Design and analysis of mandrel use in cold pilger mill

Guided By:
Prof. Rajeshkumar

External Guide:
Mr. Mathur J. Patel
(General Manager)
Ratnadeep Metal & Tubes Ltd.

Prepared By:
Suthar Darshan B.(D12ME05)
Patel Apurv V.(11ME10)
Varma Hitesh J.(D12ME10)
Patel Sandip R.(D12ME14)
Contents

- Introduction
- Problem Definition
- Objective
- Literature Review
- Design of mandrel
  - Load Calculation
  - Design of mandrel dimension using C Program
  - Material Selection
- Analysis of mandrel
  - FEA Analysis
  - Analysis Using ANSYS 15.0
  - Comprehensive Table of analyzed result
- Comparison of analyzed result
- Conclusion
- Reference
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

1. Raw material
   - Pilgering
   - De greasing
   - Pickling
   - Heat treatment
   - Straightening
   - Final pickling
   - Cutting & deburring
   - Testing
   - Packing & Dispatch

2. Coating
   - Drawing
   - De-coating
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

1. Problem Definition
2. Find out the factors affecting on the failure of mandrel and short life span
3. Collection of data related to mandrel
4. Load calculation
5. Material Selection (H11 & M4) to compare
6. Design of mandrel
7. Structural analysis using FEA for material M4 and H11 tool steel
8. Result analysis and comparison
9. Conclusion
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 cases for checking the effect of friction.

- $\mu=0.075$ at the die/tube interface
- $\mu=0.075$ at the mandrel/tube interface
- $\mu=0.05$ at the die/tube interface
- $\mu=0.10$ at the mandrel/tube interface
- $\mu=0.05$ at the die/tube interface
- $\mu=0.10$ at the mandrel/tube interface
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.
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.

<table>
<thead>
<tr>
<th></th>
<th>parabolic shape</th>
<th>linear shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor of safety</td>
<td>6.0261e-002</td>
<td>3.4481e-002</td>
</tr>
<tr>
<td>No of cycles</td>
<td>5000 cycles</td>
<td>4000 cycles</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th></th>
<th>parabolic shape</th>
<th>linear shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Stress</td>
<td>5.852e+005 Pa</td>
<td>3.9292e+005 Pa</td>
</tr>
<tr>
<td>Maximum Stress</td>
<td>2.5e+009 Pa</td>
<td>1.4305e+009 Pa</td>
</tr>
</tbody>
</table>
6. S. Nantha Gopan, M. Gowtham J. 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.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Conventional mandrel</th>
<th>Adjustable mandrel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress</td>
<td>55.486 Mpa</td>
<td>265.3 Mpa</td>
</tr>
<tr>
<td>Strain</td>
<td>2.8 * e-4</td>
<td>1.4 * e-3</td>
</tr>
<tr>
<td>Displacement</td>
<td>0.2817</td>
<td>0.38452</td>
</tr>
</tbody>
</table>
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

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

\(\sigma_d\) = Drawing stress  
\(\sigma_b\) = Back tension  
\(h_1\) = Final thickness tube  
\(h_2\) = Initial thickness tube  
\(\mu_1\) = Coefficient of friction between ring die and tube  
\(\mu_2\) = Coefficient of friction between ring tube and mandrel  
\(\sigma_s = \sigma_b\), For paltering process

Take \(\sigma_0 = 210 \frac{N}{mm^2}\), for steel  
\(\beta = \frac{\mu_1 + \mu_2}{\tan \alpha} = \frac{0.01 + 0.006}{\tan 1.5} = 0.6110\)

\(\sigma_b = \frac{1.5 \times \sigma_0}{2 \sqrt{3}} = \frac{1.5 \times 210}{2 \sqrt{3}} = 90.9326 \frac{N}{mm^2}\)
\[
\frac{1 + \beta}{\beta} = \frac{1 + 0.6110}{0.6110} = 2.6367
\]
\[
\left(\frac{h_1}{h_2}\right)^\beta = \left(\frac{1.78}{4.00}\right)^{0.6110} = 0.6097
\]
\[
\sigma_d = \sigma_0 \frac{1 + \beta}{\beta} \left[1 - \left(\frac{h_1}{h_2}\right)^\beta\right] + \sigma_b \left(\frac{h_1}{h_2}\right)^\beta + \sigma_s
\]
\[
\sigma_d = [(210 \times 2.6367)(1 - 0.6110)] + [90.9326 \times 0.6110] + 90.9326
\]
\[
\sigma_d = 362.48 \frac{N}{mm^2}
\]

**Area of cross section at exit**

\[
= \pi \times 19.05 \times 1.78
\]
\[
= 106.52 mm^2
\]

**Drawing load**

\[
= \text{Drawing stress} \times \text{Area of exit}
\]
\[
= 362.48 \times 106.52
\]
\[
= 38611.3696 \ N
\]
Design of mandrel dimension using C Program

```c
#include<stdio.h>
#include<conio.h>
void main()
{
    float xen,xout,vi;
    int n,i;
    float di[100];
    clrscr();
    printf("Enter Mandrel Bigger Diameter value :-");
    scanf("%f", &xen);
    printf("Enter Mandreal Smaller Diameter Value : -");
    scanf("%f", &xout);
    printf("Enter Division Of Mandreal 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**

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Dia (mm)</th>
<th>Sr.No</th>
<th>Dia (mm)</th>
<th>Sr.No</th>
<th>Dia (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19.050</td>
<td>15</td>
<td>22.279</td>
<td>29</td>
<td>28.563</td>
</tr>
<tr>
<td>2</td>
<td>19.255</td>
<td>16</td>
<td>22.572</td>
<td>30</td>
<td>29.261</td>
</tr>
<tr>
<td>3</td>
<td>19.459</td>
<td>17</td>
<td>22.890</td>
<td>31</td>
<td>30.064</td>
</tr>
<tr>
<td>4</td>
<td>19.664</td>
<td>18</td>
<td>23.221</td>
<td>32</td>
<td>30.968</td>
</tr>
<tr>
<td>5</td>
<td>19.868</td>
<td>19</td>
<td>23.577</td>
<td>33</td>
<td>31.954</td>
</tr>
<tr>
<td>6</td>
<td>20.085</td>
<td>20</td>
<td>23.958</td>
<td>34</td>
<td>33.057</td>
</tr>
<tr>
<td>7</td>
<td>20.302</td>
<td>21</td>
<td>24.352</td>
<td>35</td>
<td>34.248</td>
</tr>
<tr>
<td>8</td>
<td>20.520</td>
<td>22</td>
<td>24.771</td>
<td>36</td>
<td>35.469</td>
</tr>
<tr>
<td>9</td>
<td>20.737</td>
<td>23</td>
<td>25.228</td>
<td>37</td>
<td>36.720</td>
</tr>
<tr>
<td>10</td>
<td>20.966</td>
<td>24</td>
<td>25.698</td>
<td>38</td>
<td>38.002</td>
</tr>
<tr>
<td>12</td>
<td>21.464</td>
<td>26</td>
<td>26.738</td>
<td>40</td>
<td>40.654</td>
</tr>
<tr>
<td>13</td>
<td>21.719</td>
<td>27</td>
<td>27.308</td>
<td>41</td>
<td>42.025</td>
</tr>
<tr>
<td>14</td>
<td>21.986</td>
<td>28</td>
<td>27.917</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
• PROCESS CYCLE OF MANDREL PREPARATION:

- Raw material cut on Hacksaw cutting machine
- Side facing & Cut center drilling on both face of raw material on lathe
- Storage of raw material
- Preprofile turning (soft) on copying lathe
- Profile Inspection on Surface table
- Storage of Material
- Heat Treatment of pilger mandrel
- Hardness Checking of mandrel on Hardness Tester
- Profile turning on copying lathe if require
- Profile Grinding on AGC-125 CNC grinding m/c
- Final inspection of mandrel profile
- Identification & marking of mandrel
- Mandrel profile polishing
- 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**

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>CU</th>
<th>CR</th>
<th>MN</th>
<th>MO</th>
<th>NI</th>
<th>P</th>
<th>S</th>
<th>SI</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass%</td>
<td>0.33-0.43</td>
<td>0.25</td>
<td>4.75-5.50</td>
<td>0.20-0.50</td>
<td>0.95</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.80-1.20</td>
<td>0.30-0.60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cutting tool</th>
<th>Rolls</th>
<th>Shear bladders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold pilger mandrels</td>
<td>Cold stamping tools</td>
<td>Moulds foot plastic processing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Density(kg/m3))</th>
<th>Yield strength(Mpa)</th>
<th>Ultimate Strength(Mpa)</th>
<th>Poisson's Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>7800</td>
<td>1650</td>
<td>1900</td>
<td>0.3</td>
</tr>
</tbody>
</table>
• **M4 tool steel**

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>CU</th>
<th>CR</th>
<th>MN</th>
<th>MO</th>
<th>NI</th>
<th>P</th>
<th>S</th>
<th>SI</th>
<th>V</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass%</td>
<td>1.25-1.40</td>
<td>0.25</td>
<td>3.75-4.25</td>
<td>0.15-0.40</td>
<td>4.25-5.25</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.20-0.45</td>
<td>4.00</td>
<td>5.50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Density(kg/m³)</th>
<th>Yield strength(MPa)</th>
<th>Ultimate Strength(MPa)</th>
<th>Poisson's Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>7979</td>
<td>4000</td>
<td>5129</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**Application:** Used for cutting tools of all types for machining operation.
• From this figure

\[
\frac{11.475}{590} = \frac{y_1}{491.67} \quad \Rightarrow \quad y_1 = 9.562 \text{ mm}
\]

\[
\frac{11.475}{590} = \frac{y_2}{295} \quad \Rightarrow \quad y_2 = 5.735
\]

\[
\frac{11.475}{590} = \frac{y_3}{98.33} \quad \Rightarrow \quad y_3 = 1.912
\]

\[
d_1 = 19.05 + (2y_1) = 38.175 \text{ mm}
\]

\[
d_2 = 19.05 + (2y_2) = 38.175 \text{ mm}
\]

\[
d_3 = 19.05 + (2y_3) = 38.175 \text{ mm}
\]

\[
A_1 = \frac{\pi}{4} d_1^2 = 1144.584 \text{ mm}^2
\]

\[
A_2 = 731.811 \text{ mm}^2
\]

\[
A_3 = 410.79 \text{ mm}^2
\]

\[
E_1 = E_2 = E_3 = 2 \times 10^5 \frac{N}{\text{mm}^2}
\]
\[ l_1 = l_2 = l_3 = 196.67 \text{ mm} \]

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

\[ = \frac{1144.592 \times 2 \times 10^5}{196.67} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \]

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

\[ k_2 = \frac{731.184 \times 2 \times 10^5}{196.67} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \]

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

\[ k_3 = \frac{410.967 \times 2 \times 10^5}{196.67} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \]
\[ k_3 = 10^3 \begin{bmatrix} 417.925 & -417.925 \\ -417.925 & 417.925 \end{bmatrix} \]

\[ k = k_1 + k_2 + k_3 \]

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

\[ Q = \begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \end{bmatrix} = \begin{bmatrix} 0 \\ Q_2 \\ Q_3 \\ Q_4 \end{bmatrix} \quad F = \begin{bmatrix} F_1 \\ F_2 \\ F_3 \end{bmatrix} = \begin{bmatrix} F_1 \\ F_2 \\ F_3 \end{bmatrix} = \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ -38611.3696 \end{bmatrix} \]

Now the, KQ=F
Use the elimination 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

\[
Q_2 = -0.0327 \text{ mm}
\]

\[
Q_3 = -0.0839 \text{ mm}
\]

\[
Q_4 = -0.1762 \text{ mm}
\]

Reaction force

\[
R = 10^3 \begin{bmatrix}
1163.972 & -1163.972 & 0 & 0 \\
\end{bmatrix}
\begin{bmatrix}
0 \\
-0.0327 \\
-0.0839 \\
-0.1762 \\
\end{bmatrix}
\]
\[
\sigma_1 = E \frac{1}{l_1} \begin{bmatrix} -1 & 1 \end{bmatrix} \begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix}
\]
\[
= 2 \times 10^5 \times \frac{1}{196.67} \begin{bmatrix} -1 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ -0.0327 \end{bmatrix}
\]
\[
= -33.253 \frac{N}{mm^2}
\]

\[
\sigma_2 = \frac{2 \times 10^5}{196.67} \begin{bmatrix} -1 & 1 \end{bmatrix} \begin{bmatrix} -0.0327 \\ -0.0839 \end{bmatrix} = -52.066 \frac{N}{mm^2}
\]

\[
\sigma_3 = \frac{2 \times 10^5}{196.67} \begin{bmatrix} -1 & 1 \end{bmatrix} \begin{bmatrix} -0.0839 \\ -0.1762 \end{bmatrix} = -93.86 \frac{N}{mm^2}
\]
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 steps involve the static structural analysis:
1. Engineering data
2. Geometry
3. Model
4. Solution
5. Result
## 1. Engineering Data

### AISI H11 Tool Steel

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (Kg/m³)</td>
<td>7800</td>
</tr>
<tr>
<td>Ultimate Tensile Strength (Pa)</td>
<td>1990E+06</td>
</tr>
<tr>
<td>Yield Tensile Strength (Pa)</td>
<td>1650E+06</td>
</tr>
<tr>
<td>Poison Ratio</td>
<td>0.3</td>
</tr>
<tr>
<td>Shear Modulus (Pa)</td>
<td>81E+09</td>
</tr>
</tbody>
</table>

### AISI M4 Tool Steel

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (Kg/m³)</td>
<td>8166</td>
</tr>
<tr>
<td>Ultimate Tensile Strength (Pa)</td>
<td>5129E+06</td>
</tr>
<tr>
<td>Yield Tensile Strength (Pa)</td>
<td>4000E+06</td>
</tr>
<tr>
<td>Poison Ratio</td>
<td>0.27</td>
</tr>
<tr>
<td>Shear Modulus (Pa)</td>
<td>126E+09</td>
</tr>
</tbody>
</table>
2. Geometry

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Length X (mm)</th>
<th>Length Y-Z (mm)</th>
<th>Volume (mm³)</th>
<th>Mass (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parabolic</td>
<td>590</td>
<td>42.025</td>
<td>3.38E+05</td>
<td>2.64</td>
</tr>
<tr>
<td>Linear</td>
<td>590</td>
<td>42.025</td>
<td>3.52E+05</td>
<td>2.88</td>
</tr>
</tbody>
</table>
3. Model

Meshing of Parabolic Mandrel
Meshing of Linear Mandrel

<table>
<thead>
<tr>
<th>Node</th>
<th>Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>8364</td>
<td>1748</td>
</tr>
</tbody>
</table>
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

Shear-Moment Diagram

- Max: 38611 N at 0. mm
- Min: 1.4723e-09 N at 563.18 mm
- Max: 1.139e+07 N-mm at 0. mm
- Min: 8.9634e-08 N-mm at 590. mm
- Max: 7.8176 mm at 590. mm

Total Displacement (mm) vs. Bending Moment (N-mm)
5. Result & Comparison

<table>
<thead>
<tr>
<th>Material</th>
<th>H11</th>
<th>M4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Parabolic</td>
<td>Linear</td>
</tr>
<tr>
<td>Life</td>
<td>Max 5.0238E+05, Min 2038.5</td>
<td>Max 5.4124E+05, Min 2157.3</td>
</tr>
<tr>
<td>Equivalent Stress</td>
<td>Max 4.3829, Min 0.16899</td>
<td>Max 4.3033, Min 0.1648</td>
</tr>
<tr>
<td>Deformation</td>
<td>0.000021298</td>
<td>0.002091</td>
</tr>
</tbody>
</table>
Conclusion

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

<table>
<thead>
<tr>
<th></th>
<th>Life</th>
<th>Deformation</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>H11 Linear Profile</td>
<td>H11 Parabolic Profile</td>
</tr>
<tr>
<td>2</td>
<td>M4 Linear Profile</td>
<td>M4 Linear Profile</td>
</tr>
<tr>
<td>3</td>
<td>H11 Parabolic Profile</td>
<td>M4 Parabolic Profile</td>
</tr>
<tr>
<td>4</td>
<td>M4 Parabolic Profile</td>
<td>H11 Linear Profile</td>
</tr>
</tbody>
</table>
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!...Thank You...!