Heinz Tschaetsch

Metal Forming Practice

Processes – Machines – Tools

Translated by Anne Koth

Springer
Preface

The book “Metal Forming”, a translation of the eighth revised edition of “Umformtechnik” in German, describes the latest technology in the sector of metal forming.

Part I covers metal forming and shearing processes. It describes the main features of these processes, the tooling required and fields of application. Practical examples show how to calculate the forces involved in forming and the strain energy.

Part II describes forming machines and shows how to calculate their parameters.

This section also introduces flexible manufacturing systems in metal forming and the handling systems required for automation (automatic tool changing and workpiece conveyor systems).

Part III includes tables and flow diagrams with figures needed to calculate forming forces and strain energy.

These production units are automated as much as possible using modern CNC engineering to reduce non-productive time and changeover time, and thus also manufacturing costs. Alongside these economic advantages, however, another important reason for using metal working processes is their technical advantages, such as:

- material savings
- optimal grain direction
- work hardening with cold forming.

This book runs through all the main metal forming and shearing processes and the tooling and machines they involve. Incremental sheet forming was recently added in Chapter 15.4.

For engineers on the shop floor, this book is intended as an easily-navigable reference work. Students can use this book for reference, saving them time making notes in the lecture theatre so that they can pay better attention to the lecture.

I would particularly like to thank my colleague, Prof. Jochen Dietrich, Ph.D.eng. h.c., lecturer in production processes and CNC engineering at Dresden University of Applied Sciences, Germany (Hochschule für Technik und Wirtschaft), for his involvement as co-author from the 6th edition.

Thanks also to Dr. Mauerman of the Fraunhofer Institute for Machine Tools and Forming Technology, Chemnitz, Germany (Institut für Werkzeugmaschinen und Umformtechnik), for his collaboration on the 7th edition of the book.

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Heinz Tschätsch
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# Terms, symbols and units

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<td>$W$</td>
<td>Nm</td>
</tr>
<tr>
<td>Force (force of pressure)</td>
<td>$F$</td>
<td>N</td>
</tr>
<tr>
<td>Drawing force</td>
<td>$F_{dr}$</td>
<td>N</td>
</tr>
<tr>
<td>Blank holder force</td>
<td>$F_{BH}$</td>
<td>N</td>
</tr>
<tr>
<td>Velocity</td>
<td>$v$</td>
<td>m/s, m/min</td>
</tr>
<tr>
<td>Strain rate</td>
<td>$\dot{\phi}$</td>
<td>s$^{-1}$</td>
</tr>
<tr>
<td>Pressure</td>
<td>$p$</td>
<td>Pa, bar</td>
</tr>
<tr>
<td>Shear stress</td>
<td>$\tau$</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Tensile stress</td>
<td>$R, \sigma$</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>$R_m$</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Yield strength</td>
<td>$R_e$</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Elastic limit</td>
<td>$R_{P_{0.2}}$</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Elongation</td>
<td>$\varepsilon$</td>
<td>m/m, %</td>
</tr>
<tr>
<td>Flow stress</td>
<td>$k_{str}$</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Flow stress before forming (cold forming)</td>
<td>$k_{str0}$</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Flow stress after forming (cold forming)</td>
<td>$k_{str1}$</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Resistance to flow</td>
<td>$p_{fl}$</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Deformation resistance</td>
<td>$k_r$</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>$E$</td>
<td>N/mm²</td>
</tr>
<tr>
<td>Density</td>
<td>$\rho$</td>
<td>t/m³, kg/dm³, g/cm³</td>
</tr>
<tr>
<td>Blank length before forming</td>
<td>$h_0, l_0$</td>
<td>m, mm</td>
</tr>
<tr>
<td>Blank length after forming</td>
<td>$h_1, l_1$</td>
<td>m, mm</td>
</tr>
<tr>
<td>Area</td>
<td>$A$</td>
<td>m², mm²</td>
</tr>
<tr>
<td>Area before forming</td>
<td>$A_0$</td>
<td>m², mm²</td>
</tr>
<tr>
<td>Area after forming</td>
<td>$A_1$</td>
<td>m², mm²</td>
</tr>
<tr>
<td>Volume</td>
<td>$V$</td>
<td>m³, mm³</td>
</tr>
<tr>
<td>Forming temperature</td>
<td>$T$</td>
<td>K, °C</td>
</tr>
<tr>
<td>Coefficient of friction</td>
<td>$\mu$</td>
<td>–</td>
</tr>
<tr>
<td>Efficiency</td>
<td>$\eta$</td>
<td>–</td>
</tr>
<tr>
<td>Term</td>
<td>Symbol</td>
<td>Unit (selection)</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>--------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Deformation efficiency</td>
<td>$\eta_F$</td>
<td>–</td>
</tr>
<tr>
<td>Impact effect (with hammers)</td>
<td>$\eta_i$</td>
<td>–</td>
</tr>
<tr>
<td>Power</td>
<td>$P$</td>
<td>Nm/s, W</td>
</tr>
<tr>
<td>Acceleration</td>
<td>$a, g$</td>
<td>m/s²</td>
</tr>
<tr>
<td>Press strokes per minute</td>
<td>$n$</td>
<td>min⁻¹, s⁻¹</td>
</tr>
<tr>
<td>Stroke length</td>
<td>$H, h$</td>
<td>m, mm</td>
</tr>
<tr>
<td>Mass moment of inertia</td>
<td>$I_d, \theta$</td>
<td>kgm²</td>
</tr>
<tr>
<td>Mass</td>
<td>$m$</td>
<td>kg</td>
</tr>
<tr>
<td>Angular velocity</td>
<td>$\omega$</td>
<td>s⁻¹</td>
</tr>
<tr>
<td>Moment</td>
<td>$M$</td>
<td>Nm, J</td>
</tr>
<tr>
<td>Tangential force (with crank presses)</td>
<td>$T_p$</td>
<td>N</td>
</tr>
<tr>
<td>Crank angle (with crank presses)</td>
<td>$\alpha$</td>
<td>°</td>
</tr>
</tbody>
</table>
Part I: Metal forming and shearing processes
1 Types of manufacturing process

The manufacturing processes are subdivided into six main groups.

Of these six main groups, this book will study metal forming processes (Fig 1.2) and shearing processes (Fig. 1.3).

Metal forming is producing parts by plastic modification of the shape of a solid body. During this process, both mass and material cohesion are maintained.
Shearing is separating adjacent parts of a workpiece, or shearing apart whole workpieces without creating chips.

With the separation processes, a difference is made between shearing and wedge-action cutting according to the form of the blade.

In industry, shearing is of greater importance (Fig. 1.4).

<table>
<thead>
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<th>Main group 3</th>
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<tr>
<td>Shearing without the creation of chips</td>
</tr>
<tr>
<td>Shearing</td>
</tr>
<tr>
<td>Shearing off</td>
</tr>
<tr>
<td>Blanking</td>
</tr>
<tr>
<td>Lancing</td>
</tr>
<tr>
<td>Notching</td>
</tr>
<tr>
<td>Notching and trimming</td>
</tr>
<tr>
<td>Piercing</td>
</tr>
</tbody>
</table>

Fig. 1.4 (top) Cutting.
a) Wedge-action cutting, b) Shearing

Fig. 1.3
(left) Types of shearing method
2 Terms and parameters of metal forming

2.1 Plastic (permanent) deformation

Unlike elastic deformation, during which, for example, a rod under a tensile load returns to its initial length as long as a defined value (elastic limit of the material, \( R_{p0.2} \) limit) is not exceeded, a workpiece which is plastically deformed retains its shape permanently.

For the elastic range, the following applies:

\[
\sigma_z = \varepsilon \cdot E \\
\varepsilon = \frac{\Delta l}{l_0} = \frac{l_0 - l_1}{l_0}
\]

![Fig. 2.1 Tension test bar – change in length under stress](image)

- \( \sigma_z \) in N/mm\(^2\) tensile stress
- \( \varepsilon \) in – elongation
- \( l_0 \) in mm initial length
- \( l_1 \) in mm length under the influence of force
- \( \Delta l \) in mm lengthening
- \( R_m \) in N/mm\(^2\) tensile strength (was \( \sigma_B \))
- \( R_e \) in N/mm\(^2\) resistance at the yield point (was \( \sigma_S \))
- \( E \) in N/mm\(^2\) modulus of elasticity.

In the plastic range, a permanent deformation is caused by sufficiently high shear stresses. This makes the atoms in row \( A_1 \) (Fig. 2.2) change their state of equilibrium in relation to row \( A_2 \). The extent of the displacement is proportional to the extent of the shear stress \( \tau \).
If the effective shear stress is less than $\tau_f$ ($\tau_f$ yield shear stress) then $m < a/2$ and after the stress is removed the atoms return to their original position - elastic deformation.

If, however, the yield shear stress limit is exceeded, then $m > a/2$ or $m > n$, the atoms move into the field of attraction of the adjacent atoms and a new, permanent state of equilibrium is attained – plastic deformation.

The limit which must be exceeded is known as the plasticity criterion, and the associated resistance as the

**flow stress** $k_{str}$

### 2.2 Flow stress $k_{str}$ in N/mm$^2$

#### 2.2.1 Cold forming

In cold forming, $k_{str}$ depends only on the extent of the deformation $\varphi_r$ (principal strain) and on the material to be formed. The diagram showing the flow stress depending on the extent of the deformation (Fig. 2.3) is called a flow stress curve.

This denotes the strain hardening behaviour of a material. Flow stress curves can be approximately represented by the following equation.

$$k_{str} = k_{str100\%} \cdot \varphi^n = c \cdot \varphi^n$$

- $n$ – strain hardening coefficient
- $c$ – equivalent to $k_{str1}$ when $\varphi = 1$ or when $\varphi = 100\%$
- $k_{str0}$ – flow stress before forming for $\varphi = 0$.

**Mean flow stress** $k_{strm}$

In some manufacturing processes the “mean flow stress” is needed to calculate force and work. It can be approximately determined from:

$$k_{strm} = \frac{k_{str0} + k_{str1}}{2}$$

- $k_{strm}$ in N/mm$^2$ mean flow stress
- $k_{str0}$ in N/mm$^2$ flow stress for $\varphi = 0$
- $k_{str1}$ in N/mm$^2$ flow stress at the end of forming ($\varphi_r = \varphi_{max}$).
2.2 Flow stress in $k_{str} \text{ N/mm}^2$

2.2.2 Hot forming

In hot forming above the recrystallisation temperature, $k_{str}$ is independent of the degree of deformation $\varphi$. Here, $k_{str}$ depends upon the strain rate $\dot{\varphi}$ (Fig. 2.4), the deformation temperature (Fig. 2.5) and the material to be deformed.

---

**Fig. 2.3**
Flow stress curve - cold forming
$k_{str} = f(\varphi)$, $a = f(\varphi)$ in Nmm/mm$^3$

**specific strain energy**

**Flow stress curve**

<table>
<thead>
<tr>
<th>Material: Ck15 soft annealed</th>
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<tbody>
<tr>
<td>$a$</td>
</tr>
<tr>
<td>[Nmm]</td>
</tr>
</tbody>
</table>

---

**Fig. 2.4**
$k_{str} = f(\dot{\varphi})$ in hot forming

**Fig. 2.5**
$k_{str} = f$ (temperature and of the material) in hot forming. With higher carbon steels, $k_{str}$ decreases at a faster rate than with low carbon steels.
At high strain rates \( k_{\text{str}} \) rises during hot forming since the cohesion-reducing processes which arise due to recrystallisation no longer take place completely.

### 2.2.3 Calculation of the flow stress \( k_{\text{str,sh}} \) for semi-hot forming

\[
k_{\text{str,sh}} = c \cdot \varphi_p^n \cdot \dot{\varphi}^m
\]

- \( k_{\text{str,sh}} \) in N/mm\(^2\) flow stress in semi-hot forming
- \( T \) in °C temperature in semi-hot forming
- \( c \) in N/mm\(^2\) empirical calculation coefficient
- \( \varphi_p \) – principal strain
- \( n \) – exponent of \( \varphi_p \)
- \( \dot{\varphi} \) in s\(^{-1}\) strain rate
- \( m \) – exponent of \( \varphi \)

#### Table 2.1 Exponents and semi-hot forming temperatures

<table>
<thead>
<tr>
<th>Material</th>
<th>( n )</th>
<th>( m )</th>
<th>( T ) °C</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>C 15</td>
<td>0.1</td>
<td>0.08</td>
<td>500</td>
<td>300</td>
</tr>
<tr>
<td>C 22</td>
<td>0.09</td>
<td>0.09</td>
<td>500</td>
<td>300</td>
</tr>
<tr>
<td>C 35</td>
<td>0.08</td>
<td>0.10</td>
<td>550</td>
<td>283</td>
</tr>
<tr>
<td>C 45</td>
<td>0.07</td>
<td>0.11</td>
<td>550</td>
<td>283</td>
</tr>
<tr>
<td>C 60</td>
<td>0.06</td>
<td>0.12</td>
<td>600</td>
<td>267</td>
</tr>
<tr>
<td>X 10 Cr 13</td>
<td>0.05</td>
<td>0.13</td>
<td>600</td>
<td>267</td>
</tr>
</tbody>
</table>

#### Example:

where: material C 60

operating temperature: \( T = 600 \) °C

principal strain: \( \varphi_p = 1.10 = 110 \% \)

strain rate \( \dot{\varphi} = 250 \) s\(^{-1}\)

solution:

\( c = 267, n = 0.06, m = 0.12 \) from Table 2.1

\[
k_{\text{str,sh}} = 267 \cdot 1.10^{0.06} \cdot 250^{0.12}
\]

\[
k_{\text{str,sh}} = 267 \cdot 1.0 \cdot 1.94 = \underline{515} \text{ N/mm}^2
\]

### 2.3 Deformation resistance \( k_r \)

The resistance to be overcome during a deformation is composed of the flow stress and the friction resistances in the tool, which are brought together under the term “resistance to flow”.

\[ k_t = k_{str} + p_{fr} \]

- \( k_t \) in N/mm\(^2\) deformation resistance
- \( k_{str} \) in N/mm\(^2\) flow stress
- \( p_{fr} \) in N/mm\(^2\) resistance to flow

The resistance to flow \( p_{fr} \) can be calculated mathematically for rotationally symmetric pieces.

\[ p_{fr} = \frac{1}{3} \mu \cdot k_{str} \frac{d_1}{h_1} \]

From this it follows that for the deformation resistance \( k_w \)

\[ k_t = k_{str} \left( 1 + \frac{1}{3} \mu \cdot \frac{d_1}{h_1} \right) \]

- \( k_{str} \) in N/mm\(^2\) flow stress at the end of forming
- \( d_0 \) in mm diameter before forming
- \( h_0 \) in mm height before forming (Fig. 4.6)
- \( \mu \) – coefficient of friction (\( \mu = 0.15 \))
- \( d_1 \) in mm diameter after forming
- \( h_1 \) in mm height after forming
- \( \eta_F \) – deformation efficiency.

For asymmetric pieces, which can only be studied mathematically to a limited extent, the deformation resistance is determined with the help of the deformation efficiency.

\[ k_t = \frac{k_{str}}{\eta_F} \]

### 2.4 Deformability

This means the ability of a material to be deformed. It depends upon:

#### 2.4.1 Chemical composition

In steels, for example, the cold deformability depends on the C content, the components of the alloy (Ni, Cr, Va, Mo, Mn) and the phosphor content. The higher the C content, the P content and the alloy components, the lower the deformability is.

#### 2.4.2 Crystalline structure

Here, the grain size and above all the pearlite structure are important.

- Grain size

Steels should be as fine-grained as possible, since in steels with small to medium grain size, the crystallites are easier to displace on the crystallite slip planes.
Pearlite structure
Pearlite is the carbon carrier in the steel. It is difficult to deform. For this reason it is important that the pearlite is equally distributed in the ferritic matrix, which is easy to cold form.

2.4.3 Heat treatment
An equally-distributed structure is achieved by normalising (above Ac3) and fast cooling. The resulting hardness is cancelled out by subsequent soft annealing (around Ac1).
Note: only soft annealed material can be cold formed.

2.5 Degree of deformation and principal strain

2.5.1 Bulk forming process
The measure of the extent of a deformation is the degree of deformation. The calculation is generally made from the relation between an indefinitely small measurement difference, \( dx \), and an existing measurement \( x \). By integrating it into the limits \( x_0 \) to \( x_1 \) this produces

\[
\phi_x = \int_{x_0}^{x_1} \frac{dx}{x} = \ln \frac{x_1}{x_0}.
\]

when it is presumed that the volume of the body to be deformed remains constant during forming.

\[
V = l_0 \cdot w_0 \cdot h_0 = l_1 \cdot w_1 \cdot h_1.
\]

According to which value changes the most during forming, a difference is made (Figure 2.6) between

Figure 2.6
Cuboid before forming with the measurements \( h_0, w_0, l_0 \) and after forming with the measurements \( h_1, w_1, l_1 \)
2.5 Degree of deformation and principal strain

Degree of upsetting \( \varphi_1 = \ln \frac{h_1}{h_0} \)

Degree of lateral flow \( \varphi_2 = \ln \frac{w_1}{w_0} \)

Degree of elongation \( \varphi_3 = \ln \frac{l_1}{l_0} \)

If the change of cross section or the change of wall thickness are dominant values, \( \varphi \) can also be determined from these values:

in the case of a change in wall thickness \( \varphi = \ln \frac{s_1}{s_0} \)

in the case of a change of cross section \( \varphi = \ln \frac{A_1}{A_0} \).

The sum of the three deformations in the three main directions (length, width, height) is equal to 0. What is lost in the height is gained in width and length – Figure 2.6.

\[ \varphi_1 + \varphi_2 + \varphi_3 = 0 \]

This means one of these three deformations is equal to the negative sum of the two others.

For example, \( \varphi_1 = - (\varphi_2 + \varphi_3) \).

This, the greatest deformation, is known as the principal strain, “\( \varphi_p \).”

It characterises the manufacturing process and enters into the calculation of force and work.

It is how the extent of a deformation is measured.

The degree of deformation that a material can withstand, i.e. how great its deformability is, can be taken from tables of standard values showing permissible deformation \( \varphi_{p \, \text{perm}} \).

The workpiece can only be produced in a single pass if actual deformation during its production is equal to or less than \( \varphi_{p \, \text{perm}} \). Otherwise, several passes are required with intermediate annealing (soft annealing).

2.5.2 Sheet metal forming

During deep drawing, the number of draws required can be determined from the drawing ratio \( \beta \).

\[ \beta = \frac{D}{d} = \frac{\text{blank diameter}}{\text{punch diameter}}. \]

As the values \( D \) and \( d \) are known for a particular workpiece during deep drawing, they can be used to calculate \( \beta \).
Here, tables of standard values (see the chapter on deep drawing) are once more used to find the permissible drawing ratio $\beta_{\text{perm}}$; it is then compared with the calculated drawing ratio. The workpiece can only be produced in a single phase if $\beta$ is equal to or less than $\beta_{\text{perm}}$. Otherwise, several passes are necessary.

### 2.6 Strain rate

If a deformation is carried out in the time $t$, this results in an average strain rate of:

\[
\omega_m = \frac{\varphi}{t} \quad \begin{align*}
\omega_m & \quad \text{in \%/s} \quad \text{mean strain rate} \\
\varphi & \quad \text{in \%} \quad \text{degree of deformation} \\
t & \quad \text{in s} \quad \text{deformation time}
\end{align*}
\]

It may, however, also be determined by the ram / slide velocity and the initial height of the workpiece.

\[
\varphi = \frac{v}{h_0} \quad \begin{align*}
\varphi & \quad \text{in s}^{-1} \quad \text{strain rate} \\
v & \quad \text{in m/s} \quad \text{velocity of the ram / slide} \\
h_0 & \quad \text{in s} \quad \text{height of the blank}
\end{align*}
\]

### 2.7 Exercise on Chapter 2

1. Which conditions must be met in order to achieve plastic (permanent) deformation?
2. What is meant by “flow stress” $k_{\text{str}}$?
3. How can the flow stress value be ascertained?
4. How can the mean yield stress be (approximately) calculated?
5. What influence does the forming temperature have on flow stress?
6. What influence does the strain rate have on flow stress?
   a) during cold forming
   b) during hot forming?
7. What is meant by “cold forming”?
8. What is meant by “deformability”?
9. What factors does the deformability of a material depend upon?
10. Explain these terms:
    - degree of upsetting
    - degree of lateral flow
    - degree of elongation.
11. What is meant by “principal strain”?
3 Surface treatment

If the blanks (sections of wire or rods) were simply inserted into the moulding die and then pressed, the die would be made useless after only a few units. Galling would occur in the die because of cold welding between the workpiece and the die. As a result, burrs would form on the die which would make the pressed parts unusable. For this reason, the blanks must be carefully prepared before pressing. This preparation, which is summed up as “surface treatment”, includes

pickling, phosphating, lubricating.

3.1 Cold bulk forming

3.1.1 Pickling

The pickling process is intended to remove oxidic coatings (rust, scale) so that the surface of the press blank is metallically clean, ready for the actual surface treatment. Diluted acids are used as a pickling agent, e.g. for steel, 10% sulphuric acid (percent by volume).

3.1.2 Phosphating

If grease, oil or soap were directly applied to a metallically clean (pickled) blank as a lubricant, the lubricant would have no effect. The film of lubricant would come off during pressing and cold welding and galling would take place. Therefore a lubricant carrier coating must be applied first, forming a firm bond with the blank material. Phosphates are used as a carrier coating. Phosphating applies a non-metallic lubricant carrier, firmly bonded with the base material of the blank made of

  steel (with the exception of Nirosta steels)
  zinc and zinc alloys
  aluminium and aluminium alloys.

This porous layer acts as a lubricant carrier. The lubricant diffuses into the pores and can thus no longer be rubbed off of the blank. Coating thicknesses of the applied phosphates range between 5 and 15 μm.
3.1.3 Lubrication

- **Function of the lubricant:**
  The lubricant is intended to:
- prevent the die and the workpiece from coming into direct contact with one another, in order to make it impossible for material to be transferred from the die to the workpiece (cold welding);
- reduce friction between the surfaces gliding against one another;
- keep the heat which occurs during forming within limits.

- **Lubricants for cold forming**
  For cold forming, the following materials can be employed as lubricants.
  
  - **Lime (liming)**
    Liming means that the blanks are immersed in a solution of water with 8 percent lime by weight heated to 90°C. Liming can only be used for steel for small deformations.
  
  - **Soap**
    Here, for example, solutions of hard soap are used with 4-8 percent soap by weight at 80°C and an immersion time of 2-3 minutes. Their use is appropriate when there is a medium lubricant requirement.
  
  - **Mineral oils (possibly with a little supplementary grease)**
    These lubricants, available on the market as “Press Oils”, are suited to high lubricant requirements, above all in automatic production. As well as lubrication, they also assume a cooling function.
  
  - **Molybdenum disulphide (molycote suspensions)**
    For lubricants on a molybdenum disulphide basis, which are suited to the highest lubrication requirements,

    MoS₂ water suspensions

    are mainly used. Immersion time ranges from 2 to 5 minutes at a temperature of 80 °C. The concentration (mean value) is around 1 : 3 (i.e. 1 part molycote, 3 parts water).

    For particularly difficult deformations, higher-concentrated suspensions are also used.

3.2 Cold sheet forming

As a rule pure lubricating agents such as drawing oils or drawing greases suffice for deep drawing, preventing direct contact between the die and the workpiece.
3.3 Hot forming (drop forging)

During drop forging, sawdust and graphite suspensions are used as lubricants and anti-seize agents. Optimal results can be achieved with 4% colloidal graphite in water or light oil. With the liquid lubricants, however, attention must be paid to correct dosage. Too much suspension raises the gas pressure in the die and makes moulding difficult.

3.4 Exercise on Chapter 3

1. What is the function of the lubricant during forming?
2. Why can the blank not simply be lubricated with oil or grease during cold forming?
3. How must the blanks be pre-treated (surface treated) before a cold forming pressing process?
4. What lubricants are used in cold forming?
5. What lubricants are used in drop forging?
4 Upset forging

4.1 Definition

Upset forging is a bulk forming process where the effect of the pressure is on the longitudinal axis of the workpiece.

4.2 Application

Commonly used for the production of mass-produced parts such as screws, rivets, head bolts, valve lifters etc. (Figures 4.1, 4.2 and 4.3).

4.3 Starting stock

The starting stock is a length of rod cut from round or shaped stock. In many cases, above all in screw and bolt production, production is carried out from wire coils (Figure 4.2). As rolled stock is cheaper than drawn stock, it is used most commonly.

Figure 4.1 Typical upset parts
4.4 Permissible deformations

Here, a difference must be made between two criteria:

4.4.1 Measurement for the extent of deformation

This sets the limits for the material to be formed (deformability).
Upsetting $\varepsilon_p$

\[ \varepsilon_p = \frac{h_0 - h_1}{h_0} \]

Degree of upsetting $\varphi_p$

\[ \varphi_p = \ln \left( \frac{h_1}{h_0} \right) \]

Initial length or length after upset forging, if the permissible deformation is provided

\[ h_0 = h_1 \cdot e^{\varphi_p} \]

Calculation of $\varphi_p$ from $\varepsilon_p$

\[ \varphi_p = \ln (1 - \varepsilon_p) \]

**Table 4.1 Permissible deformation**

<table>
<thead>
<tr>
<th>Material</th>
<th>$\varphi_{p, \text{perm}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al 99.88</td>
<td>2.5</td>
</tr>
<tr>
<td>Al MgSil</td>
<td>1.5 – 2.0</td>
</tr>
<tr>
<td>Ms 63–85</td>
<td>1.2 – 1.4</td>
</tr>
<tr>
<td>CuZn 37–CuZn 15</td>
<td>1.2 – 1.4</td>
</tr>
<tr>
<td>Ck10–Ck 22</td>
<td>1.3 – 1.5</td>
</tr>
<tr>
<td>St 42–St 50</td>
<td>1.2 – 1.4</td>
</tr>
<tr>
<td>Ck 35–Ck 45</td>
<td>1.3</td>
</tr>
<tr>
<td>St 60–St 70</td>
<td>1.2 – 1.4</td>
</tr>
<tr>
<td>Cf 53</td>
<td>0.8 – 0.9</td>
</tr>
<tr>
<td>15 CrNi 6</td>
<td>0.7 – 0.8</td>
</tr>
<tr>
<td>42 CrMo 4</td>
<td></td>
</tr>
</tbody>
</table>

**4.4.2 Upsetting ratio**

The upsetting ratio $s$ sets the limits of stock dimensions in relation to the danger of buckling during upset forging. What is known as the “upsetting ratio” is the ratio of free length of stock not inserted in the die to the initial diameter of the stock (Figure 4.4).
4.4 Permissible deformations

Upsetting ratio $s$

$$s = \frac{h_0}{d_0} = \frac{h_{0,\text{bd}}}{d_0}$$

- $h_0$ in mm stock length
- $h_1$ in mm length after upset forging
- $d_0$ in mm initial diameter
- $h_{0,\text{bd}}$ in mm length of stock not inserted into the die

**Figure 4.4**
a) free length of bolt not inserted in the die. 1 bottom die, 2 ejector, 3 stock before upset forging; b) open-die upset forging, between parallel surfaces

If the permissible upsetting ratio is exceeded then the bolt buckles (Fig 4.5).

**Figure 4.5**
Buckling of the blank when the upsetting ratio is exceeded

Permissible upsetting ratio:
- if the upset part is to be produced in one operation (Figure 4.6).

$$s \approx 2.6$$

**Figure 4.6**
Head bolt produced in one operation