ME5005/ME4002
DESIGN FOR MANUFACTURE
PRODUCTION ENGINEERING

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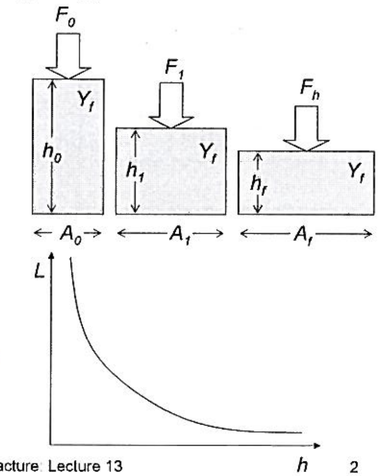
Lecture 13: Design for Forging

General forging loads

- For homogenous upset forging:
  $$F = Y_f A$$
- and volume V is constant:
  $$V = A_0 h_0 = A_1 h_1 = A_f h_f$$
- So:
  $$A = \frac{V}{h}$$
- Hence:
  $$F = Y_f \frac{V}{h}$$
- Required load F is inversely proportional to the desired height h
- zero height can never be reached



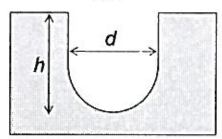
Web loading considerations

- Forging components with very thin webs requires:
  - Very high loads
    - increasing inversely proportional to web thickness
  - Special forging techniques (e.g. coining)
- Webs or thin areas parallel to the parting line are limited by:
  - Die geometry
  - Forging load and material flow
- Minimum and preferred thicknesses depending on plan area of web

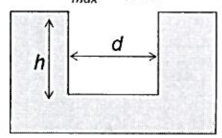
Plan area (cm^2)	Minimum thickness (mm)	Preferred thickness (mm)
20	4	7
100	5	11
200	7	13
500	8	16
1000	10	18

Forging blind holes

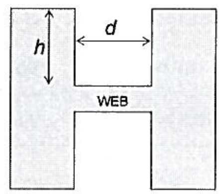
$h_{max} = d$



$h_{max} \approx 1.5d$

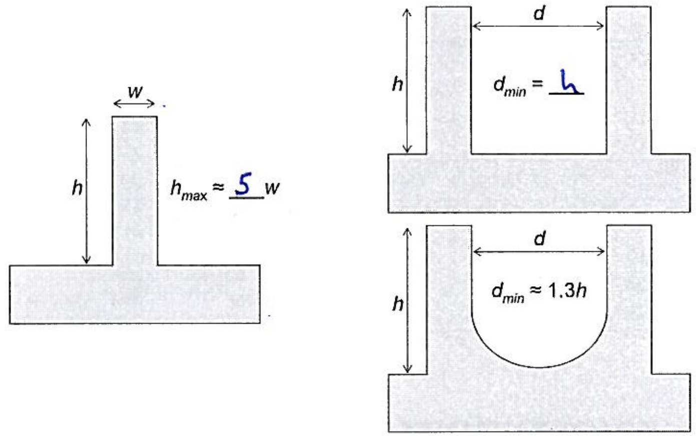


$h_{max} = d$

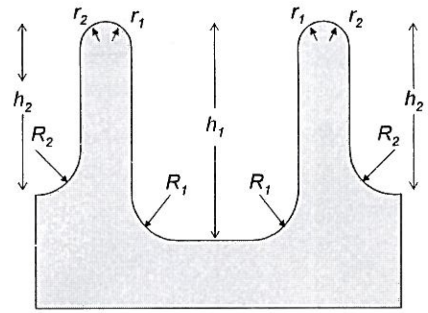


- Maximum hole depth determined by hole diameter and whether hole base is:
  - Rounded
  - Flat
  - Opposite another hole (forming a thin web)

Forging ribs



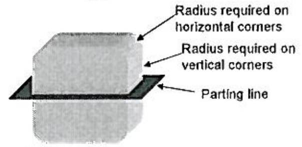
Radiusing corners for forging



$r = 0.07h$	recommended
$r_{min} = 0.04h$	minimum
$R = 0.25h$	recommended
$R_{min} = 0.17h$	minimum

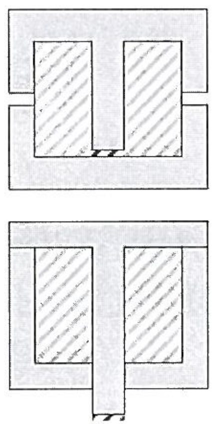
To commonise, use ______
$R_{min} = 0.25h$ recommended

- All corners running parallel or perpendicular to the forging direction will require radiusing



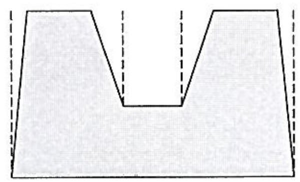
Forging through holes

- Holes are not usually forged in a single operation
  - As hole is forged, a thin web is produced at the base of the hole
  - Thin webs require excessive loads, cannot forge to zero thickness
  - Large hole diameters will leave thicker webs as greater loads required
  - High stresses in the die cores
- Holes formed in two separate stages requiring different dies:
  - Create main shape
  - Punch through thin web in a second operation
- Forged holes mean extra dies
  - Increase in component cost
- Consider post-machining operation



Draft angles

- All surfaces perpendicular to parting lines will require draft angles
- Internal angles higher than external
  - Forged component recovers elastically when load is removed and grips any cores in the die
- Draft angles for presses are lower than for hammers
  - Hammer impacts are initially high energy and force the component onto the die
  - Presses have a continuous average load
- Forged component may be held in top part of die if top surface draft angles are reduced by 0.5° – 1 °
  - Facilitates component removal



	INTERNAL	EXTERNAL
HAMMER	7° - 10°	5° - 7°
PRESS	3° - 5°	2° - 3°

Forging plant size

- Presses (hydraulic) preferred when large deformation of material is required
  - Apply a load without an impact
  - Load may be maintained continuously over the stroke length
    - Small: ~ 100 tonnes: €0.25M
    - Medium: ~ 500-1,000 tonnes: €1.0M
    - Large: ~ 5,000-10,000 tonnes: €5.0M - €10.0M
- Hammers preferred when large area thin sections are required
  - Apply a load utilizing an impact (kinetic energy)
  - Loads vary as the kinetic energy is used up
  - Load depends on the rate of deceleration
    - Small: ~ 500 m.kg
    - Medium: ~ 5,000 m.kg
    - Large: ~ 50,000 m.kg

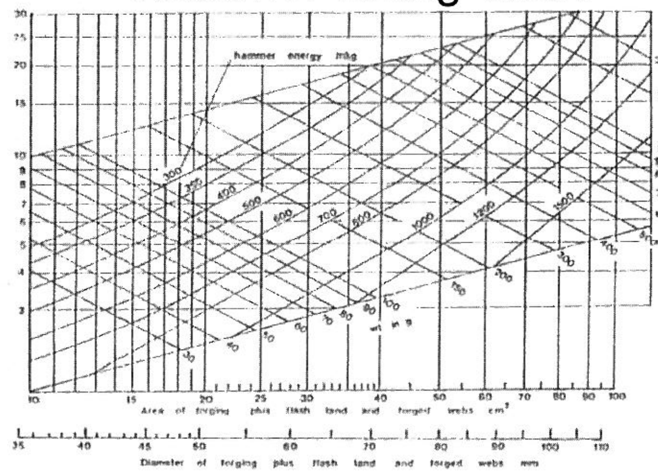
Estimate press loads

- Methods not accurate enough to guarantee a press working if near its maximum load
  - Gives an indication of plant size and cost
- For impression dies (most common):
  - Calculate the plan area A
  - Estimate flash lands
    - General rule of add 10% all the way around
    - Quick method - multiply plan area by 1.2 x 1.2 = 1.44
  - Estimate maximum true strain: $\varepsilon = \ln(h_0/h_f)$
  - Estimate maximum flow stress: $Y_f = K\varepsilon^n$
  - Estimate shape factor: K_f = 6.0, 8.0 or 10.0 (simple → complex)
    - Use: $F = K_f Y_f A$
  - Include scaling factors for:
    Aluminium: x 0.9 Stainless Steel: x 1.8 Titanium alloy: x 2.5
    20% increase in forging temperature: x 0.8

Estimate hammer energy

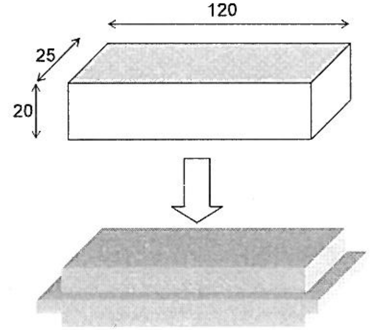
- Estimates more accurate but more complex
- Really requires die design and layout, but most parameters can be estimated
  - Calculate the component plan area A
  - Estimate flash land area
    - General rule of add 10% all the way around
    - Quick method - multiply plan area by 0.44
  - Calculate total plan area $A + A_{flash}$
  - Calculate the component volume V
  - Estimate flash volume using a flash thickness of 5 mm
  - Calculate total volume $V + V_{flash}$
  - Calculate *mean thickness* t = total volume/total area
  - Use a *hammer sizing chart*
    - Different charts exist for different materials and hammer sizes

Hammer sizing chart

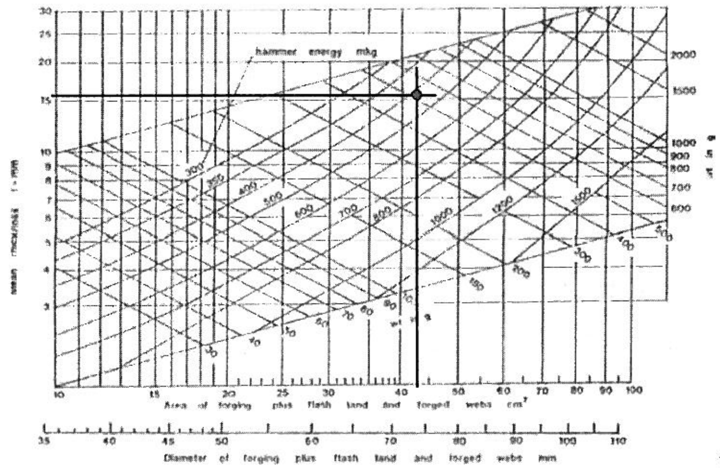


Hammer sizing example #1

- Plan area: 120 x 25 = 3,000mm^2
- Flash area: 3,000 x 0.44 = 1,320mm^2
- Total plan area: 4,320 mm^2 = 43.2cm^2
- Component volume = 20 x 3,000 = 60,000mm^3
- Flash volume: 1,320 x 5 = 6,600mm^3
- Total volume: 60,000 + 6,600 = 66,600mm^3
- Mean thickness = 66,600/4,320 = 15.42mm
- Use chart
- Hammer energy = ???m.kg

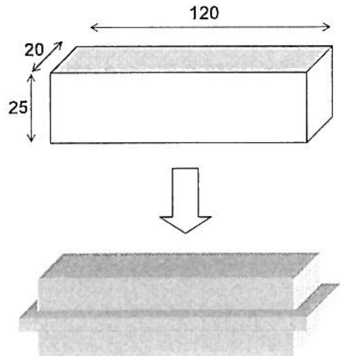


Hammer sizing chart

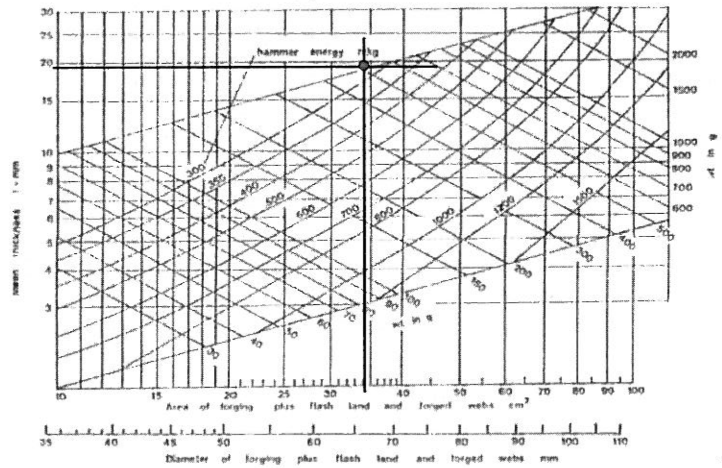


Hammer sizing example #2

- Plan area: 120 x 20 = 2,400mm^2
- Flash area: 2,400 x 0.44 = 1,056mm^2
- Total plan area: 3,456 mm^2 = 34.6cm^2
- Component volume = 25 x 2,400 = 60,000mm^3
- Flash volume: 1,056 x 5 = 5,280mm^3
- Total volume: 60,000 + 5,280 = 65,280mm^3
- Mean thickness = 65,280/3,456 = 18.89mm
- Use chart
- Hammer energy = ???m.kg

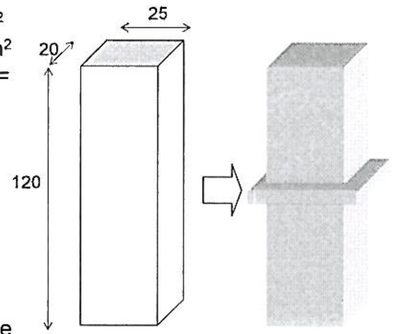


Hammer sizing chart



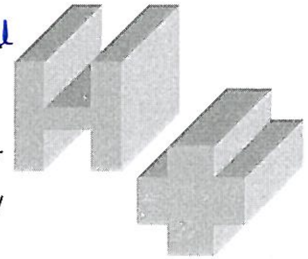
Hammer sizing example #3

- Plan area: 25 x 20 = 500mm^2
- Flash area: 500 x 0.44 = 220mm^2
- Total plan area: 720mm^2 = 7.2cm^2
- Component volume = 120 x 500 = 60,000mm^3
- Flash volume: 220 x 5 = 1,100mm^3
- Total volume: 60,000 + 1,100 = 61,100mm^3
- Mean thickness = 61,100/720 = 84.9mm
- Use chart
- Hammer energy = ???m.kg
- Plan area and mean thickness are not on the chart!!



Component orientation

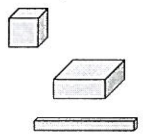
- Component orientation in the dies is vital when sizing forging plant
  - Plan area is the surface area *perpendicular* to the forging load
- Example 3 is *impossible* to forge
  - Material must deform too far perpendicular to the parting line
  - Flash lands will not be able to fill the cavity
- Example 2 is *uncertain*
  - Required hammer energy is on the boundary of the sizing chart
  - Insufficient accuracy to guarantee hammer size required
- Example 1 requires a 500m.kg hammer
- Shape and component complexity not considered, e.g.: holes



- Same plan area *A*
- Same volume *V*
- Same flash area, volume and mean thickness *t*
- 'H' section harder to forge than '+' section

Estimate starting shape

- Choice of the correct pre-formed workpiece can simplify forging design
  - Try and minimise amount of deformation required
- Semi-finished pre-forms are standard:
  - Bars/rods (round, square, hexagonal), slab, plate, bloom
- Check overall dimensions of desired component:
  - If 3 axes are roughly equal:
    - Use bar, slab or plate
  - If 2 axes are larger than the other:
    - Use plate or slab
  - If 1 axis larger than the others:
    - Use rod or bar



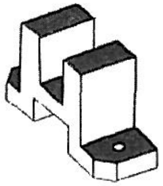
- For significant deformation, starting shape not critical
  - e.g. round bar or square bar?

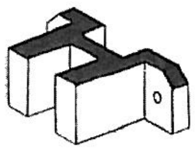
Component redesign

- Estimate starting shape of pre-formed workpiece
- Eliminate impossible geometry that cannot be forged
- Select suitable parting line(s) to avoid die kick
- Check suitability of individual features and redesign:
  - Ribs, webs, slots, holes
- Radius corners that require it (parallel to parting line)
- Check draft: internal, external, top/bottom die
- Check orientation of component in the dies
- Hammer or press?
  - May depend on orientation
- Estimate hammer/press size
- Re-check!

Self-study exercise

- Top slot of bracket holds edge of a large rectangular plate in a specific position
- Base slot fits over a guide rail
- No movement allowed between plate and clamp in *any* direction
- Bolt hole locations and chamfered corners locate with other geometry
- No cosmetic surfaces
- Increase in strength required
- Redesign for forging in aluminium alloy using:
  1. A hammer
  2. A hydraulic press
- Discuss the suitability for forging in *either* of the two orientations shown
  - Shaded surfaces give plan area





Bracket dimensions (mm)