  - Buckling analysis
  - Non linear analysis
  - Static and dynamic kinematic analysis
  - Thermal analysis
  - Electromagnetic analysis
  - Fluid flow analysis
  - Piezoelectric analysis
- Analysis involves three phase
  - Pre-processor
  - Solution
  - Post-processor

➢Static structural analysis

- ➢ Following step involve the static structural analysis

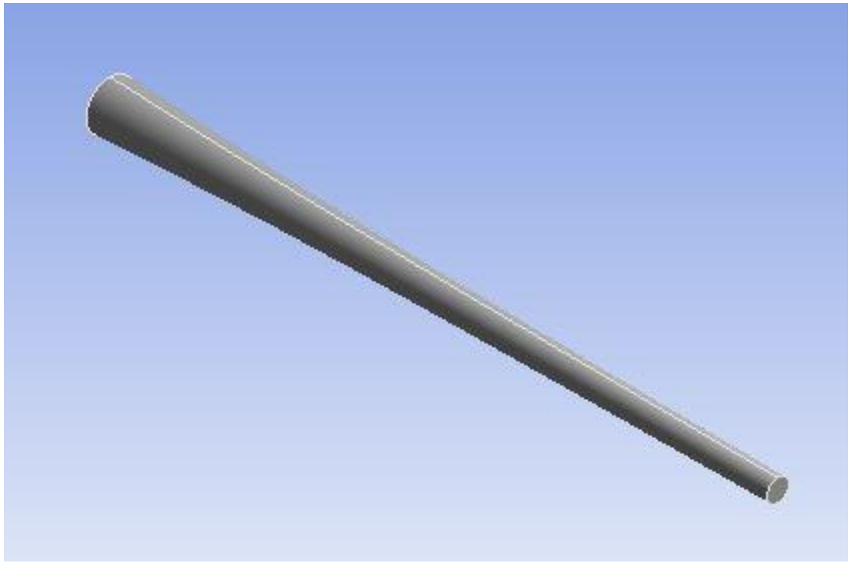
1. Engineering data
2. Geometry
3. Model
4. Solution
5. Result

1. Engineering Data

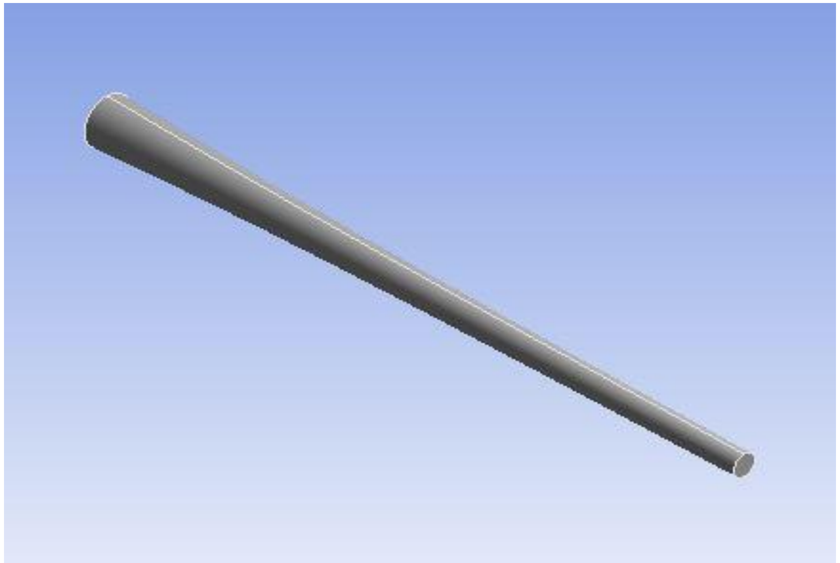
AISI H11 TOOL STEEL				
Density (Kg/m3)	Ultimate Tensile Strength(Pa)	Yield Tensile Strength(Pa)	Poison Ratio	Shear Modulus(Pa)
7800	1990E+06	1650E+06	0.3	81E+09

AISI M4 TOOL STEEL				
Density (Kg/m3)	Ultimate Tensile Strength(Pa)	Yield Tensile Strength(Pa)	Poison Ratio	Shear Modulus(Pa)
8166	5129E+06	4000E+06	0.27	126E+09

2. Geometry



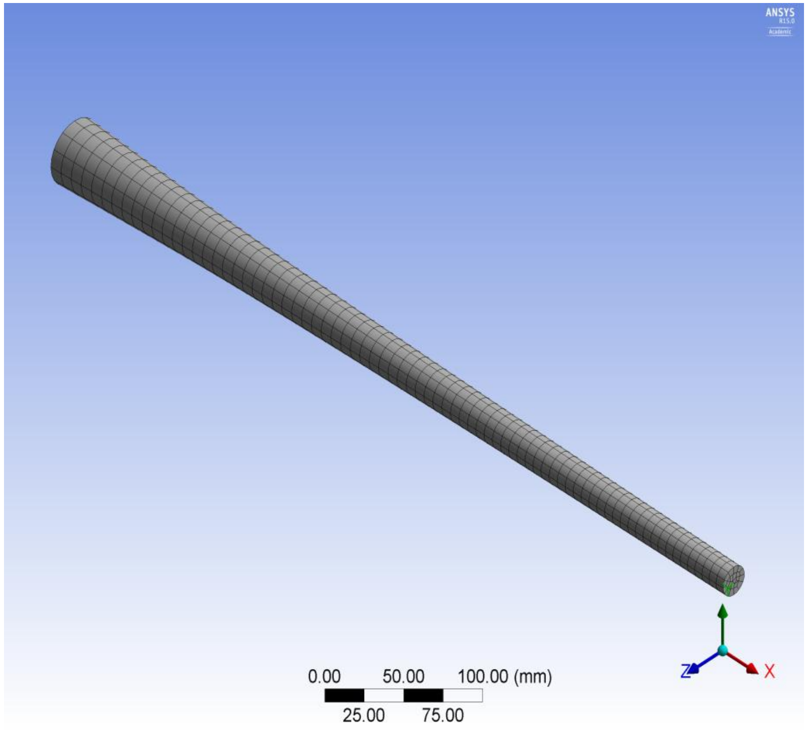
Parabolic geometry



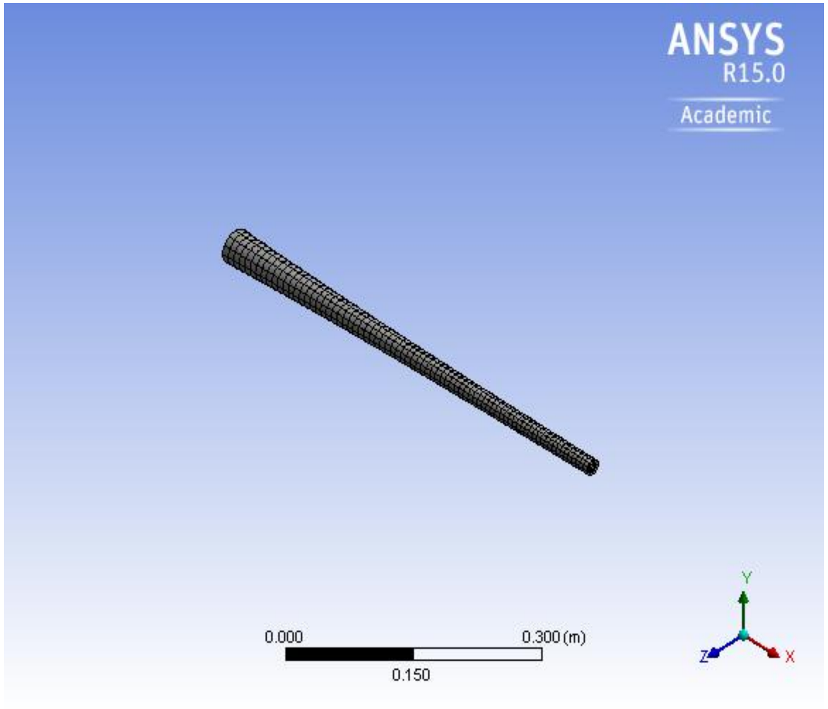
Linear geometry

Geometry	Length X(mm)	Length Y-Z(mm)	Volume (mm3)	Mass(Kg)
Parabolic	590	42.025	3.38E+05	2.64
Linear	590	42.025	3.52E+05	2.88

3. Model



Meshing of Parabolic Mandrel

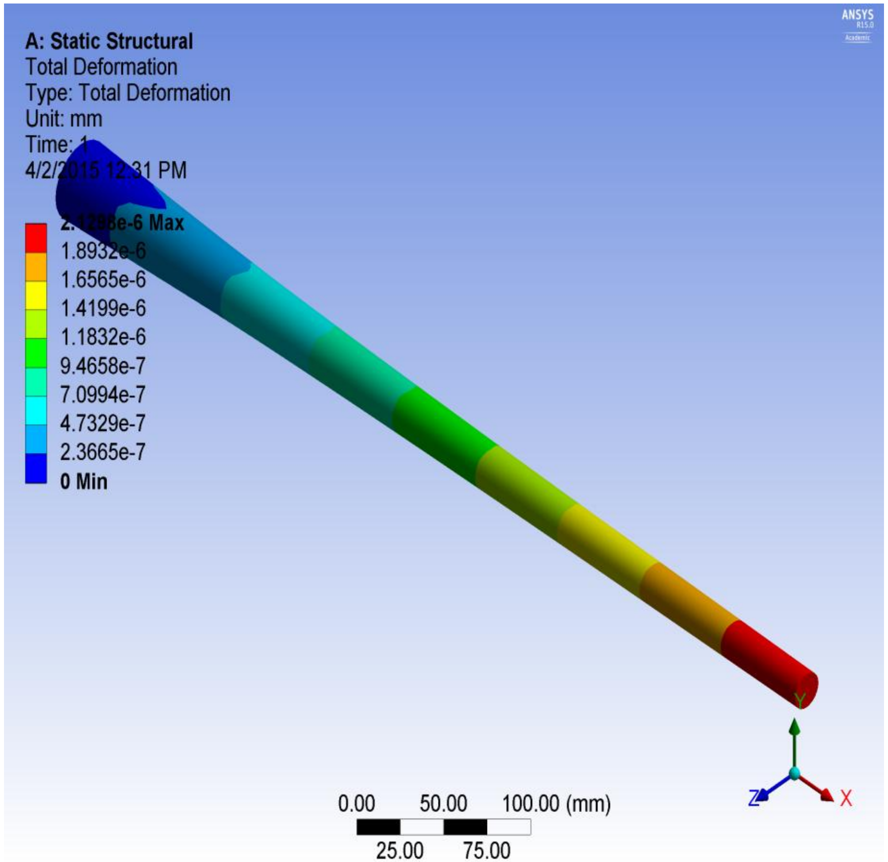


Meshing of Linear Mandrel

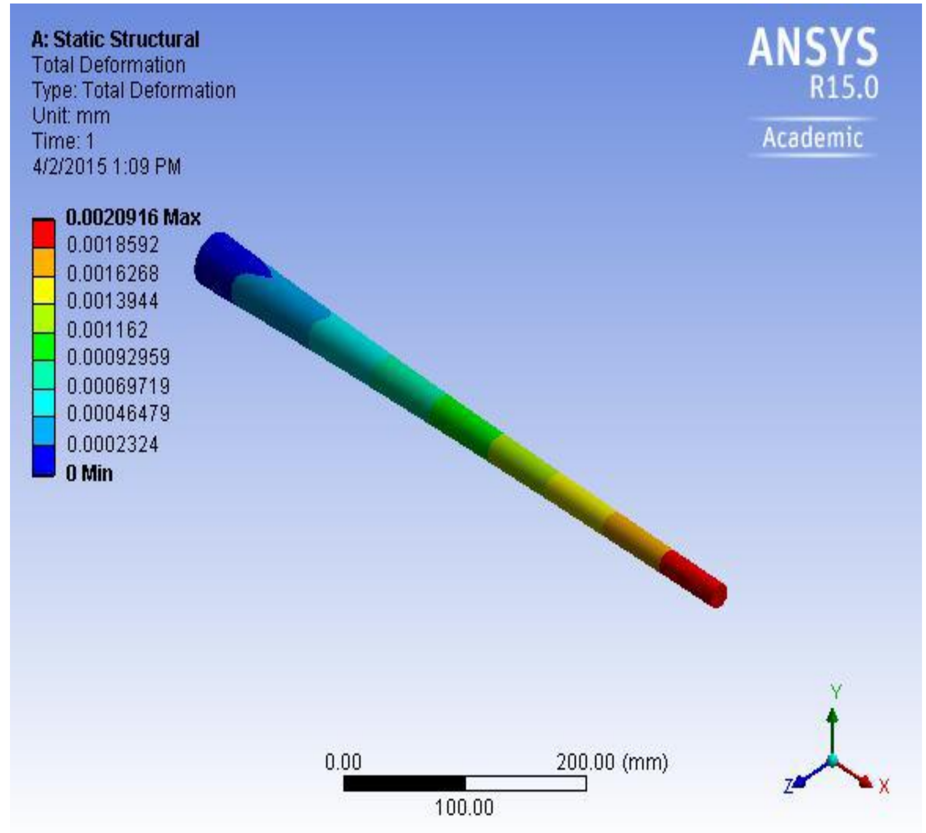
Node	Element
8364	1748

4. Solution

- Total Deformation

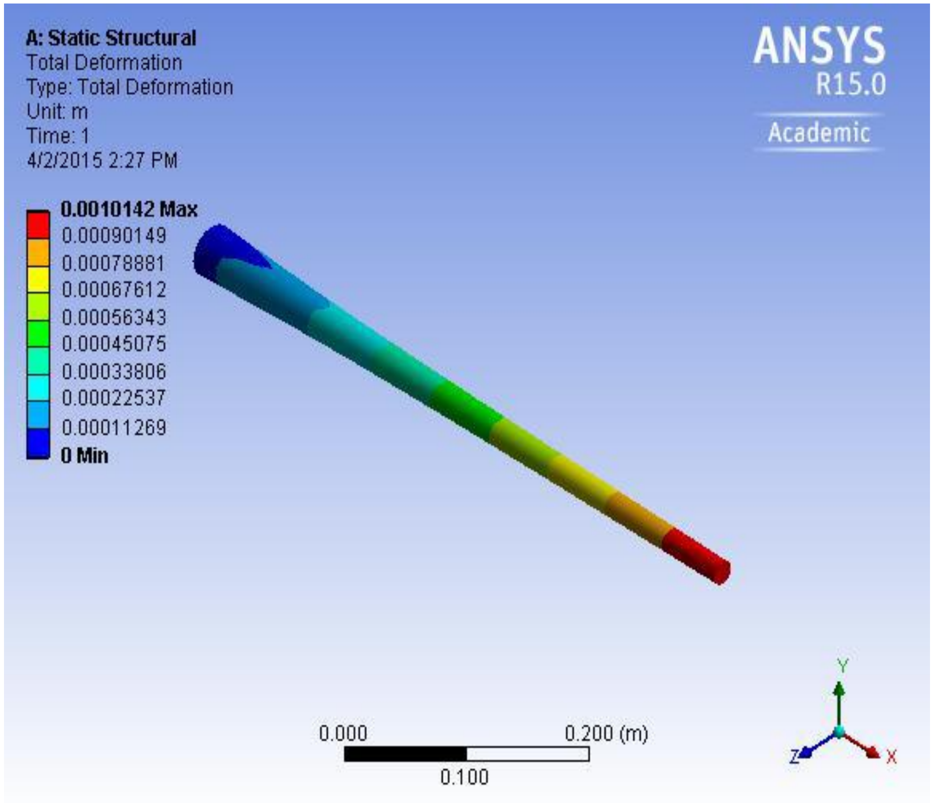


H11 Parabolic Profile

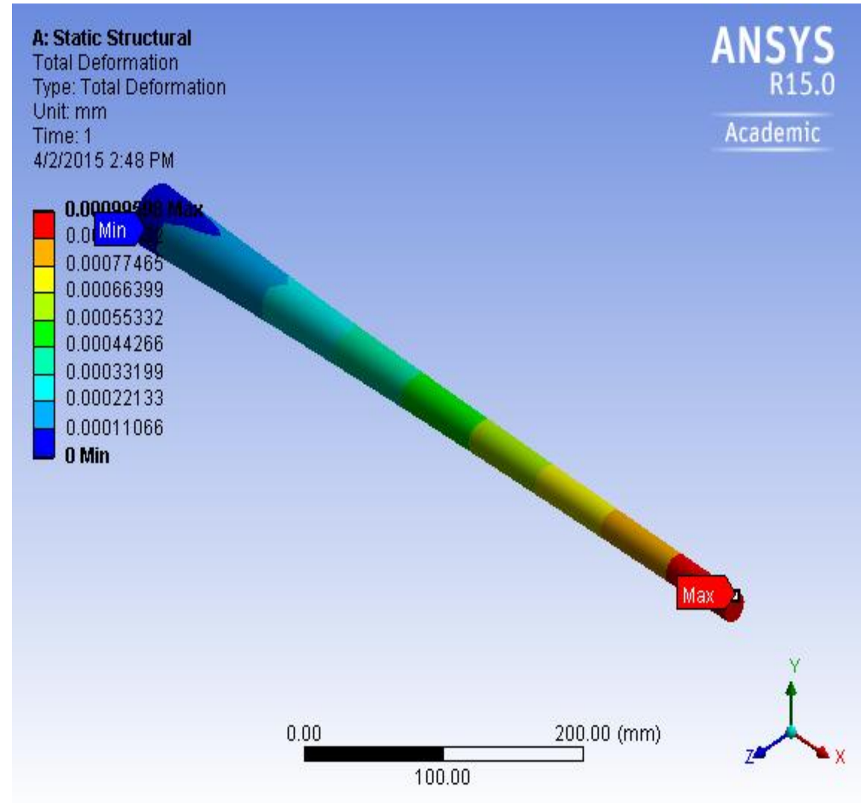


H11 Linear Profile

- Total Deformation

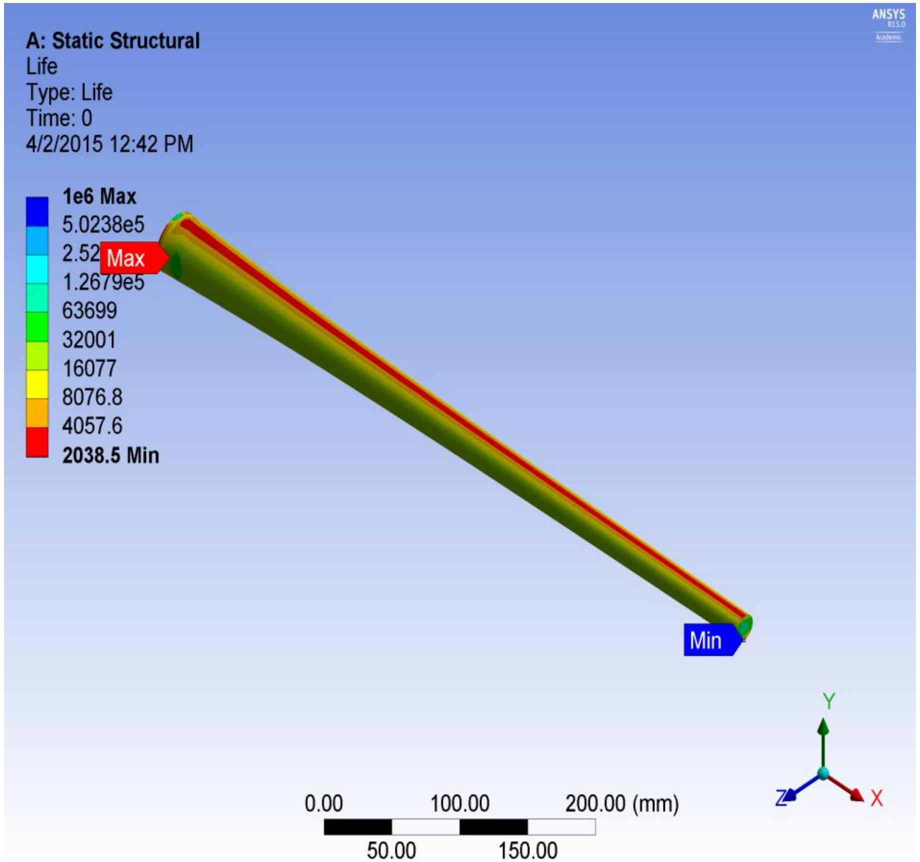


M4 Parabolic Profile

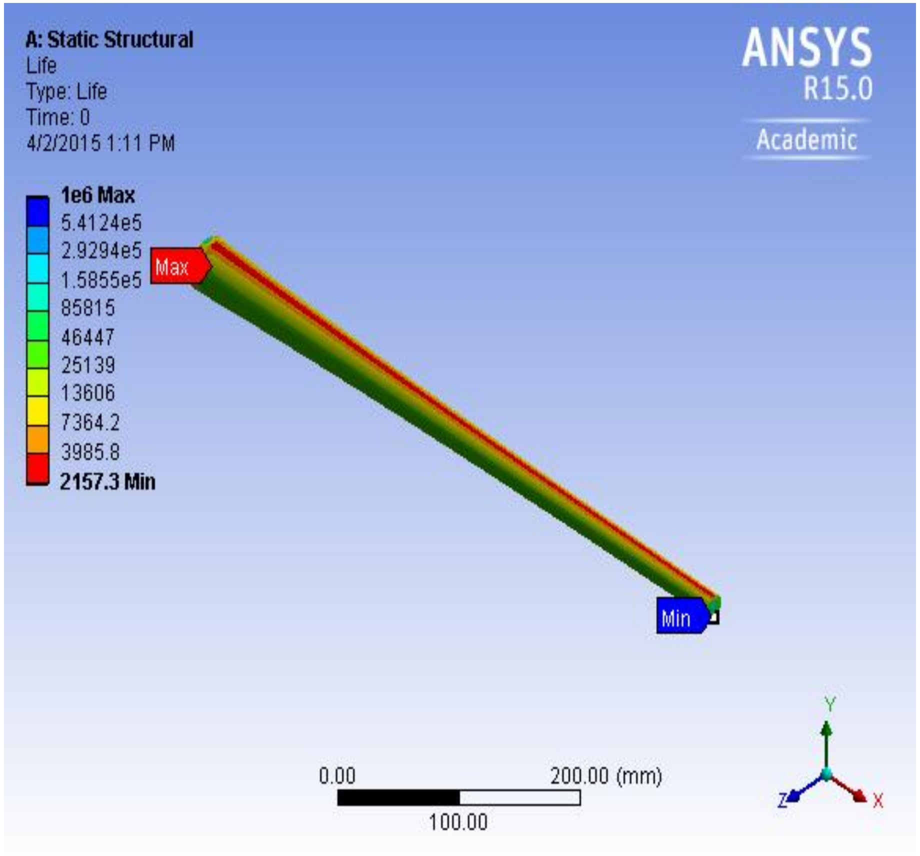


M4 Linear Profile

Life in cycle

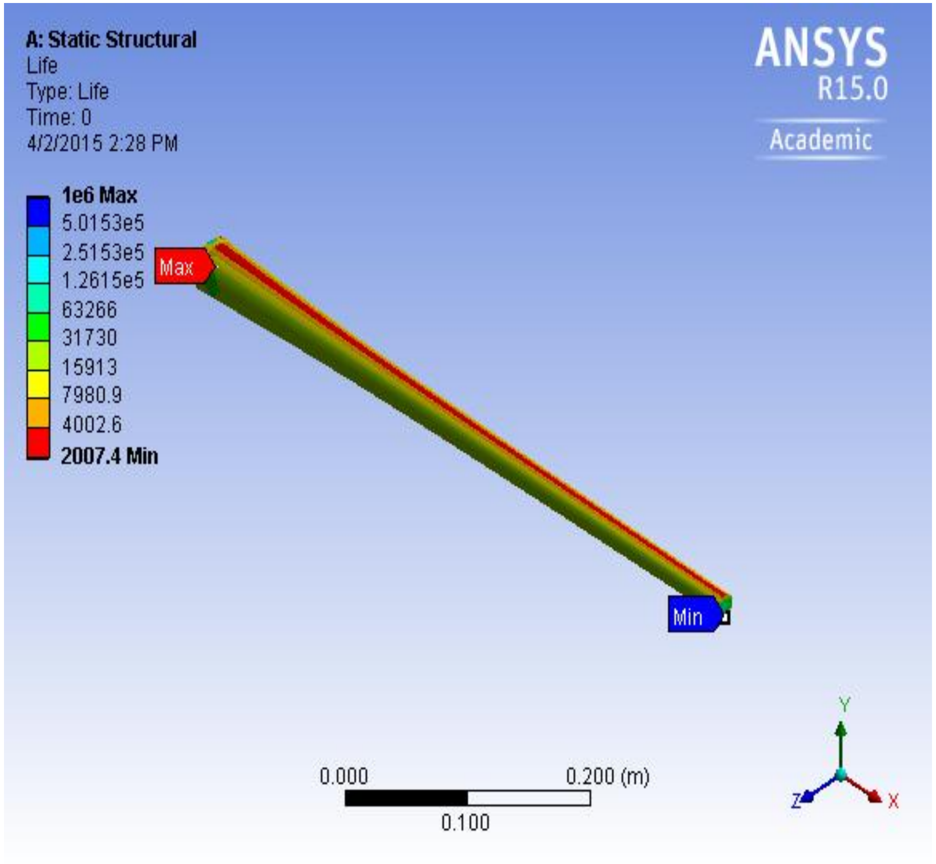


H11 Parabolic Profile

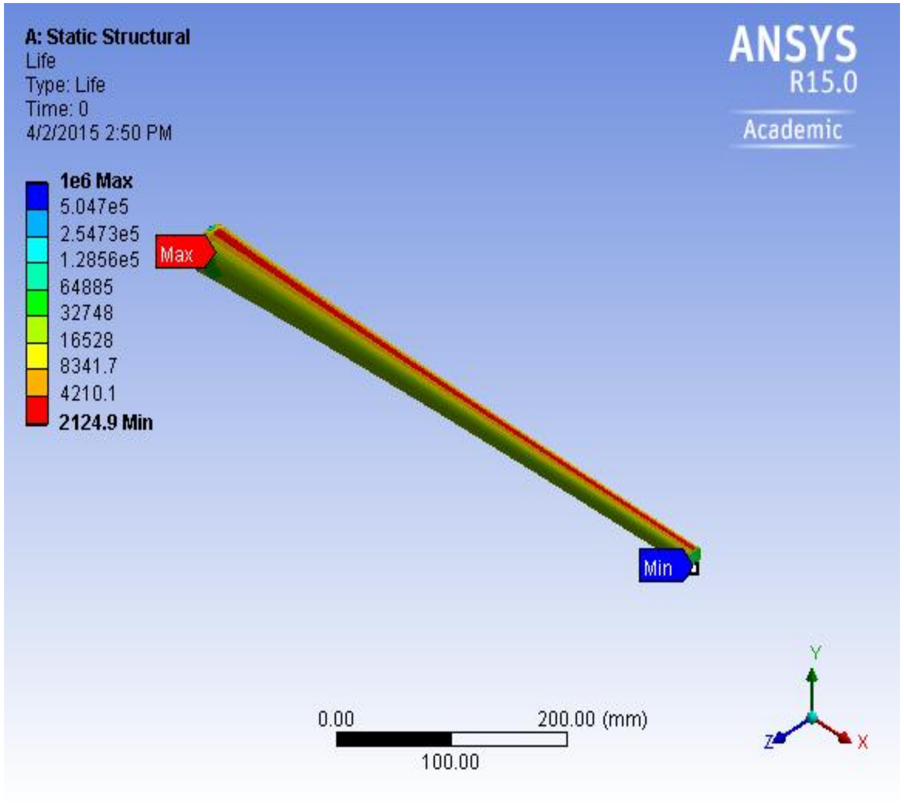


H11 Linear Profile

Life in cycle

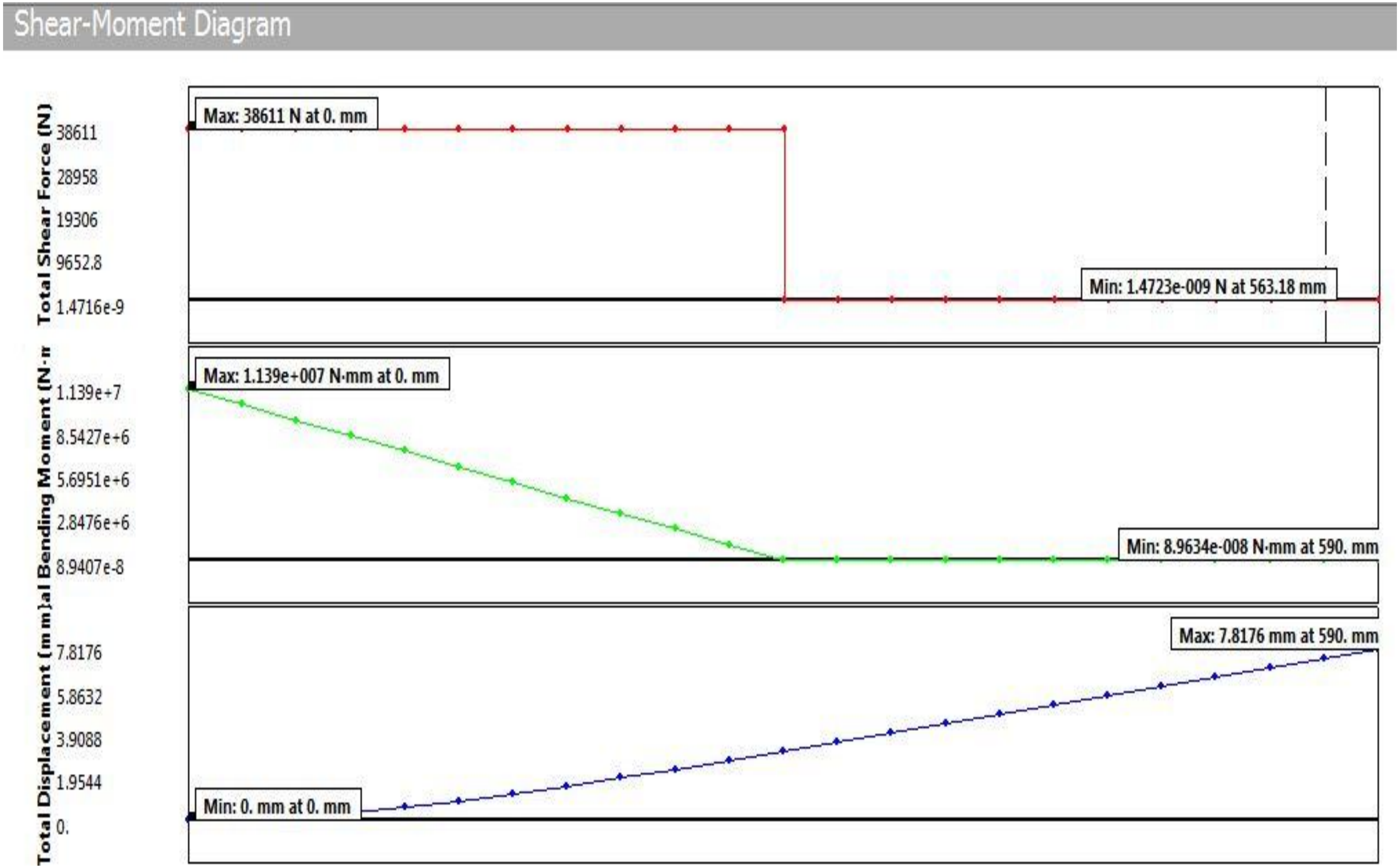


M4 Parabolic Profile



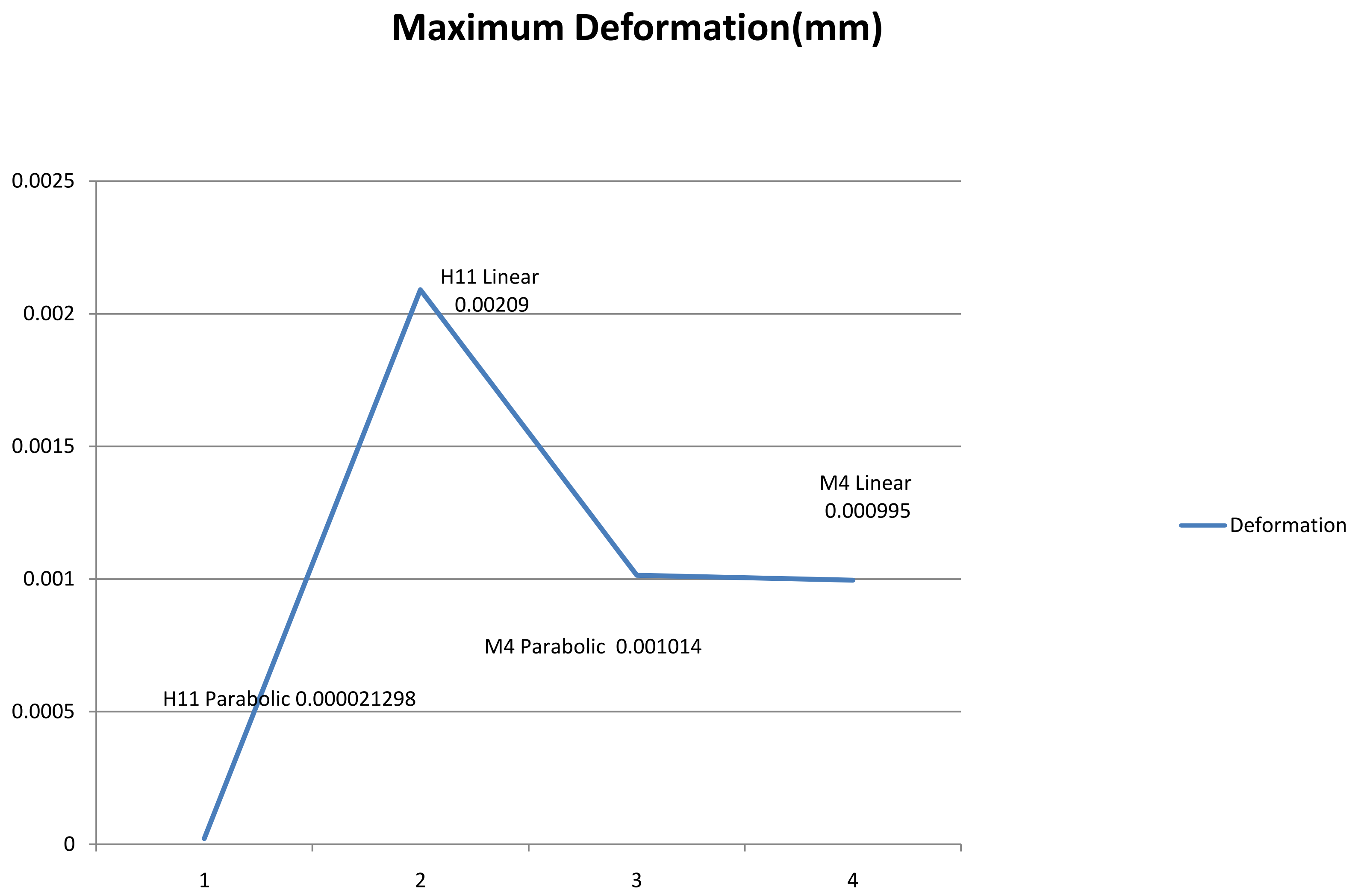
M4 Linear Profile

Shear moment diagram

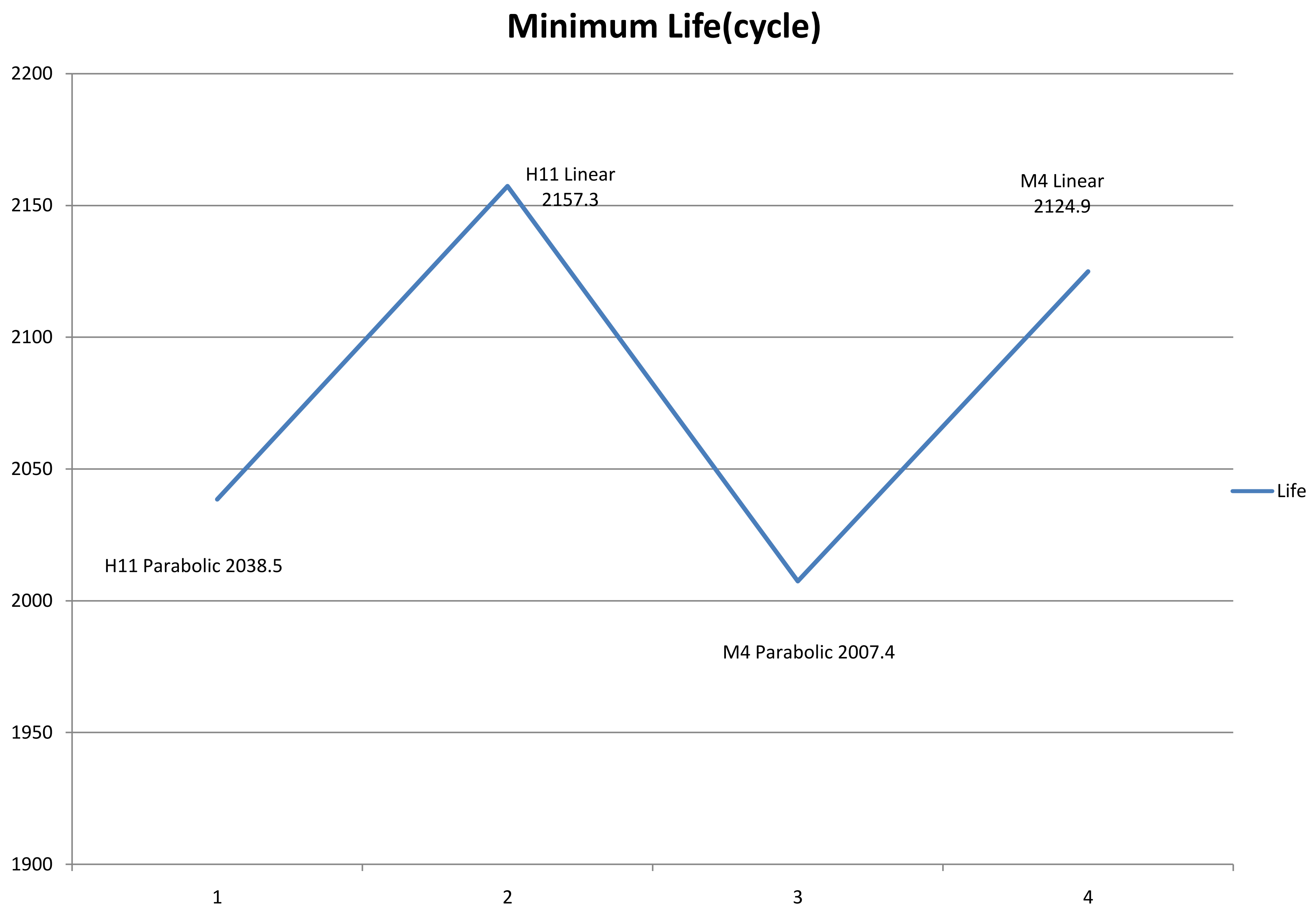


5. Result & Comparison

Material	H11				M4			
	Parabolic		Linear		Parabolic		Linear	
	Max	Min	Max	Min	Max	Min	Max	Min
Life	5.0238E+05	2038.5	5.4124E+05	2157.3	5.0153E+05	2007.4	5.047E+05	2124.9
Equivalent Stress	4.3829	0.16899	4.3033	0.1648	4.4047	0.19936	4.3244	0.19543
Deformation	0.000021298	0	0.002091	0	0.001014	0	0.000995	0



Maximum Deformation(mm)
0.0025
0.002
0.0015
0.001
0.0005
0
1
2
3
4
H11 Linear 0.00209
M4 Linear 0.000995
M4 Parabolic 0.001014
H11 Parabolic 0.000021298
Deformation



Minimum Life(cycle)
2200
2150
2100
2050
2000
1950
1900
H11 Linear
2157.3
M4 Linear
2124.9
H11 Parabolic 2038.5
M4 Parabolic 2007.4
1
2
3
4
Life

Conclusion

- According to prioritization based on life and deformation, the following material is suitable for using mandrel:-

	Life	Deformation
1	H11 Linear Profile	H11 Parabolic Profile
2	M4 Linear Profile	M4 Linear Profile
3	H11 Parabolic Profile	M4 Parabolic Profile
4	M4 Parabolic Profile	H11 Linear Profile

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!...Thank You...!