

MEP 291 METAL FORMING

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Chapter-3 | Metal-Forging

Ch.3 Metal Forging

- **Forging:** is a process in which workpiece is shaped by compressive forces applied through various dies and tooling.
- It is one of the oldest metal working operations (4000 B.C).
“blacksmiths-by hammer and anvil”
- Unlike **Rolling** operations in Ch.2 that produce continues parts.
Forging produce discrete parts.
- Since the metal flow in a die and the material's grain structure can be controlled, forged parts have a good strength and toughness.
- Forged parts are very reliable for highly stressed and critical applications.

Ch.3 Metal Forging

- **Typical parts made by forging:** Bolts, rivets, knives, gears, and rail roads.
- **Cold forging:** requires higher forces (due to higher strength of work piece material). The workpiece material must have sufficient ductility at room temperature to deformed without cracking.
- **Cold-forged:** parts have a good surface finish and dimensional accuracy.



Figure 14.1 (a) Schematic illustration of the steps involved in forging a knife.

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3.1 Open-die Forging (upsetting or flat-die forging)

- The workpiece placed between two flat dies and reduced in height by compression.
- In real operations there is friction and the part develops a barrel shape called **Barreling**.
- **Barreling:** is caused by friction forces and can be reduced by using an affective lubricant.

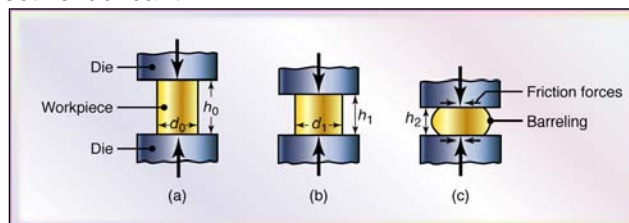


Figure 14.3 (a) Solid cylindrical billet upset between two flat dies. (b) Uniform deformation of the billet without friction. (c) Deformation with friction. Note the barreling of the billet caused by friction forces at the billet-die interfaces.

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3.1 Open-die Forging (upsetting or flat-die forging)

Forging force:

$$F = Y_f \pi r^2 \left(1 + \frac{2\mu r}{3h} \right)$$

Where,

F = The forging force

Y_f = The flow stress of the material

μ = The coefficient of friction

r = The instantaneous radius of the workpiece

h = The instantaneous height of the workpiece

Example-1

A solid cylindrical workpiece made of 304 stainless steel ($K=1275$ MPa, $n=0.45$) is 150 mm in diameter and 100 mm high. It is reduced in height by 50% at room temperature by open-die forging with flat dies. Assuming that the coefficient of friction is 0.2, calculate the forging force.

Solution:

$K=1275$ MPa, $n=0.45$

$h_o=100$ mm

$h_f=50$ mm

$d_o=150$ mm

$\mu=0.2$

Example-1

Constant volume:

$$\pi r_0^2 h_0 = \pi r_f^2 h_f$$

$$r_f = r_0 \sqrt{\frac{h_0}{h_f}} = 75 \sqrt{\frac{100}{50}} \Rightarrow r_f = 106 \text{ mm}$$

$$\varepsilon = \ln\left(\frac{h_0}{h_f}\right) = \ln\left(\frac{100}{50}\right) \Rightarrow \varepsilon = 0.69$$

$$Y_f = K \cdot \varepsilon^n = 1275(0.69)^{0.45} = 1079 \text{ MPa}$$

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Example-1

Continue:

$$F = Y_f \pi r^2 \left(1 + \frac{2\mu r}{3h}\right)$$

$$F = (1079) \pi (106)^2 \left(1 + \frac{2(0.2)(106)}{3(50)}\right)$$

$$F = (1079) \pi (106)^2 (1.28) \Rightarrow F = 48,853,632 \text{ N}$$

$$F = 48,853,632 \cancel{\text{N}} \times \frac{1 \text{ MN}}{10^6 \cancel{\text{N}}} = 48.85 \text{ MN}$$

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Example-2

A solid cylindrical workpiece made of 304 stainless steel ($K=1275 \text{ MPa}$, $n=0.45$) is 6 in in diameter and 4 in high. It is reduced in height by 50% at room temperature by open-die forging with flat dies. Assuming that the coefficient of friction is 0.2, calculate the forging force.

Solution:

$$K=1275 \text{ MPa}, n=0.45$$

$$h_0=4 \text{ in}$$

$$h_f=2 \text{ in}$$

$$d_0=6 \text{ in}$$

$$\mu=0.2$$

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Example-2

Constant volume:

$$\pi r_0^2 h_0 = \pi r_f^2 h_f$$

$$r_f = r_0 \sqrt{\frac{h_0}{h_f}} = 3 \sqrt{\frac{4}{2}} \Rightarrow r_f = 4.24 \text{ in}$$

$$\varepsilon = \ln\left(\frac{h_0}{h_f}\right) = \ln\left(\frac{4}{2}\right) \Rightarrow \varepsilon = 0.69$$

$$1275 \text{ MPa} \times \frac{145 \text{ Psi}}{1 \text{ MPa}} = 184875 \text{ Psi}, [1 \text{ MPa} = 145 \text{ Psi}]$$

$$Y_f = K \cdot \varepsilon^n = 184875 (0.69)^{0.45} = 156444.5 \text{ Psi}$$

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Example-2

Continue:

$$F = Y_f \pi r^2 \left(1 + \frac{2\mu r}{3h} \right)$$

$$F = (156444.5) \pi (4.24)^2 \left(1 + \frac{2(0.2)(4.24)}{3(2)} \right)$$

$$F = (156444.5 \text{ Psi}) \pi (4.24 \text{ in})^2 (1.28) \Rightarrow F = 11309720 \text{ lbf}$$

$$\left[1 \text{ Psi} = 1 \frac{\text{lbf}}{\text{in}^2} \right]$$

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3.2 Impression-die & Closed-die Forging

- The workpiece takes the shape of the die cavity while compressed between two shaped dies.

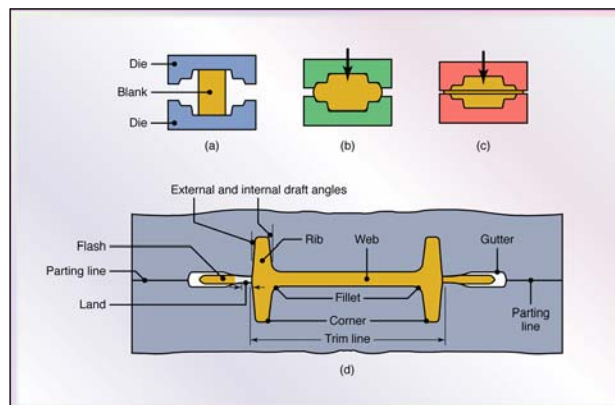


Figure 14.5 (a) through (c) Stages in impression-die forging of a solid round billet. Note the formation of **Flash**, which is excess metal that is subsequently trimmed off (see Fig. 14.7). (d) Standard terminology for various features of a forging die.

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3.2 Impression-die & Closed-die Forging

Forging force:

$$F = k' Y_f A$$

Where,

F = The forging force

Y_f = The flow stress of the material

k' = Multiplying factor

A = The are of forging, including the flash

TABLE 14.2

Range of k' Values for Eq. (14.2)

Simple shapes, without flash	3–5
Simple shapes, with flash	5–8
Complex shapes, with flash	8–12

Example-1

A workpiece with $K=400$ MPa and $n=0.3$ is forged by impression-die. The workpiece has a true strain of 0.69 with a forging area of 100 mm^2 and a flash area of 10 mm^2 . Assuming the workpiece has a simple shape, calculate the forging force.

Solution:

$K=400$ MPa, $n=0.3$

$k'=6.5$ (simple shape, with flash)

Forging area= 100 mm^2

Flash area= 10 mm^2

Example-1

Continue:

$$F = k' Y_f A$$

$A = \text{Forging area} + \text{Flash area}$

$$A = 100 + 10 = 110 \text{ mm}^2$$

$$Y_f = K \varepsilon^n$$

$$Y_f = 400(0.69)^{0.3} = 358 \text{ MPa}$$

$$F = k' Y_f A$$

$$F = 6.5(358)(110) = 255870 \text{ N}$$

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3.3 Compression of Disk

Forging force:

$$F = P_{av} A, [A = \pi r^2]$$

Where,

P_{av} = Average pressure

A = The area

Power:

$$\text{Power} = Fv$$

Where,

F = Forging force

v = Velocity

Average Pressure:

$$P_{av} = \frac{1}{2} \left(\frac{1}{b} \right)^2 Y_f' \left((e^{2b}) - (2b) - 1 \right), \left[b = \frac{\mu r}{h} \right]$$

Where,

μ = Coefficient of friction

r = Final radius of the disk

h = Final height of the disk

Average Pressure for small $\frac{r}{h}$:

$$P_{av} = Y_f' \left(1 + \left(2 \left(\frac{\mu r}{3h} \right) \right) + \left(\frac{\mu r}{6h} \right) \right)$$

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Example-1

A workpiece made of AISI 1045 steel with a diameter of 50 mm and a height of 50 mm was cold disk forged to 10 mm in height with a coefficient of friction of 0.1 ($K=950 \text{ MPa}$ and $n= 0.12$). Calculate the required force and power to complete this process knowing that the velocity is 0.8 mm/sec.

Solution:

$K=950 \text{ MPa}$, $n=0.12$

$d_o=50 \text{ mm}$

$h_o=50 \text{ mm}$

$h_f=10 \text{ mm}$

$v=0.8 \text{ mm/sec}$

$\mu=0.1$

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Example-1

Continue:

$$\varepsilon = \ln\left(\frac{50}{10}\right) = 1.61$$

$$Y'_f = \frac{K \varepsilon^n}{(1+n)} = \frac{(950)(1.61)^{0.12}}{1.12} = 898 \text{ MPa}$$

$$r_0 = \frac{d_0}{2} = \frac{50}{2} = 25 \text{ mm}$$

$$\pi r_0^2 h_0 = \pi r_f^2 h_f \Rightarrow r_f = 55.9 \text{ mm}$$

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Example-1

Continue:

$$P_{av} = \frac{1}{2} \left(\frac{1}{b} \right)^2 Y_f \left((e^{2b}) - (2b) - 1 \right)$$

$$b = \frac{(0.1)(55.9)}{10} = 0.559$$

$$P_{av} = \frac{1}{2} \left(\frac{1}{0.559} \right)^2 (898) \left((e^{2(0.559)}) - (2(0.559)) - 1 \right)$$

$$P_{av} = 1353.5 \text{ MPa}$$

Force:

$$F = P_{av} A$$

$$A = \pi r^2 = \pi (55.9)^2$$

$$F = 1353.5 \pi (55.9)^2 = 13292459.3 \text{ N}$$

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Example-1

Continue:

Power:

$$\text{Power} = Fv$$

$$\text{Power} = 13292459.3 \text{ N} \left(0.8 \frac{\text{mm}}{\text{sec}} \right), [1 \text{ m} = 1000 \text{ mm}], \left[J = \text{Nm} \ \& \ W = \frac{J}{s} \right]$$

$$\text{Power} = 10634 \text{ W}, [1 \text{ KW} = 1000 \text{ W}]$$

$$\text{Power} = 10634 \text{ W} \times \frac{1 \text{ KW}}{1000 \text{ W}} = 10.63 \text{ KW}$$

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