Upsetting, upset forging
Definition:
Upset forging is a bulk forming process where the effect of the pressure is on the longitudinal axis of the workpiece.

Application:
Production of mass-produced parts: screws, rivets, head bolts, valves etc.
Screw production

0 shear off stock
1 pre-form head
2 finish head
3 reduce shank to diameter for thread rolling
4 stamp out hexagon
5 chamfer shank (round off)
6 thread rolling
Introduction

Engine valve

1. initial blank
2. preform (several steps, induction heated)
3. final heading
Limits - material

Limits: material and geometry

Material’s formability

Equivalent logarithmic strain:

\[ \varphi = \ln \frac{h_0}{h_1} = 2 \ln \frac{d_1}{d_0} \]

Important:

surface layer quality
Permissible deformation for some materials

<table>
<thead>
<tr>
<th>Material</th>
<th>$\varphi_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al 99.88</td>
<td>2.5</td>
</tr>
<tr>
<td>Al MgSi 1</td>
<td>1.5 – 2.0</td>
</tr>
<tr>
<td>CuZn 37</td>
<td>1.2 – 1.4</td>
</tr>
<tr>
<td>St 42–St 50</td>
<td>1.3 – 1.5</td>
</tr>
<tr>
<td>34 CrMo 4</td>
<td>0.8 – 0.9</td>
</tr>
<tr>
<td>42 CrMo 4</td>
<td>0.7 – 0.8</td>
</tr>
</tbody>
</table>
Limits - geometry

a) free length not inserted in the die
1  bottom die
2  ejector
3  stock before upset forging;

b) open-die upset forging between parallel surfaces

Upsetting ratio

\[ s = \frac{h_0}{d_0} \]

- \( h_0 \) - stock’s free length
- \( d_0 \) - initial diameter
Limits - geometry

Maximum upsetting ratio – forming in one step

\[ s = \frac{h_{0hd}}{d_0} < 2 \]

\( h_{0hd} \) - stock’s free length
\( d_0 \) - initial diameter

Maximum upsetting ratio – forming in two steps

\[ s = \frac{h_{0hd}}{d_0} < 4.5 \]

\( h_{0hd} \) - stock’s free length
\( d_0 \) - initial diameter

This case is typical for standard screw heads.
Preforming

Forming in two steps – pre-form shape

<table>
<thead>
<tr>
<th>Upsetting ratio</th>
<th>Cone angle</th>
<th>Guide length</th>
<th>Length of the tapered part of the pre-former</th>
</tr>
</thead>
<tbody>
<tr>
<td>s = h₀/d₀</td>
<td>2α [degree]</td>
<td>a [mm]</td>
<td>c [mm]</td>
</tr>
<tr>
<td>2.5</td>
<td>15</td>
<td>0.6 d₀</td>
<td>1.37 d₀</td>
</tr>
<tr>
<td>3.3</td>
<td>15</td>
<td>1.0 d₀</td>
<td>1.56 d₀</td>
</tr>
<tr>
<td>3.9</td>
<td>15</td>
<td>1.4 d₀</td>
<td>1.66 d₀</td>
</tr>
<tr>
<td>4.3</td>
<td>20</td>
<td>1.7 d₀</td>
<td>1.66 d₀</td>
</tr>
<tr>
<td>4.5</td>
<td>25</td>
<td>1.9 d₀</td>
<td>1.45 d₀</td>
</tr>
</tbody>
</table>
Upsetting force

\[ F = A_1 \cdot \sigma_{f1} \left( 1 + \frac{1}{3} \mu \frac{d_1}{h_1} \right) \]

- \( F \) - upsetting force
- \( A_1 \) - surface after upset forging
- \( \sigma_{f1} \) - flow stress at the end of upsetting
- \( \mu \) - coefficient of friction (0.1 – 0.15)
- \( d_1 \) - diameter after upsetting
- \( h_1 \) - height after upsetting
Calculations

Upsetting work

\[ W = \frac{V \cdot \sigma_{fm} \cdot \varphi_{eq}}{\eta_F} \]

or

\[ W = F(h_0 - h_1) \cdot x \]

\[ x = \frac{F_m}{F_{max}} \quad x \approx 0.6 \]

- \( W \) - upsetting work
- \( V \) - volume involved in deformation
- \( \sigma_{fm} \) - mean flow stress
- \( \varphi_{eq} \) - equivalent strain
- \( \eta_F \) - deformation efficiency (0.6 – 0.9)
- \( h_0 \) - stock height
- \( h_1 \) - active stroke
- \( x \) - process factor
- \( F_m \) - mean force
- \( F_{max} \) - maximum force
Tooling

a) pressure plate
b) punch (snap die)
c) retaining ring (shrink fit)
d) counterpunch
e) ejector

Reinforced die
Tooling

1. raw material from coil
2. initial piece
3. reduction
4. Scheme of reduction

- a) shearing blade
- b) shearing bottom die
- c) pre-former
- d) heading punch
- e) bottom / reducing die
- f) reinforcement
- g) ejector

The axial stress here shall be smaller than the flow stress.
Tooling

Cutting of the hexagonal head

1) cutting die
2) punch
3) ejector
<table>
<thead>
<tr>
<th>Description of the tool</th>
<th>Steel grade used for the tool</th>
<th>Material no.</th>
<th>Hardness of the tool HRC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Short designation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Shearing blade</td>
<td>X 155 CrVMo 12 1</td>
<td>1.2379</td>
<td>57 to 60</td>
</tr>
<tr>
<td></td>
<td>X 165 CrMoV 12</td>
<td>1.2601</td>
<td>57 to 60</td>
</tr>
<tr>
<td></td>
<td>S 6-5-2</td>
<td>1.3343</td>
<td>57 to 60</td>
</tr>
<tr>
<td></td>
<td>60 WCrV 7</td>
<td>1.2550</td>
<td>48 to 55</td>
</tr>
<tr>
<td>b) Shearing bottom die</td>
<td>X 155 CrVMo 12 1</td>
<td>1.2379</td>
<td>57 to 60</td>
</tr>
<tr>
<td></td>
<td>X 165 CrMoV 12</td>
<td>1.2601</td>
<td>57 to 60</td>
</tr>
<tr>
<td></td>
<td>S 6-5-2</td>
<td>1.3343</td>
<td>57 to 60</td>
</tr>
<tr>
<td></td>
<td>60 WCrV 7</td>
<td>1.2550</td>
<td>54 to 58</td>
</tr>
<tr>
<td>c) Solid pre-former</td>
<td>C 105 W 1</td>
<td>1.1545</td>
<td>57 to 60</td>
</tr>
<tr>
<td></td>
<td>100 V 1</td>
<td>1.2833</td>
<td>57 to 60</td>
</tr>
<tr>
<td></td>
<td>145 V 33</td>
<td>1.2838</td>
<td>57 to 60</td>
</tr>
<tr>
<td>c) Shrink pre-former</td>
<td>X 165 CrMoV 12</td>
<td>1.2601</td>
<td>60 to 63</td>
</tr>
<tr>
<td></td>
<td>S 6-5-2</td>
<td>1.3343</td>
<td>60 to 63</td>
</tr>
<tr>
<td>d) Solid finishing punch</td>
<td>C 105 W1</td>
<td>1.1545</td>
<td>58 to 61</td>
</tr>
<tr>
<td></td>
<td>100 V 1</td>
<td>1.2833</td>
<td>58 to 61</td>
</tr>
<tr>
<td></td>
<td>145 V 33</td>
<td>1.2838</td>
<td>58 to 61</td>
</tr>
<tr>
<td>d) Shrink finishing punch</td>
<td>X 165 CrMoV 12</td>
<td>1.2601</td>
<td>60 to 63</td>
</tr>
<tr>
<td></td>
<td>S 6-5-2</td>
<td>1.3343</td>
<td>60 to 63</td>
</tr>
</tbody>
</table>
### Die materials for upsetting - 2

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>e)</td>
<td>Solid bottom die</td>
<td>C 105 W 1</td>
<td>1.1545</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100 V 1</td>
<td>1.2833</td>
</tr>
<tr>
<td></td>
<td></td>
<td>145V33x</td>
<td>1.2838</td>
</tr>
<tr>
<td>e)</td>
<td>Shrunken bottom die</td>
<td>S 6-5-2</td>
<td>1.3343</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X 155 CrVMo 12</td>
<td>1.2379</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X 165 CrMoV 12</td>
<td>1.2601</td>
</tr>
<tr>
<td>f)</td>
<td>Retaining ring</td>
<td>56 NiCrMoV 7</td>
<td>1.2714</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X 40 CrMoV 5</td>
<td>1.2344</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X 3 NiCoMoTi 1895</td>
<td>1.2709</td>
</tr>
<tr>
<td>g)</td>
<td>Ejector</td>
<td>X 40 CrMoV 5</td>
<td>1.2344</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60 WCrV 7</td>
<td>1.2550</td>
</tr>
</tbody>
</table>

**Shearing tool: (slide 14)**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bottom die</td>
<td>S 6-5-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Punch</td>
<td>60 WCrV 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X 155 CrVMo 12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X 165 CrMoV 12</td>
</tr>
<tr>
<td>3</td>
<td>Ejector</td>
<td>X 40 CrMoV 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60 WCrV 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Precision

Cold upsetting

<table>
<thead>
<tr>
<th>Nominal size in mm</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head height tolerance in mm</td>
<td>0.18</td>
<td>0.22</td>
<td>0.28</td>
<td>0.33</td>
<td>0.38</td>
<td>0.42</td>
<td>0.5</td>
</tr>
<tr>
<td>Head diam. tolerance in mm</td>
<td>0.12</td>
<td>0.15</td>
<td>0.18</td>
<td>0.20</td>
<td>0.22</td>
<td>0.25</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Hot upsetting

Tolerances are approximately five times higher.
<table>
<thead>
<tr>
<th>Defect</th>
<th>Cause</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buckling</td>
<td>Upsetting ratio is too high</td>
<td>Reduce by pre-forming</td>
</tr>
<tr>
<td>Longitudinal crack in the head</td>
<td>Die scars or surface damage in the starting material.</td>
<td>Check the stock for surface damage.</td>
</tr>
<tr>
<td>Shear cracks in the head</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal cracks in the head</td>
<td>Formability exceeded</td>
<td>Reduce degree of deformation Divide forming into two operations.</td>
</tr>
</tbody>
</table>
**Example**

**Head volume:**

\[ V_{\text{head}} = \frac{d_1^2 \pi}{4} h_1 = 1570 \text{ mm}^3 \]

\[ h_0 = 19.98 \approx 20 \text{ mm} \]

**Upsetting ratio:**

\[ s = \frac{h_0}{d_0} = 2 \]

2 steps for safety

max. for 1 step

---

C10100 commercial purity Cu

(OFHC - oxygen-free, high-conductivity copper)
Example

Formability:
\[
\varphi = \ln\left(\frac{h_0}{h_1}\right) = \ln\left(\frac{20}{5}\right) = 1.38 \quad \text{good}
\]

Pre-form geometry:

- \(a = 0.6 \quad d_0 = 6 \text{ mm}\)
- \(\alpha = 7.5^\circ\)
- \(c = 1.37 \quad d_0 = 13.7 \text{ mm} \rightarrow 14 \text{ mm}\)
Check the pre-form geometry

Example

\[ \varnothing 10 \]

15°

14

6

20

20

\[ \varnothing 10 \]

d_01

t \approx 1 \text{ mm}

d_01 \approx 19.5 \text{ mm}
Example

Force at pre-forming

\[ F_{01} = A_{01} \cdot \sigma_{f_{01}} = \frac{d_{01}^2 \pi}{4} \cdot \sigma_{f_{01}} \]

\[ \varphi_{01} = 2 \ln \left( \frac{d_{01}}{d_0} \right) = 2 \ln \left( \frac{12.5}{10} \right) = 0,44 \]

\[ \to \quad \sigma_{f_{01}} = 283 \text{ MPa} \]

(also the axial stress on the punch)

\[ F_{01} = 298 \text{ mm}^2 \cdot 283 \text{ MPa} \]

\[ F_{01} = 84 \text{ kN} \]
**Example**

**Force at ready forming**

\[
\sigma_f = C_1 + C_2 \varphi^n \quad \varphi_1 = 1.38
\]

\[
\sigma_{f1} = 84 + 286 \cdot \varphi_1^{0.442} = 413 \text{ MPa}
\]

\[
\mu = 0.1
\]

\[
F_1 = A \cdot \sigma_{f1} \left(1 + \frac{1}{3} \mu \frac{d_1}{h_1}\right)
\]

\[
A = \frac{20^2 \pi}{4} = 314 \text{ mm}^2
\]

\[
F_1 = 314 \cdot 413 \left(1 + \frac{1}{3} \cdot 0.1 \frac{20}{5}\right) = 147 \text{ kN}
\]
Example

**Work at ready forming** (Method 1)

\[ W = \frac{V_{head} \cdot \sigma_{fm} \cdot \varphi}{\eta} \]

\[ \eta = 0.6 \ldots 0.9 \]

let assume \( \eta \approx 0.6 \)

\[ \varphi_1 = 1.38 \]

\[ \sigma_{fm} = \frac{\sigma_{f0} + \sigma_{f1}}{2} = \frac{84 + 413}{2} = 249 \text{ MPa} \]

\[ W_{\text{ready}} = \frac{1570 \cdot 249 \cdot 1.38}{0.6} = 899 \text{ J} \]
Example

Making the two forming steps parallel

Assume, as it is usual, we are using such tooling and forming machine which makes possible to make the two steps parallel. Therefore, the total force at one machine stroke is the sum of the two forces:

\[ F_{stroke} = F_0 + F_1 = 84 + 147 = 231 \text{ kN} \]

The total work at one stroke is the sum of the two works:

\[ W_{stroke} = W_{pre} + W_{ready} \]

Estimated work at preforming:

\[ W_{pre} \approx F_0 \cdot \Delta h_0 = 84 \text{ kN} \cdot 3 \text{ mm} = 252 \text{ J} \]

Total work at one machine stroke

\[ W_{\text{total}} = 252 + 1323 = 1575 \text{ J} \]
Example

Power for parallel operation

Assume, the forming machine can make 80 stroke per minute (that means 80 workpieces), therefore the work for one second:

\[ W = \frac{80}{60} W_{\text{łęk}} = 1.33 \cdot 1575 \, J = 2099 \, J \]

The minimum required power and minimum loadability of the forming machine to perform the given technology:

\[ P_{\text{min}} = 2.1 \, kW \]

\[ F_{\text{min}} = 231 \, kN \]

In addition, the tooling has to be applicable on the forming machine to perform the given technology.