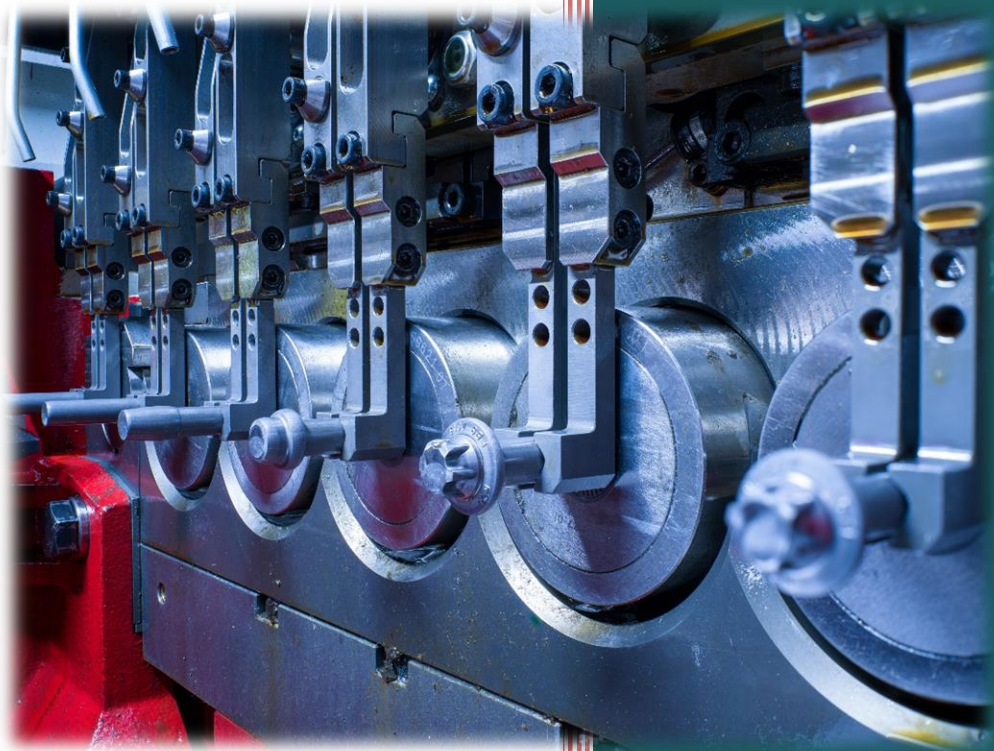


Department of Materials Science
and Engineering



Cold forming



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1. Plastic deformation and its mechanism in metals

We speak of plastic deformation when a body is subjected to such a load that it causes irreversible changes in the microstructure of the material. The body does not return to its original shape after the load is removed, but suffers a permanent deformation. The microstructural reason for this is that the atoms that make up the body rearrange under the influence of the load.

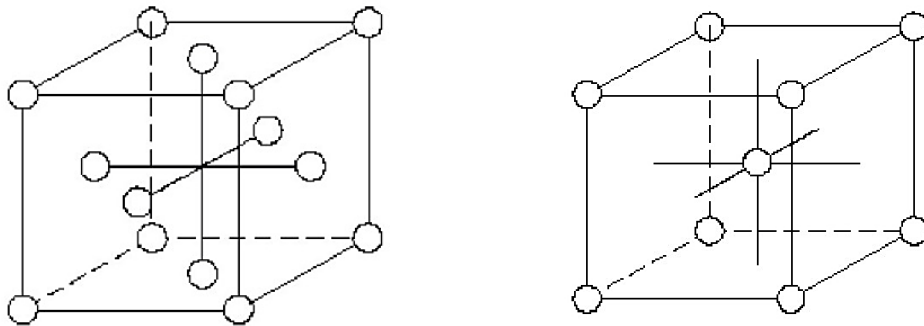


Figure 1. Surface-centered cubic unit cell (left) and space-centered cubic unit cell (right)

Metals and alloys used in engineering practice have a crystalline structure. This means that the spatial lattice characteristic of the crystal structure ideally repeats regularly in all three directions of space: the atoms that make up the given material can be found at each location in the lattice points of the crystal structure (Figure 1).

In real crystals, the ideal lattice structure is disturbed by various disorders, lattice defects. Of these, the role of dislocations is of paramount importance from the point of view of plastic deformation (Figure 2).

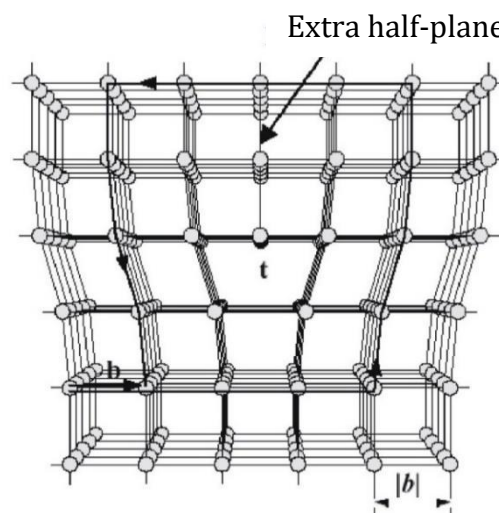


Figure 2. Schematic diagram of an edge dislocation in a primitive cubic lattice.

Plastic deformation typically occurs when a particular atomic layer slides relative to an adjacent atomic layer. This sliding does not occur in a single step, but rather by the sliding of dislocations along the crystal plane, as illustrated in the following figure:

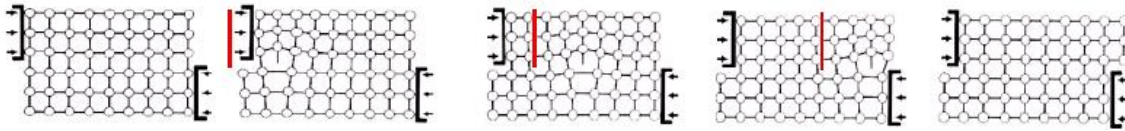


Figure 3. Dislocation slip - Mechanism of plastic deformation.

When the stress reaches the yield strength of the material, dislocations begin to slip and thus plastic deformation begins. A dislocation causes only a small displacement of the atomic planes. As plastic deformation increases, more and more dislocations are formed.

The strength-increasing effect of cold forming

In the case where no softening process takes place (e.g. recrystallization, see: hot forming), the strength of the material increases with increasing plastic deformation. The reason for this is that more and more dislocations are required for an increasingly large macroscopic deformation, their density increases during the deformation process and their movement is increasingly hindered by other dislocations. Consequently, an increasingly large stress is required to initiate or maintain plastic deformation, and therefore the strength and hardness of the material increase.

Figure 4 shows a yield curve typical of cold forming: it shows the increase in the forming strength (k_f) as a function of the plastic deformation. The toughness and the degree of further formability decrease with the cold forming process. Excessive deformation leads to damage to the material (e.g. fracture).

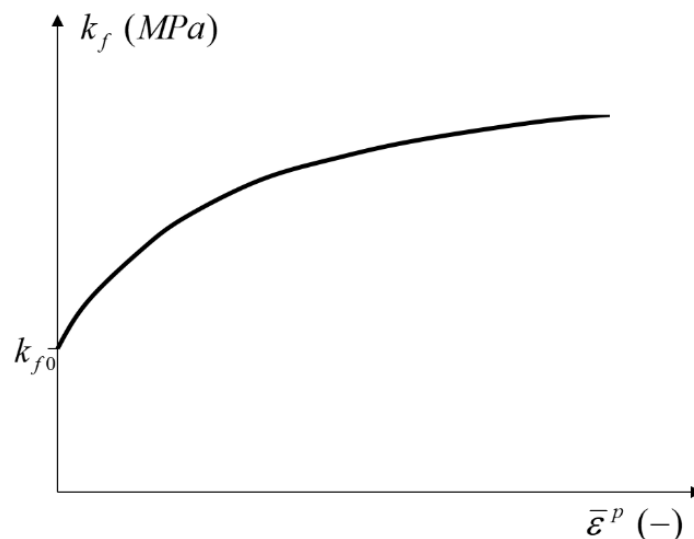


Figure 4. Typical yield curve for cold forming: Equivalent stress required for forming as a function of plastic deformation

Temperature range of cold forming

Cold forming must always be carried out below the recrystallization temperature. Above this we are talking about hot forming. In general, we can say that if the forming is carried out at a temperature below 60% of the melting point given in Kelvin for the given metal, then recrystallization will no longer occur. So:

$$T_{cold} < 0,6 \cdot T_{melt}$$

Advantages and disadvantages of cold forming processes

- *Good surface quality.* Since the forming takes place at room or low temperatures, the surface of the workpiece does not oxidize, and good surface quality can be achieved.
- *Forming forces.* Compared to hot forming, higher forming forces are required.
- *High precision.* Cold forming techniques can produce parts with greater precision than hot forming.
- *Formability.* As the degree of deformation increases, toughness and further formability decrease, excessive deformation leads to damage to the material.
- *Increasing strength.* The strength of the material can be increased by cold forming.

2. Cold forming technologies

Cold forming technologies can be divided into two main groups according to the shape of the processed raw material: volumetric and sheet forming. Volumetric technologies include forward, backward and combined extrusion technologies, cutting and tube and bar drawing technologies. Sheet forming technologies include deep drawing, bending and cutting and punching.

Forward, backward and combined extrusion

During forward extrusion, the bulk material is pushed through a narrowing channel using a die, during which the side of the workpiece is supported all the way. This process usually produces cylindrical products, but it can also produce profiled and hollow products, depending on the design of the die. During backward extrusion, we place our starting material in a closed die and shape it using a punch. The diameter of the punch is smaller than the inner diameter of the die, so the material can only flow in one direction: backward. This is where the name comes from, since the punch moves forward while the formed piece flows backward. In contrast, during forward extrusion, the movement of the workpiece and the punch was in the same direction. In the case of combined flow, both techniques are used simultaneously. With these processes, we can produce thin-walled hollow products, rods of different diameters, or, for example, toothpaste tubes.

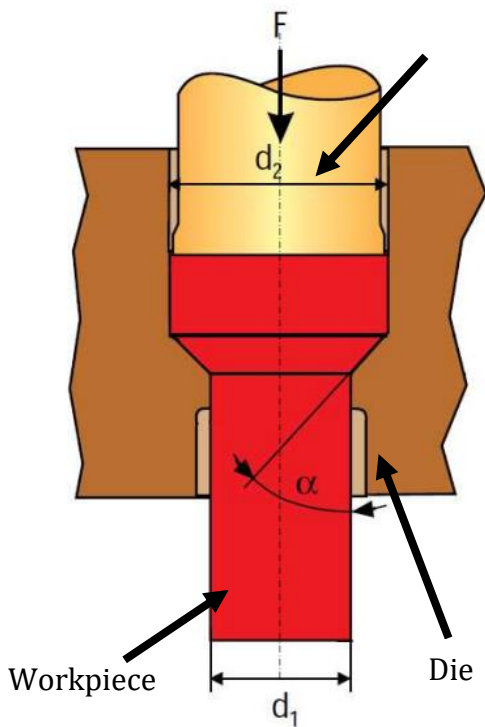


Figure 5. Schematic diagram of the forward extrusion

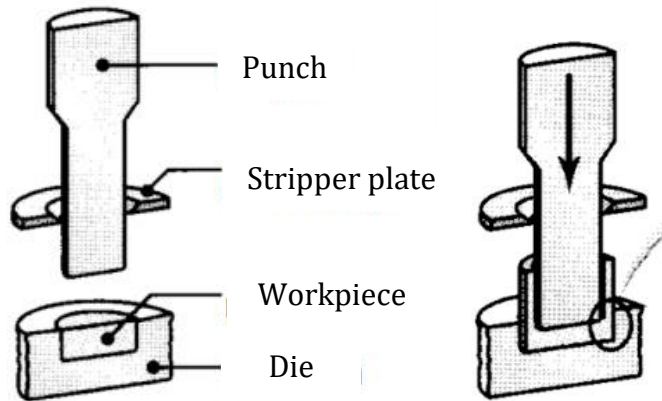


Figure 6. Schematic diagram of the backward extrusion

Heading

During the finishing process, we start from a bar product, of which only a small part is shaped. In this case, the unformed part must be supported so that it does not change shape. The majority of screws are manufactured using this process technique. The following figure shows an example of this process.

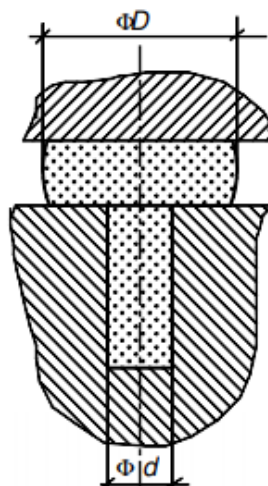


Figure 7. Preparation of the screw head by heading.

Pipe or rod drawing

The material in this case also passes through a conical die, as in the case of forward drawing, but here the diameter changes are much smaller than in forward drawing, so the material to be formed is only supported on the conical part. Also, the point of application of the force required for forming is not at the back of the piece, but at the front. Typically, thin wires and tubes are produced in this way, through up to 10-20 drawing steps in a single machine. Figure 8 shows an example of tube drawing.

Pipe drawing with
fixed plug

- 1) Drawing ring
- 2) Plug
- 3) Shaft
- 4) Pipe

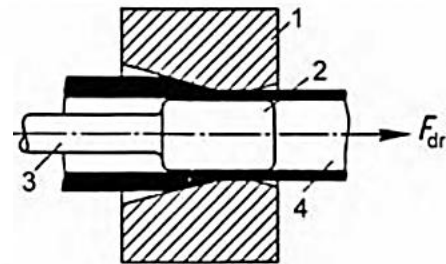


Figure 8. Pipe drawing with fixed plug

Deep drawing

Using the deep drawing process, sheet metal blanks are formed into hollow products. During the operation, the punch pushes the sheet through the die opening, causing it to take on the shape of the die, while the excess material forms the wall of the resulting product. To prevent wrinkling of the workpiece during manufacturing, meaning the formation of folds in the wall, a blank holder must be applied. This tool component clamps the portion of the sheet that has not yet been drawn through the die, thereby preventing the sheet from buckling and wrinkling. Since this results in extensive contact and friction between the sheet and the tooling surfaces, ensuring proper lubrication is of crucial importance.

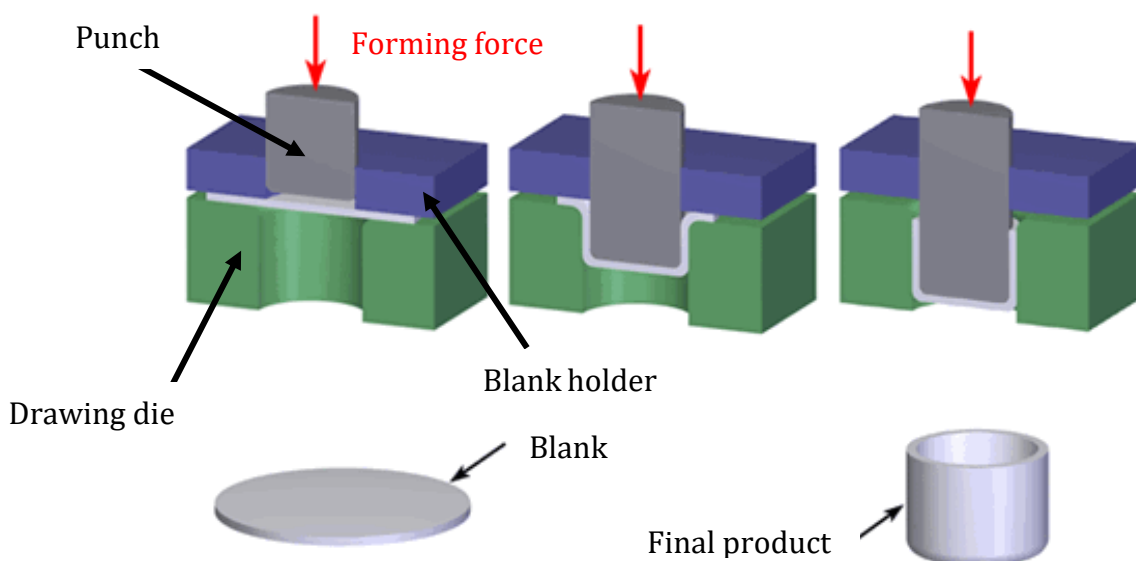


Figure 9. Steps of deep drawing

3. What to expect during the lab?

The purpose of the measurement is to measure how the hardness of the material changes as a result of cold forming. The forming is done by cold rolling, during which the hardness of the material is continuously measured. As a result of the measurement, the hardness is plotted as a function of the relative reduction in sheet thickness.

Measurement tools: duo rolling mill, Rockwell hardness tester, caliper

Measurement procedure

The initial dimensions and hardness of the annealed aluminum specimen are measured first. Subsequently, the specimen is cold rolled in several passes, initially with small thickness reductions and later with larger reductions. After each rolling step, the hardness and thickness of the specimen are measured. Hardness measurements are performed using a Rockwell hardness tester, employing an indenter and scale (B, E, F, or custom settings deviating from the standard) appropriate for the hardness of the material.

Evaluation of the measurement

The stepwise thickness reduction (q) is calculated from the measured thickness values using the equation given below. The measured hardness values are then plotted as a function of the reduction. Finally, a curve is fitted to the experimental data points.

$$q = \frac{h_0 - h}{h_0} \cdot 100\%$$

The laboratory report must be completed during the laboratory session and presented for signature.

Questions to help you prepare:

1. How do the mechanical properties change as a result of cold working?
2. What are the advantages of cold working compared to hot working?
3. What are the disadvantages of cold working compared to hot working?
4. Draw a flow curve characteristic of cold working.
5. List at least five cold forming processes.
6. What causes the increase in strength during cold working?
7. What is the temperature-based definition of cold working?
8. What is the role of the blank holder during deep drawing?
9. What is the difference between forward extrusion and wire drawing?
10. Give the two main categories of cold working and provide one example for each.

Used and recommended literature:

- Ziaja György: Alakítástechnika előadásjegyzet
- Kurt Lange: Handbook of Metal Forming