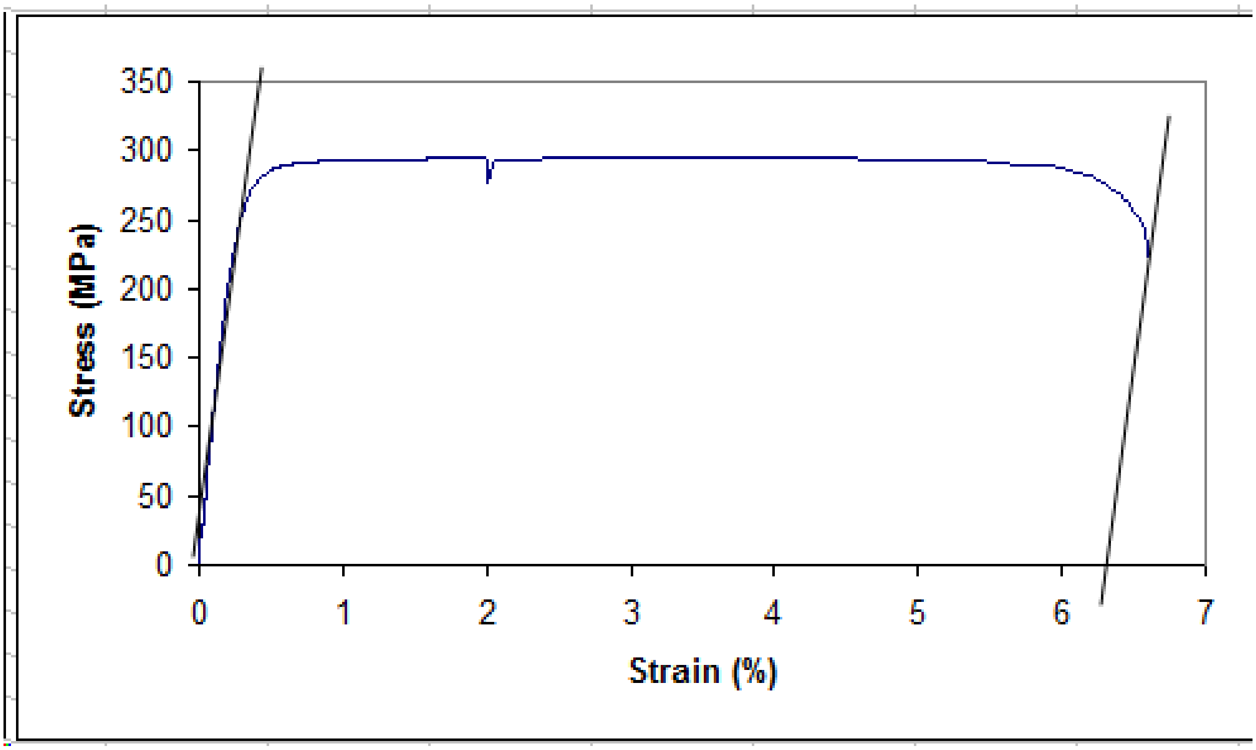
Solutions to Homework Number One
Due Wednesday October 14, 2015

1) The attached Word File has the stress strain curves for 6 different materials (3 copper alloys and 3 steel alloys).

· For each material determine the ductility, maximum strain, modulus, ultimate tensile strength and yield strength

The determination of the material properties for Copper Never in Furnace is shown below.

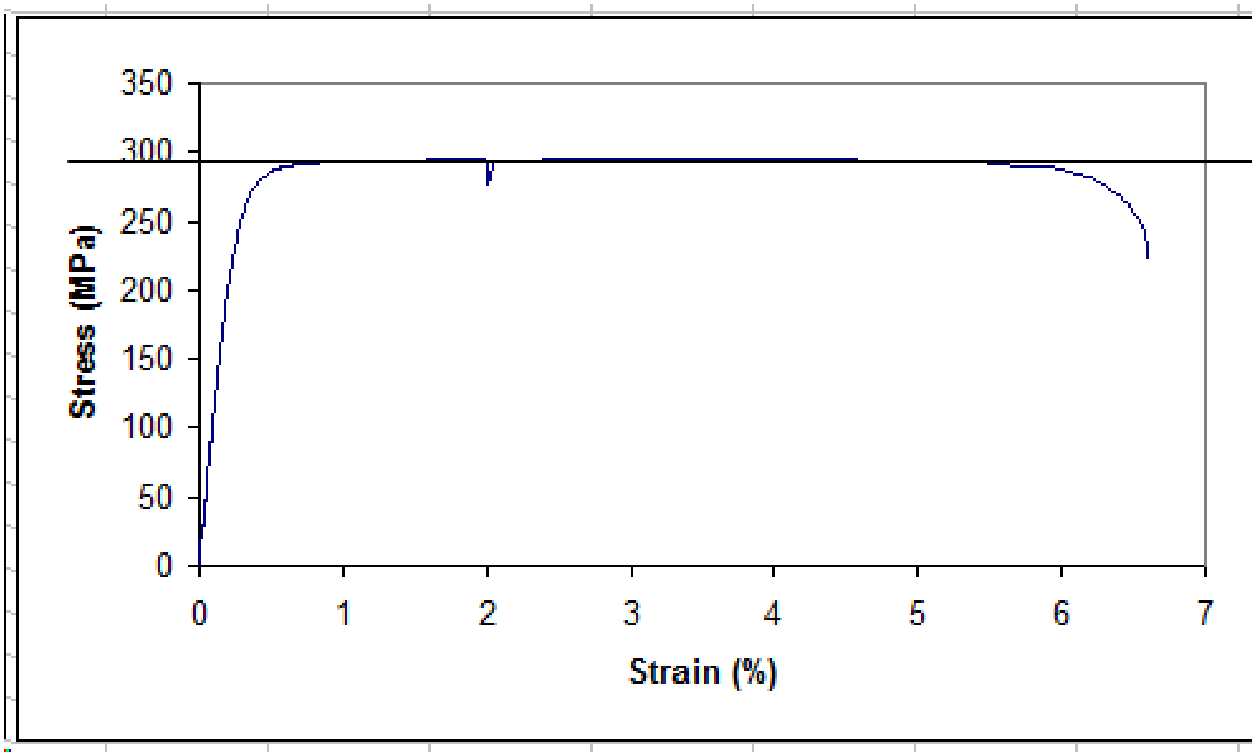
Ductility



The ductility is 6.3%

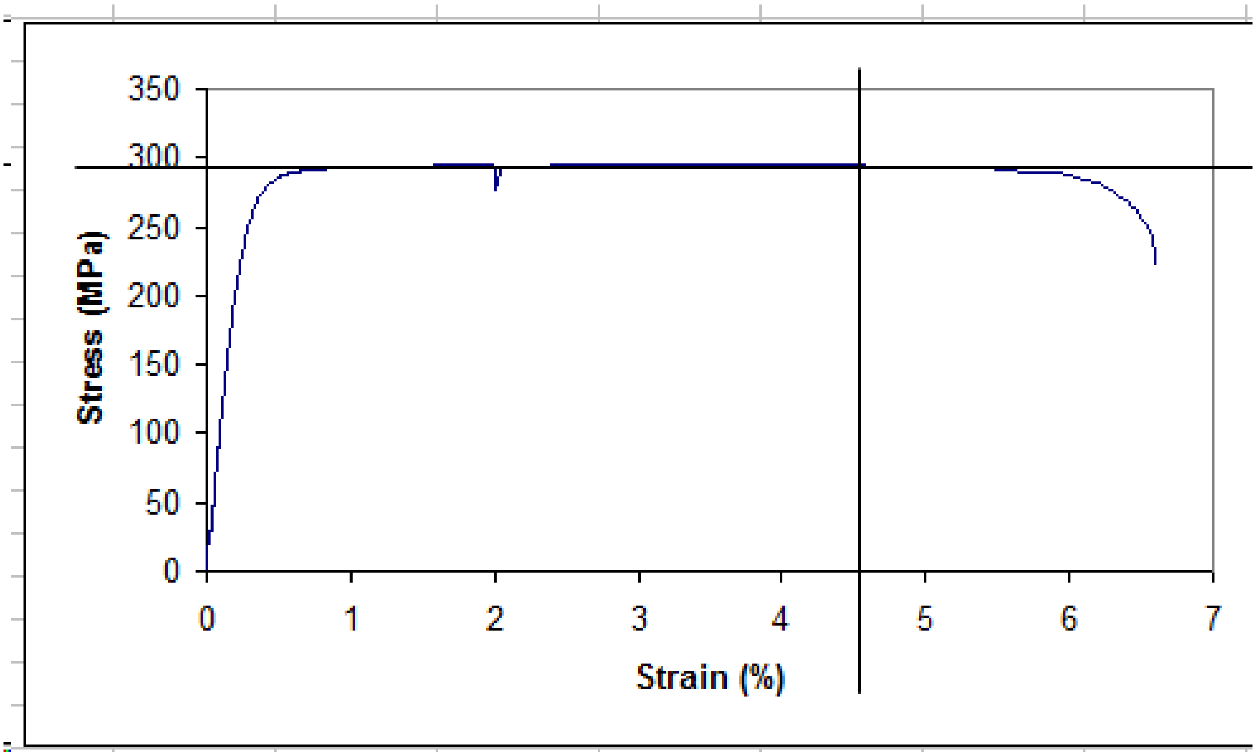
The maximum strain is the strain at UTS so it is easier to determine the ultimate tensile strength first.

Ultimate Tensile Strength



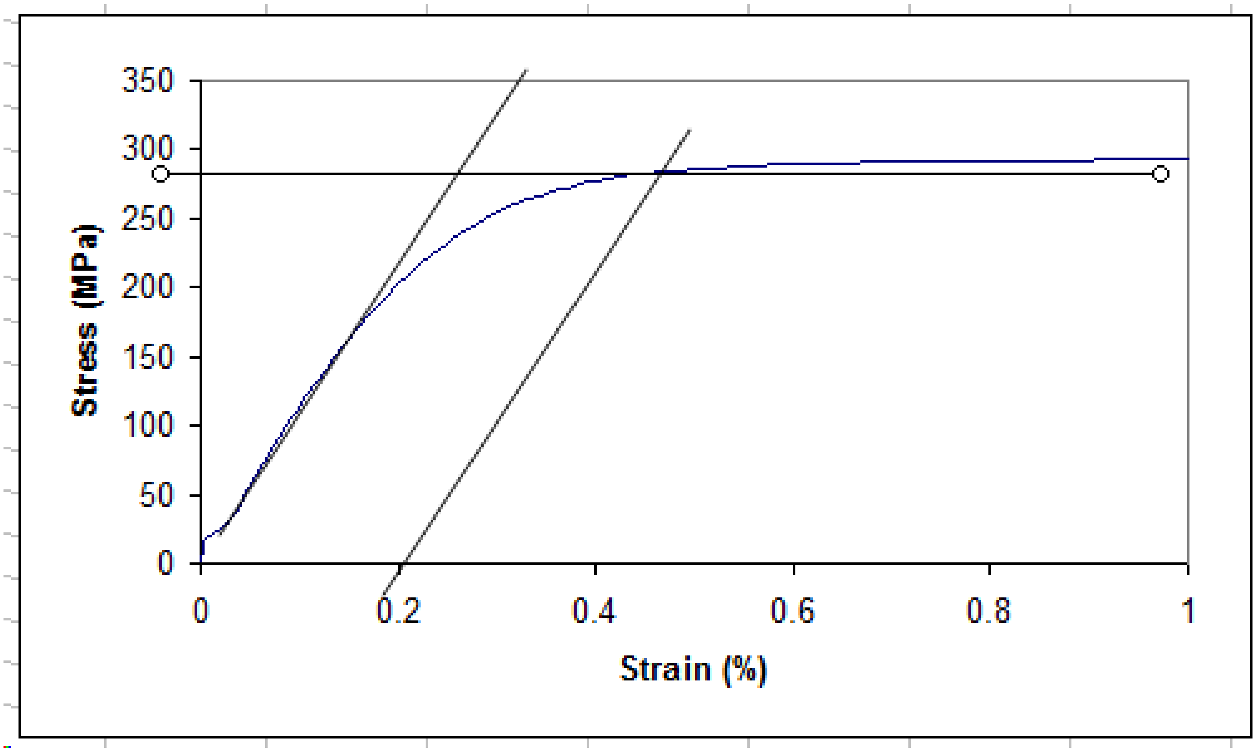
The Ultimate Tensile Strength is Approximately 295 MPa

Maximum Strain



The maximum strain is 4.5%

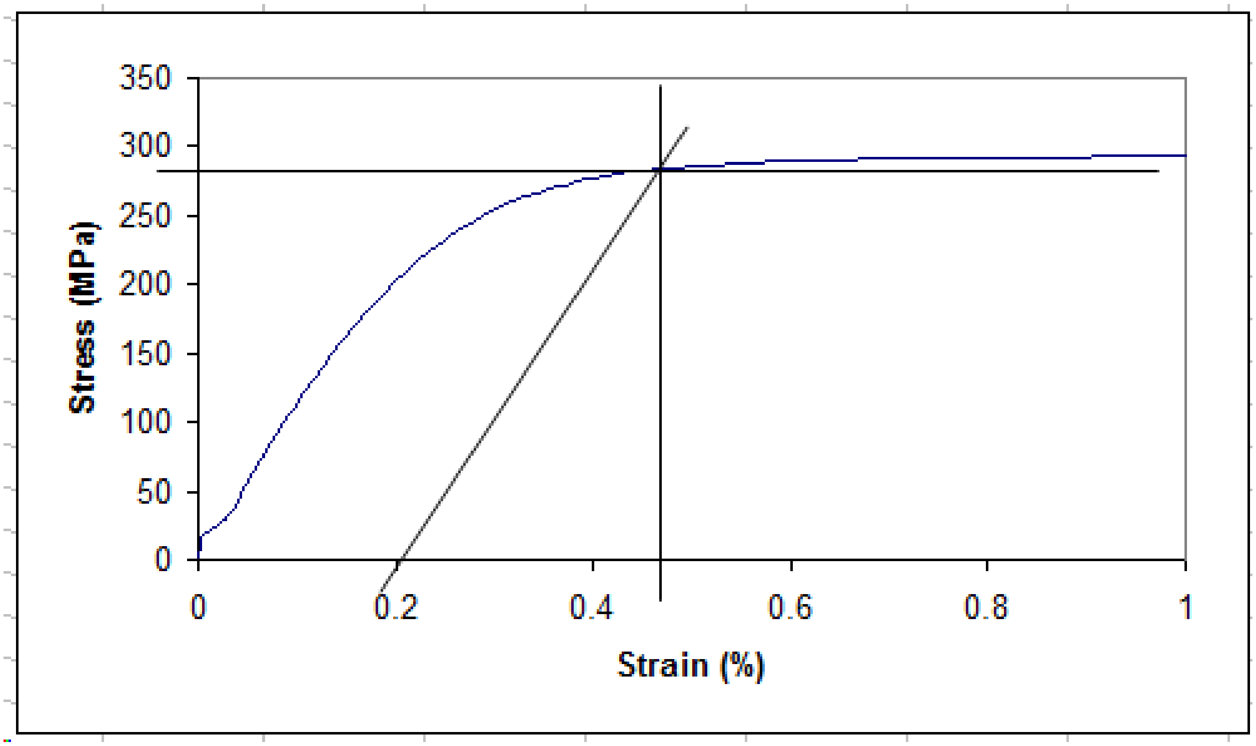
Yield Strength



The yield strength based on the 0.2% offset is 280 MPa

Modulus

The Modulus is the slope of the initial (linear) region of the stress-strain curve. However using the line to determine the yield strength can be used.



The modulus is thus

$$E = \frac{(\sigma_2 - \sigma_1)}{(\varepsilon_2 - \varepsilon_1)} = \frac{(280\,MPa - 0\,MPa)}{(4.5\times10^{-3} - 2.0\times10^{-3})} = 110\times10^{3}\,MPa$$

Sample Forging Calculation

Reducing the height by 5% through open die forging means h=0.95h0 thus using the following equations

$$\varepsilon = \frac{h_0}{h} - 1$$

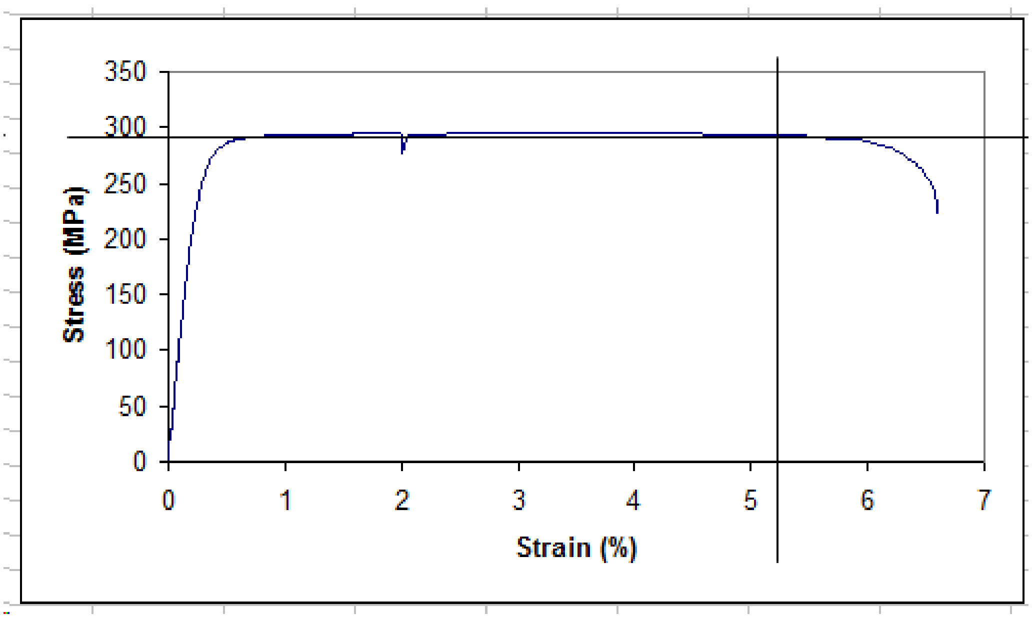
$$F = K\sigma\ A$$

$$K = 1 + \frac{0.4\mu D}{h}$$

Notice the only difference between the six materials will be the stress corresponding to a strain of 5.3%

Thus the strain is:

$$\varepsilon = \frac{1}{0.95} - 1 = 0.053 = 5.3\%$$



Thus the stress required is 285MPa.

Effect of Temperature

Copper	Ductility (%)	Max Strain (%)	YS (MPa)	UTS (MPa)	Modulus (MPa)	Forging Stress (MPa)
Never in Furnace	6.3	4.5	280	295	110000	285
1250 F 1hr	40	33	37	220	74000	120
1650 F 1 hr	15.5	17	27	200	N/A	120

Note N/A means not possible to determine based on data presented

Steel	Ductility (%)	Max Strain (%)	YS (MPa)	UTS (MPa)	Modulus (MPa)	Forging Stress (MPa)
Never in Furnace	6.7	9.5	320	500	210000	495
1250 F 1hr	10.5	8	360	495	200000	480
1650 F 1 hr	0.36	0.36	1000	1000	280000	No

Notice that copper and steel behave very differently. For the three copper alloys those prepared at elevated temperature had a lower yield strength, higher ductility, and higher max strain that simply left at room temperature. This also reduced the force (stress needed for forging). In Steel there was a slight increase in ductility and maximum strain and very little change in other properties when the material was exposed to 1250F for one hour. However the steel at 1650F is much stronger and much more brittle. This is due to the solid state phase change observed in iron which is not observed in copper.

2) Explain the advantages and disadvantages of using hardness for quality control.

Hardness testing (except for Brinell) is typically non destructive. This means one does not have to destroy a piece of material to determine if it is “in-spec”. Tensile testing involves destroying a piece of material or making the piece of material unsuitable for further use. However hardness numbers are empirical. Therefore it is difficult to analyze small differences in hardness numbers.

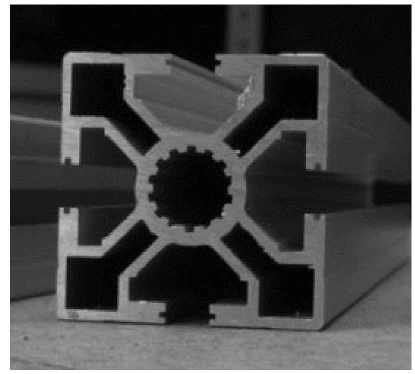
For example if a hardness test were performed 3 times on a small piece of material a range of 2-3 would be expected and 4-6 not surprising.

3) Compare the extrusion, forging, deep drawing, and drawing processes. Include the mechanical properties of interest in your analysis.

Extrusion, forging and deep drawing all use compressive forces to change the shape of a piece of material. Drawing uses a tensile force.

Extrusion and drawing are often confused because extrusion is pushing a piece of material through a die and drawing is pulling a piece of a material through a die. It is the difference between pushing (compressive) and tensile (pulling) that best differentiates the two processes.

The key difference between those processes using a compressive force (extrusion, forging, and deep-drawing) is the nature through which the compressive force is applied to the piece of material. In extrusion a piece of material is pushed into a die. For example a square bar could be pushed through a die such that the final shape is as shown on the right.



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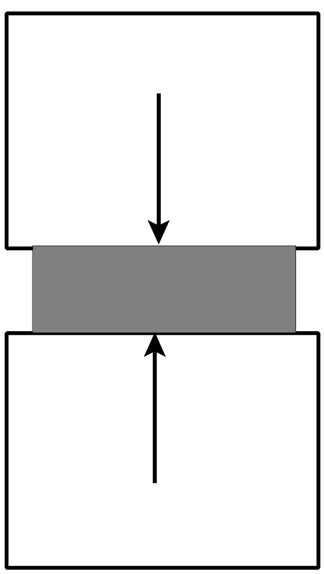
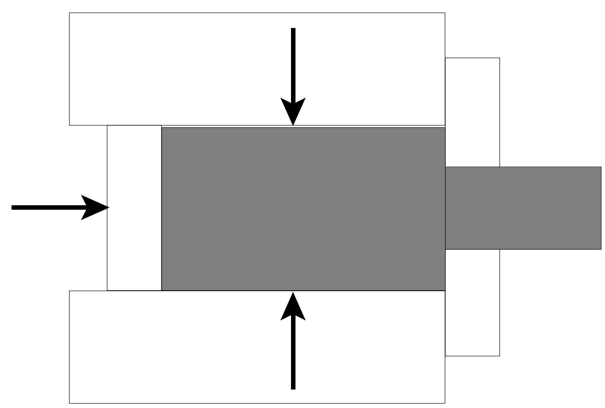
Forging does not involve pushing through a die. The key word is through. While a compressive force may be used to force a piece of material into a die, forging does not mean through a die. The difference is shown below. Pay careful attention to the third arrow in the extrusion figure.



Dieter G. E.

Forging



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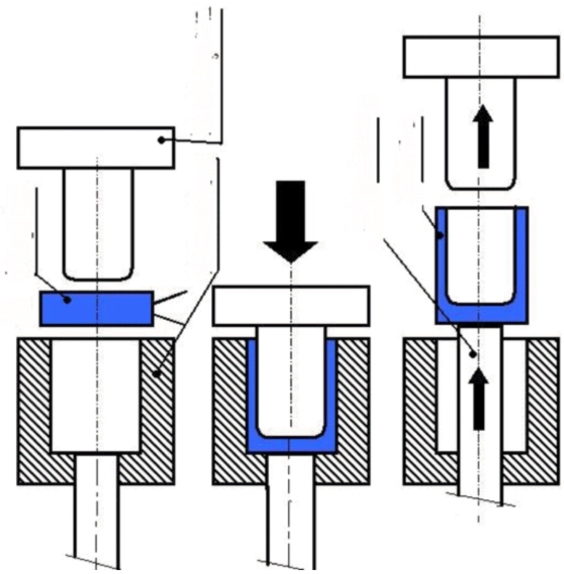
Extrusion

Deep drawing involves forcing a thin piece of material (usually called a sheet) to form a pre-defined shape by pushing into a die. This is not pushing through (which would be extrusion). It is similar to forging in that a compressive force is applied to ensure the piece of material is changed such that it has a predefined shape. The key difference is how the force is applied. This is shown below.



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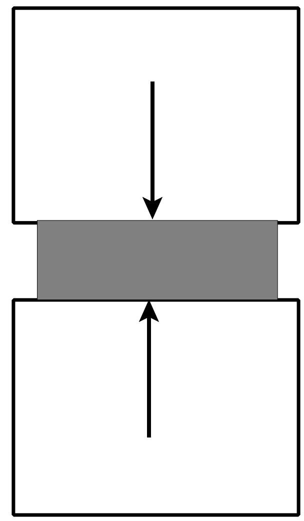
Deep Drawing - Piece pushed into Die and then Ejected



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Forging - Both Dies Moving

4) During the sheet metal practica you made a bowl. Describe what you did using proper terminology. Would it be possible to make the same bowl using a steel alloy with an ultimate tensile strength of 50ksi and a yield strength of 30ksi? Assume the sheet was 0.010" thick and that the disk was 4.00" in diameter.

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The bowl was made in two steps: blanking and deep drawing. In blanking a disk was sheared from a sheet of metal using the blanking press. This desk was then placed in the deep drawing press, where it was drawn over a die. The metal was permanently deformed to the shape of the die. In some cases it was stretched. The load capacity of the blanking press is 75 tons, and that of the deep drawing press is 150 tons. Thus, if the capacity of the blanking press is sufficient, it would be possible to make this bowl.

The force required to shear material is,

$$F = 0.7 t l \sigma_{UTS}$$

where t is the thickness of the material, l is the length of the cut, and σ_{UTS} is the ultimate tensile strength of the material. The length of the cut will be the perimeter of the circle being blanked. This is,

$$l = \pi d = \pi(4.0in) = 12.6in$$

The force required is therefore,

$$F = 0.7\sigma_{UTS} lt = 0.7(50\times 10^3\, psi)(12.6in)(0.010in) = 6.3\times 10^3\, lb$$

Thus 6,300 lbs, or 3.15 tons is required. Clearly the part could be made.

5) Determine how much force an extrusion machine must apply to a copper square bar (4cmx4cm) in order to make it a square bar (3cmx3cm) at 500C and 800C. Under what conditions would it be worthwhile to operate at the higher temperature? Under what conditions would it be worthwhile to operate at the lower temperature? The extrusion coeffiecients for copper are 260MPa at 500C and 100MPa at 800C

- For reference 1 ton equals 8.96kN (8960N)
- The extrusion coefficients for copper are 260MPa at 500C and 100MPa at 800C
- The initial cross sectional area A_0 of the bar is 16x10^{-4} m^2
- The final cross sectional area A_f of the bar is 9x10^{-4} m^2
- Therefore the force required to extrude the bar at 500C is,

$$F = A_0 k \ln\left(\frac{A_0}{A_f}\right)$$

$$= \left(16\times 10^{-4} m^2\right)\left(260\times 10^6 \frac{N}{m^2}\right)\ln\left(\frac{16\times 10^{-4} m^2}{9\times 10^{-4} m^2}\right)$$

$$= 239\times 10^3\, N = 27.5 tons$$

At 800C the only thing that changes is the extrusion coefficient, thus

$$\frac{F_{800C}}{F_{500C}} = \frac{A_0 k_{800C} \ln\left(\frac{A_0}{A_f}\right)}{A_0 k_{500C} \ln\left(\frac{A_0}{A_f}\right)}$$

$$= \frac{k_{800C}}{k_{500C}}$$

$$F_{800C} = F_{500C} \frac{k_{800C}}{k_{500C}} = 27.5 tons \frac{100 MPa}{260 MPa} = 11.1 tons$$

Thus a press with a capacity of at least 27.4 tons is needed to extrude the bar at 500C, whereas a press with only a capacity of 11.1 tons is needed to extrude the bar at 800C.

Business Analysis (This is meant to explain the final answer and get you thinking about costs)

The 27.4 ton extrusion press is likely to be more expensive to purchase than the 11.1 ton extrusion press. Price difference will not be 1:1 but it is likely that the 27.4 ton press would cost 30% more than the 11.1 ton press. The maintenance cost difference is likely to be the same.

The energy costs to run the 27.4 ton press will be 2.6x that of the 11.1 ton press.

However based on the cost necessary to heat the metal from room temperature to the extrusion temperature, the 11.1 ton press would require 60% more energy than the 27.4 ton press.

So, using the 11.1 ton press as the basis

	11.1 Ton Press	27.4 Ton Press
Purchase and Maintenance	1	1.3
Mechanical Energy	1	2.6
Heat Energy	1	0.625

The energy costs are variable, meaning occur every month (or other time period), So on a month by month basis if the mechanical energy required is 20% of the total energy required, the energy costs for the two presses would be equal. If the mechanical energy is more than 20% of the required energy it would be cheaper to operate the 11.1 ton press on a month-by-month basis. Otherwise, it would be cheaper to operate the 27.4 ton press.

The maintenance costs are also variable. So determining which is the cheaper press to operate on a monthly basis one needs to compare the monthly costs associated with maintenance to those associated with energy. The monthly maintenance costs could be more or less than the energy cost. For example, if the monthly energy costs for the 11.1 ton press is $8,000 and the maintenance costs are $5,000 one could estimate the monthly costs associated with operating the 27.4 ton press. Assuming the 20% of the energy required is mechanical and 80% thermal we can estimate the energy costs to operate the 27.4 ton press as $14,660 or $1,660 more than the 11.1 ton press.

Final Answer

To determine which press should be purchased based on cost effectiveness one needs to consider the following.

First, which press would have the lowest monthly "power bill"
Second, how do the monthly maintenance costs change the choice? Why? Does the choice become more or less desireable? Why
Third, consider the purchase price.

For the time being the best answer is
1) If the purchase price difference is negated by monthly cost savings in (the required) time period it could be worth it. Thus the reduced force and maintenance cost of the 11.1 ton press should be considered.
2) Which press is cheaper to operate on a month-by-month basis? Why?