CHAPTER 3
DEPLOYMENT OF SWAGING PROCESS FOR
PRODUCTIVITY OF TEXTILE SPINDLES

3.1 INTRODUCTION

Textile spindles are normally manufactured using a copying lathe or a single spindle automates. Here, swaging process is analyzed for improving the productivity of textile spindles. A basic overview of the principles of swaging, reduction calculations, material behavior, work hardening, calculation of the force, calculation of the power needed and effects of swaging on textile spindles are elaborated here.

3.2 REDUCTION CALCULATION

Reduction during swaging process is illustrated in Figure 3.1.

\[ \text{(a) Before swaging} \quad \text{(b) After swaging} \]

Figure 3.1 Reduction during swaging
3.2.1 Reduction Calculation Before and After Swaging

Area \( A_1 = \frac{\pi d_1^2}{4} \)

Area \( A_2 = \frac{\pi d_2^2}{4} \)

\( d_1 \) = Diameter before swaging

\( A_1 \) = Area before swaging

\( d_2 \) = Mean diameter after swaging

\( A_2 \) = Mean area after swaging

Percentage reduction, \( r = \left[ 1-\left(\frac{d_2}{d_1}\right)^2 \right] \times 100 \)

3.2.2 Calculation of Average Dimension

If \( d_1 \) is swaged with the reduction \( r \), the average dimension \( d_2 \) is calculated with the formula

\[ d_2 = d_1 \sqrt{1-r} \]

3.2.3 Calculation of the Initial Dimension

If mean dimension \( d_2 \) is to be produced with the reduction \( r \), the initial dimension \( d_1 \) is calculated with the formula

\[ d_1 = \frac{d_2}{\sqrt{1-r}} \]
In the textile spindle assembly, as shown in Figure 3.2, spindle blade and an aluminum plug are tried by a swaging process. Here, one type of spindle blade, made up of En 31 steel rod, having a length of 235mm and aluminum plug of LM4 aluminum rod, having a length of 180mm, are tried in the swaging process to form the required taper and length prior to final machining and final grinding to achieve a material and labour productivity.
3.3 MATERIAL BEHAVIOUR IN SWAGING

Swaging is the process of eccentric rotating taper rollers fixed in housing and hitting against the spindle blade and aluminum plug material. It is similar to cold forging.

The equiaxed grains are elongated in the longitudinal direction and compressed in the transverse direction. A grain at the surface will be elongated and stretched more than a similar grain at the core, due to the redundant shear which influences the material flow.

The material is work-hardened because of the grain stretching and the development of a dislocation substructure due to the changing grains.

The work hardening of materials has to be determined empirically.

At the interface, due to friction with rapid increase of temperature, spectacular new surface is formed.

In fact, with a 25 % reduction, 15 % increase of surface is achieved.

3.3.1 Uniform and Non-Uniform Elongation

Figure 3.3. Uniform elongation
In an ideal process, the elongation is uniform as shown in figure 3.3. In a real process extra shear will occur in the material during the process as shown in Figure 3.4.

![Figure 3.4. Non-uniform elongation](image)

This extra shear in the material leads to the total plastic deformation.

It is called ‘redundant work’ or non-uniform elongation. One consequence of this elongation is that the work hardening is more significant.

A more important consequence is, however, that grains near the surface are more elongated and sheared than grains in the core. This can lead to surface cracks and wrinkles during the swaging process. This can be eliminated by revolving the spindle and housing in opposite directions.

### 3.3.2 To Reduce Redundant Work

In reality, the redundant work will never be zero. To reduce the non-uniform elongation the following two steps maybe taken:

- Decreasing the taper; and
- Increasing the reduction.

Both the steps are important for a good quality of swaging surface. The combined effect of taper and reduction is shown in Figure 3.5.
Figure 3.5 Combined effect of taper and reduction

An estimation of the percentage non-uniform elongation during the swaging process with a reduction of 10 and 25 % with taper 20 and 10, is shown in Table 3.1.

It is evident that the combination of small taper and large reduction reduces the percentage of non-uniform elongation.

Table 3.1 Estimation of non-uniform elongation during swaging

<table>
<thead>
<tr>
<th>Reduction (%)</th>
<th>Taper</th>
<th>Percentage of non-uniform elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td>25</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

3.4 WORK HARDENING

During the swaging process, deformation hardening occurs. The reason for this hardening may be described using the following two explanatory models.
3.4.1 Dislocation Model

Crystalline imperfections are called dislocations. During deformation, the dislocations within every grain move in the direction $\tau$ as shown in Figure 3.6. New dislocations are generated during the deformation and they will interfere with each other.

![Figure 3.6 Dislocation model](image)

Figure 3.6 Dislocation model

The multiplication of dislocations during the plastic deformation increases the stress necessary for the dislocation motion. This is work hardening.

3.4.2 Simple Model with Grain Stretching

During the swaging process the grains are elongated and stay stretched. Stresses are introduced and this increases hardness, yield and tensile strengths as shown in Figure 3.7. Table 3.2 shows the tensile strength obtained from different reduction percentages.
A. Material before swaging  
B. Elongated grains after swaging  
C. Equiaxed grains after heat treatment

**Figure 3.7 Recrystallization**

**Table 3.2 Tensile for different reduction percentages**

<table>
<thead>
<tr>
<th>Reduction (%)</th>
<th>Tensile strength before swaging (N/mm²)</th>
<th>Tensile strength after swaging (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>450</td>
<td>550</td>
</tr>
<tr>
<td>10</td>
<td>1065</td>
<td>1085</td>
</tr>
</tbody>
</table>

During heat treatment, re-crystallization occurs and densely tangled dislocation structure is gradually replaced by new strain – free grains. After re-crystallization, elongated grains are changed to equiaxed grains. Tensile strength variation for various percentages of area reductions during work hardening is shown in Figure 3.8. The relation between various percentage reductions and reduction factor, K is shown in Figure 3.9. These are used in the calculation of swaging force.
Figure 3.8 Work hardening

Figure 3.9 Reduction vs factor K
3.5  CALCULATION OF THE SWAGING FORCE

3.5.1  Uniform Elongation

Swaging force for uniform elongation

\[ F = A_2 \cdot Y_m \cdot \ln \frac{A_1}{A_2} \]
\[ = 2 \cdot A_2 \cdot Y_m \cdot \ln \frac{d_1}{d_2} \]
\[ = A_2 \cdot Y_m \cdot \ln \frac{1}{1-r} \]

where

\[ F = \text{Swaging force (Newton)} \]
\[ A_1 = \text{Area before swaging (mm}^2\text{)} \]
\[ A_2 = \text{Mean area after swaging (mm}^2\text{)} \]
\[ Y_m = \text{Mean yield point (N/mm}^2\text{)} \]
\[ r = \text{Reduction (Figure 3.8)} \]

3.5.2  Force due to Friction

Force due to uniform and non-uniform elongation and friction.

\[ F = A_1 \cdot Y_m \left( l_n \frac{A_1}{A_2} + \frac{\mu}{\theta} l_n \frac{A_1}{A_2} + \frac{\theta}{3} \right) \]

where

\[ F = \text{Swaging force (Newton)} \]
\[ A_1 = \text{Area before swaging (mm}^2\text{)} \]
\[ A_2 = \text{Mean area after swaging (mm}^2\text{)} \]
\[ Y_m = \text{Mean yield point (N/mm}^2) \]

\[ \theta = \text{Taper} \]

\[ \mu = \text{Friction coefficient (0.06-0.1)} \]

### 3.5.3 Force due to Bearing

When the force is calculated, 10 to 20 \% of the force should be added for the friction in the bearing.

Additional force due to bearing

\[ F_b = \pi d_2. L. Y_2 \mu \]

- \[ d_2 = \text{Mean diameter after swaging (mm)} \]
- \[ L = \text{Length of the bearing} \]
- \[ Y_2 = \text{Yield point after swaging (N/mm}^2) \]

Force based on the tensile strength

\[ F = A_2. Y_m. K \]

- \[ F = \text{Swaging force (Newton)} \]
- \[ A_2 = \text{Mean area after swaging (mm}^2) \]
- \[ Y_m = \text{Mean tensile strength (N/mm}^2) \]
- \[ K = \text{Reduction factor (Figure 3.9)} \]
3.6 \hspace{1cm} \textbf{EFFECTS DURING SWAGING}

During swaging energy is added by:

- Uniform elongation;
- Non-uniform elongation;
- Friction; and
- Mechanical loss.

Around 65 \% of the total energy is converted into heat, with only 10 \% of it getting cooled. An effect of work hardening during swaging process is shown in Table 3.3.

\textbf{Table 3.3 Effect of work hardening}

<table>
<thead>
<tr>
<th>Reduction r %</th>
<th>Yield</th>
<th>Effective kW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Y_1 \hspace{1cm} Before swaging</td>
<td>Y_2 \hspace{1cm} After swaging</td>
</tr>
<tr>
<td>30</td>
<td>1025</td>
<td>835</td>
</tr>
<tr>
<td>50</td>
<td>1120</td>
<td>950</td>
</tr>
<tr>
<td>60</td>
<td>1185</td>
<td>1040</td>
</tr>
<tr>
<td>70</td>
<td>1270</td>
<td>1135</td>
</tr>
<tr>
<td>75</td>
<td>1330</td>
<td>1200</td>
</tr>
<tr>
<td>80</td>
<td>1450</td>
<td>1280</td>
</tr>
</tbody>
</table>

An analysis of force during elongation due to swaging process and power required at different reduction percentages are tabulated and shown in Table 3.4.
Table 3.4 Analysis of force and the power

<table>
<thead>
<tr>
<th>Reduction r %</th>
<th>Force at deformation Uniform N</th>
<th>Non-uniform N</th>
<th>Friction N</th>
<th>Friction in bearing</th>
<th>Total theoretical force N</th>
<th>Effective (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>4375</td>
<td>860</td>
<td>2090</td>
<td>835</td>
<td>8155</td>
<td>9.6</td>
</tr>
<tr>
<td>25</td>
<td>3380</td>
<td>760</td>
<td>1615</td>
<td>690</td>
<td>6445</td>
<td>10.4</td>
</tr>
<tr>
<td>20</td>
<td>2515</td>
<td>645</td>
<td>1200</td>
<td>580</td>
<td>4940</td>
<td>10.5</td>
</tr>
<tr>
<td>15</td>
<td>1895</td>
<td>550</td>
<td>905</td>
<td>495</td>
<td>3845</td>
<td>10.3</td>
</tr>
<tr>
<td>10</td>
<td>1450</td>
<td>480</td>
<td>695</td>
<td>430</td>
<td>3055</td>
<td>10.1</td>
</tr>
</tbody>
</table>

Initial tensile strength of 850 N/mm² is found to increase after swaging to 1,400 N/mm² in case of Spindle blade with co-efficient of friction μ=0.06

The theoretical force is recalculated to have a practical value of 1.2, thus allowing for a mechanical loss of 20 %.

Friction co-efficient, μ and bearing length, L, based on the swaging force and effect on En 31 and LM4 material with different diameter and taper can be further studied for different type of spindles.

3.7 CONCLUSION

The analysis of swaging process for one type of textile spindle is done elaborating the reduction calculations, material behavior, work hardening, calculation of the force, calculation of the power for swaging of textile spindle blade of En31 and aluminium plug of LM4. This analysis is further extended to the design a roller swaging process set-up for productivity improvement of textile spindles.