

Department of Materials Science &
Engineering



Hot forming



HOT FORMING

1. Forming at elevated temperature, recrystallization

During plastic deformation, most of the work performed is converted into heat, while the remainder is expended on deformation—specifically, the generation and motion of dislocations—thereby increasing the energy of the crystal lattice. If the deformed metal is heated to a sufficiently high temperature, a softening process is initiated, resulting in decreased strength and hardness and increased toughness and formability. In the case of hot working, this process is typically recrystallization.

The driving force behind recrystallization is the reduction of energy accumulated in the crystal lattice through plastic deformation—specifically, the increase in dislocation density. The process consists of polygonization, recrystallization, and grain coarsening, during which the old grains disappear and a new microstructure of low-dislocation-density grains forms in their place.

The recrystallization temperature depends on the material and the degree of deformation. In a heavily deformed alloy, recrystallization begins at a lower temperature than in one subjected to moderate deformation. Therefore, the recrystallization temperature varies within a temperature range based on the homologous temperature.

Forming performed above the recrystallization temperature is called hot forming, while forming performed below it is called cold forming. We speak of semi-hot forming when the forming temperature is close to the recrystallization temperature. The temperature ranges for these processes are typically defined as follows:

$$T_{cold} < 0,3 \cdot T_{melting} \quad 0,3 \cdot T_{melting} < T_{semi-hot} < 0,6 \cdot T_{melting} \quad T_{hot} > 0,6 \cdot T_{melting}$$

where $T_{melting}$ means the melting temperature in K.

During hot working, hardening (the formation of dislocations) and recrystallization occur simultaneously. After an initial stage, a balance is established between the two processes, a phenomenon observable in hot yield curves (Figure 1). This allows the material to be shaped to a large extent without damaging it. Increasing the temperature shifts the yield curve downward, allowing the same forming operation to be performed with lower forces.

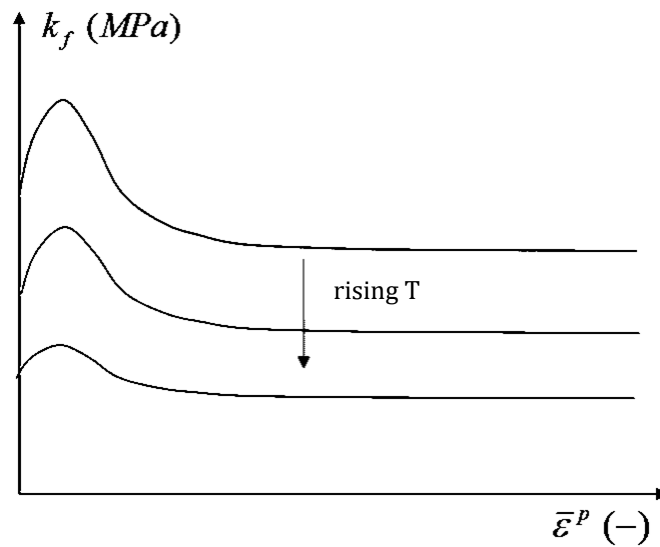


Figure 1. Typical yield curve for hot forming: Forming strength as a function of plastic deformation and the effect of increasing temperature.

The first peak in the figure arises because a certain degree of deformation is required for recrystallization to initiate. This is commonly referred to as critical deformation. The size of the newly formed grains depends largely on the degree of deformation. This is illustrated in Figure 2.

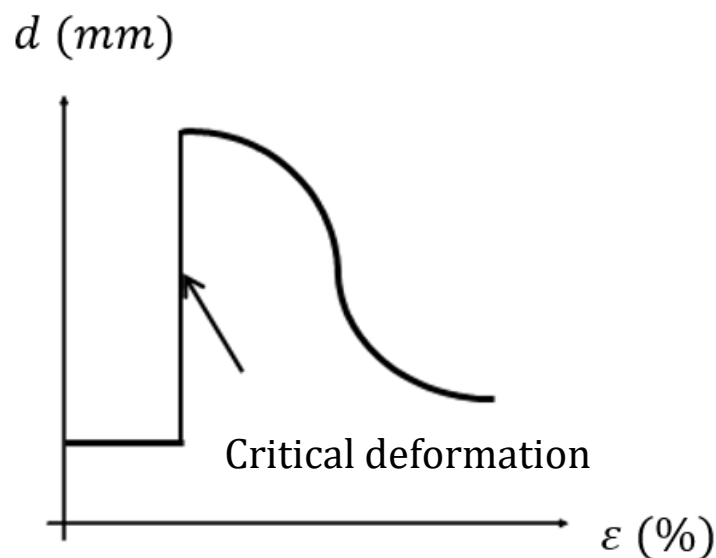


Figure 2. Change in grain size formed during recrystallization as a function of the degree of prior deformation.

Figure 2 also shows that, beyond a certain degree of deformation, small, homogeneous grains are formed, which is advantageous for mechanical properties. Aluminum is particularly susceptible to grain coarsening during recrystallization. Figure 3 shows a recrystallized aluminum sheet that had undergone varying degrees of deformation along its length prior to recrystallization.

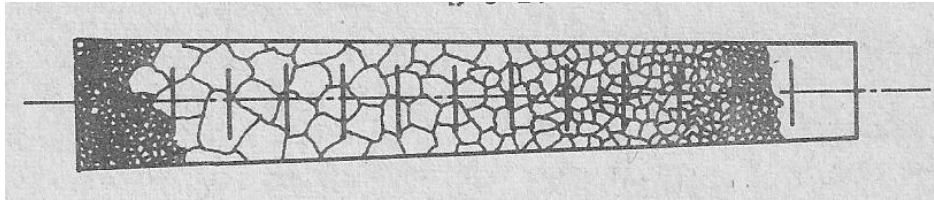


Figure 3. Recrystallization of a sheet deformed to varying degrees.

2. Advantages and disadvantages of hot forming processes

Surface quality. If the workpiece material oxidizes at the forming temperature, surface quality deteriorates. Example: During steel forging, scale (iron oxide) forms on the part's surface.

Forming forces. Since the material recrystallizes during forming, its strength does not increase—or increases only slightly—compared to cold forming; consequently, specific forming forces are lower than in cold forming.

Lower precision. Hot forming processes yield products with lower dimensional accuracy than cold forming processes. This is because the part shrinks as it cools from the forming temperature, and deformation may also occur during cooling.

Formability. Since the material recrystallizes during hot forming, its formability is theoretically unlimited.

3. Hot forming processes

Forging

Figure 4 illustrates the two main types of forging. One is open-die forging, in which relatively simple shapes are produced with simple tools; manual forging also falls into this category. The basic operations of open-die forging include drawing out, upsetting, twisting, bending, necking, punching, and drifting. In contrast, closed-die forging employs specialized tooling. Typically, two pre-formed die halves work together to shape the complex geometry of the workpiece.

Depending on the type of machine, the product may be formed in a single blow or multiple blows. Machines characterized by stroke and force parameters produce the desired shape in a single blow, whereas machines characterized by energy parameters (e.g., counter-blow hammers) require multiple blows.

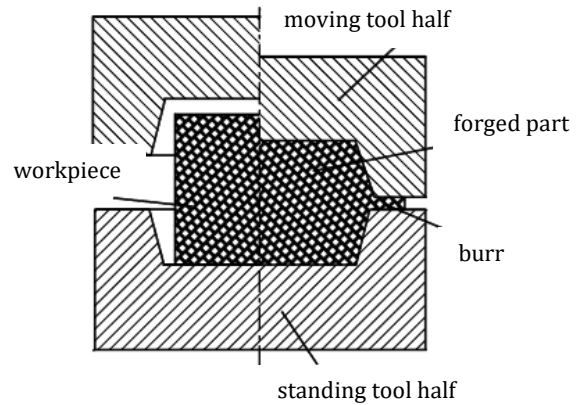


Figure 4. Schematic diagram of open-die forging (left) and closed-die forging (right) moving die

Hot Rolling

The hot rolling process is very similar to cold rolling; forming is carried out using two counter-rotating rolls, as shown in Figure 5. Modern continuous casting technology is integrated with hot rolling, whereby the cast thick plates are further processed for subsequent use. During rolling, the forming rolls undergo elastic deformation, which would otherwise result in plates of uneven thickness. This issue is typically mitigated by using backup rolls or by crowning the rolls. Figure 6 illustrates crowning, showing how the roll diameter increases towards the center of the roll.

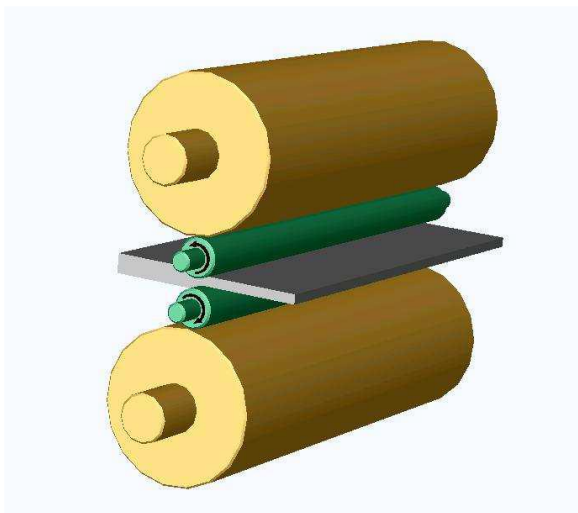


Figure 5. Schematic diagram of rolling

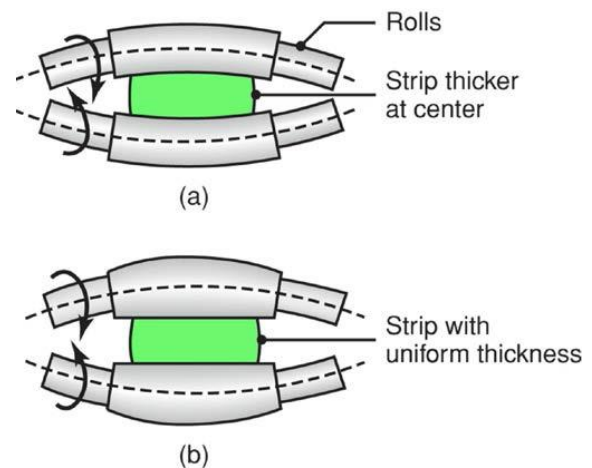


Figure 6. (a) Faulty rolling setup, resulting in uneven sheet thickness; (a) incorrect design of the rolling, as this will result in an uneven sheet thickness, (b) using convex rolls to create a uniform sheet thickness

4. What to expect during the laboratory session?

In the first part of the laboratory session, the group determines the lower limit of the hot-working temperature range by upsetting aluminum cylinders at various temperatures; in the second part, they forge a raft nail from S235JR material using manual open-die forging.

Procedure for the upsetting test

Students measure the initial dimensions of the aluminum cylinder using a caliper and determine its initial hardness using the Rockwell B or F method. Subsequently, they perform the upsetting process using an eccentric press at four different temperatures (20°C, 200°C, 300°C, and 400°C). Afterward, they measure the height and hardness of the upset specimens. Using the specimen heights and the initial height, they determine the deformation and plot changes in specimen height and hardness as a function of temperature in a common coordinate system. Finally, they fit a curve to the recorded data points.

Manual Open-Die Forging

The second task of the laboratory exercise is to produce a raft nail using manual open-die forging from an S235JR steel bar with an 8x8 mm square cross-section. Under the guidance of the instructor and their assistants, the students forge the raft nails and subsequently document the process in a report that includes sketches of the workpiece fabrication, the approximate forging temperature, and their personal impressions of the forging process.

The report must be completed and handed in during the class!

Questions to aid preparation:

1. When is a process considered hot working?
2. Sketch a hot-working flow curve.
3. Why is a much greater degree of deformation achievable through hot forming than through cold forming?
4. Define the temperature range for cold forming.
5. Define the temperature range for hot forming.
6. List the advantages of hot forming compared to cold forming.
7. List the disadvantages of hot forming compared to cold forming.
8. Name two hot-forming processes.
9. List four basic operations of open-die forging.
10. What is the difference between open-die forging and closed-die forging?