Cold, Hot and Warm Working

Metal Forming Technologies

Now we know that temperature influences the microstructure, we should be curious to find out how and what to expect when deformation is carried out at different temperatures. We know that one hand deformation should be increasing the work-hardening; on the other hand elevated temperature should decrease the effect of this work hardening, because of recovery and recrystallization.

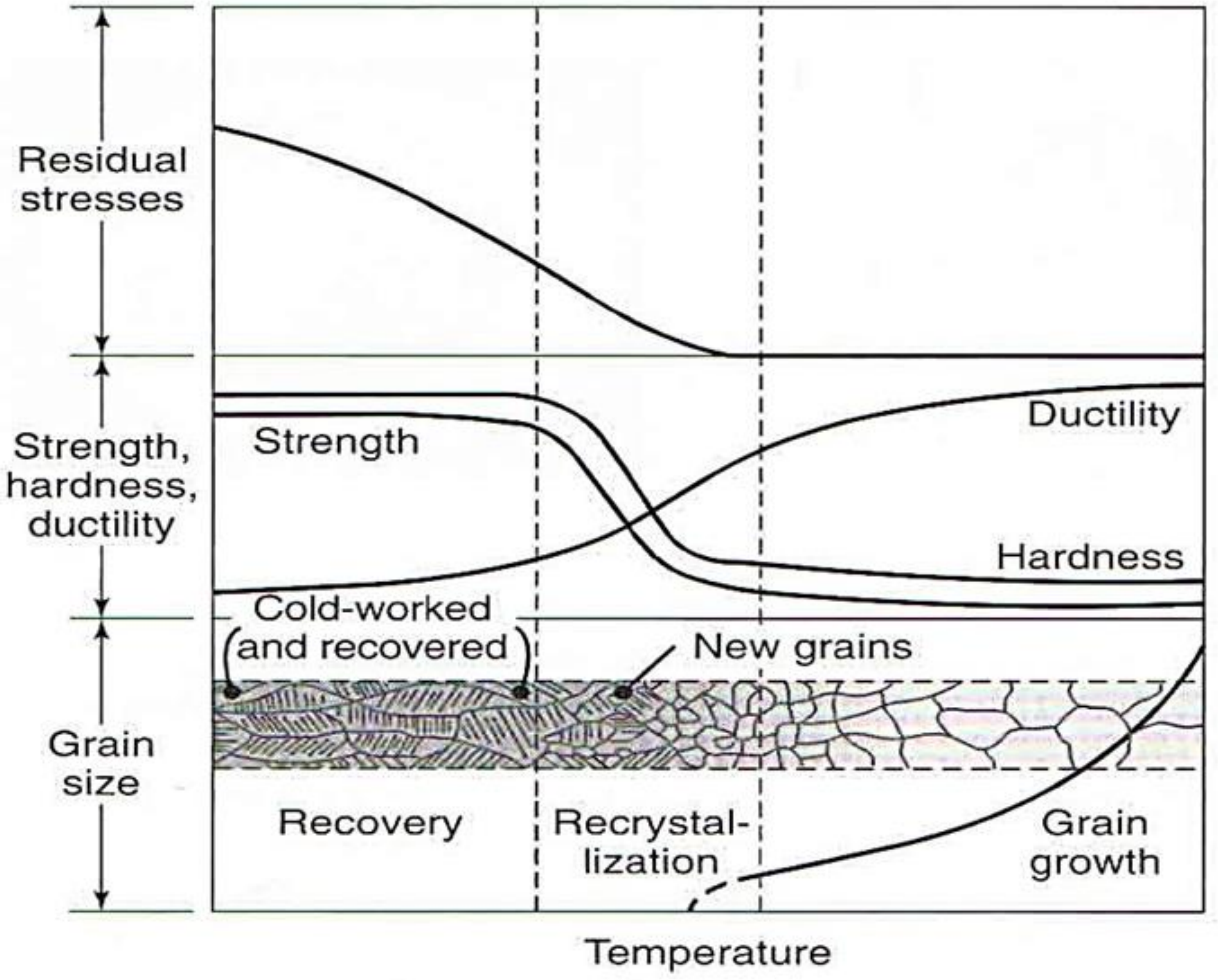
Temperature in Metal Forming

Any deformation operation can be accomplished with lower forces and power at elevated temperature

Three temperature ranges in metal forming:

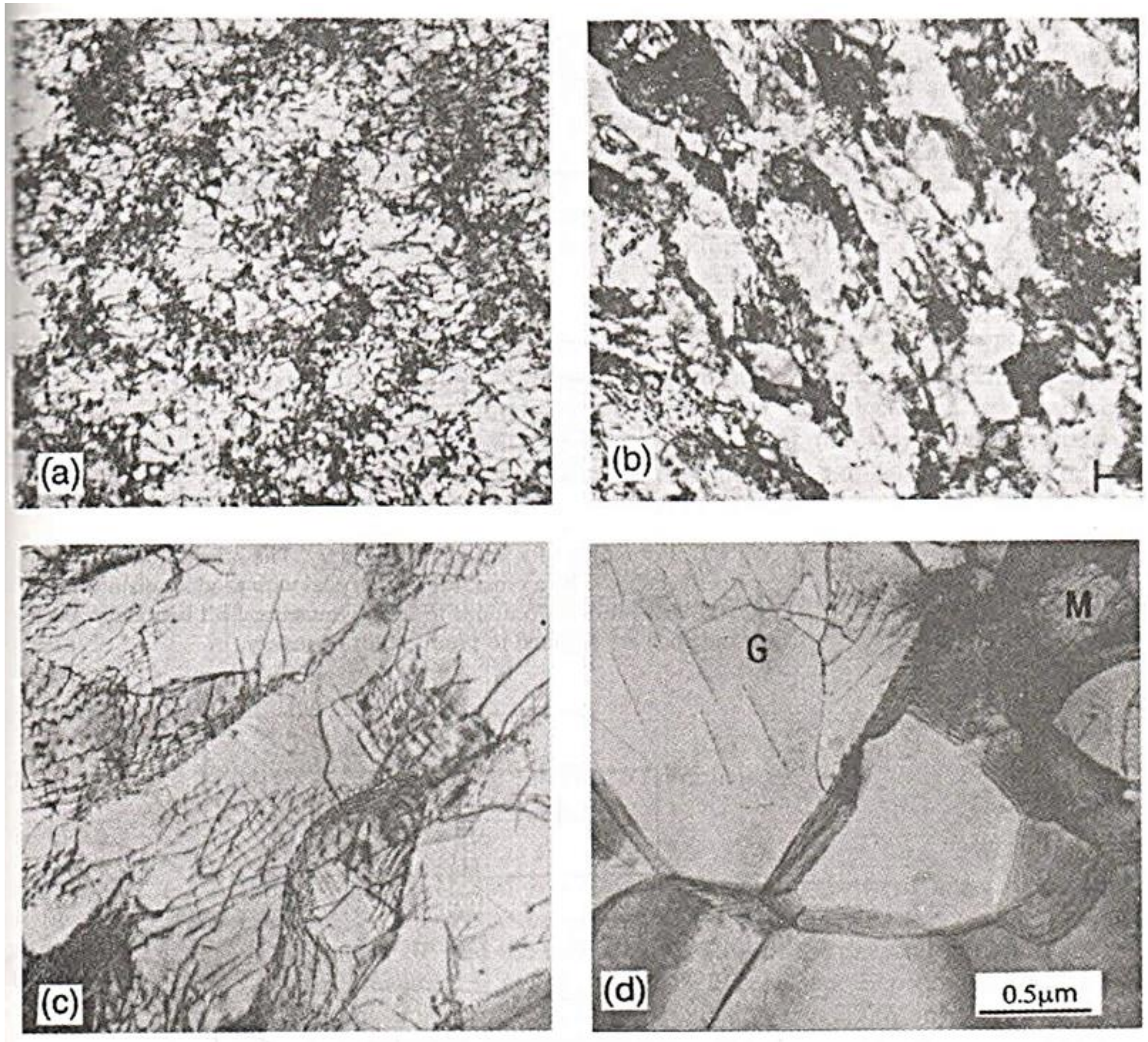
- Cold working
- Warm working
- Hot working

Effect of Annealing Temperature on Strength and Ductility



Different temperature ranges have different characteristics in terms of material properties and hence influence the deformation process in unique ways

Recovery, Recrystallization and Grain Growth



TEM micrographs illustrating the structure of deformed and annealed 3.25%Si-Fe
(a)Approximately uniform distribution of dislocations in a crystal rolled 20%
(b)Formation of small sub-grains in rolled material annealed 15min at 500C
(c)Annealed for 15min at 600C
(d)Annealed for 30min at 600C

Cold Working

Plastic deformation of metals much below the recrystallization temperature (<0.3Tm) is known as cold working.

It is generally performed at room temperature.

In some cases, slightly elevated temperatures may be used to provide increased ductility and reduced strength.

Advantages:

1. No heating is required
2. Better surface finish is obtained
3. Better dimensional control is achieved; therefore no secondary machining is generally needed (These operations are near net shape or net shape processes)
4. Products possess better reproducibility and interchangeability
5. Better strength, fatigue, and wear properties of material.
6. Directional properties can be imparted
7. Contamination problems are almost negligible

Cold Working

Disadvantages:

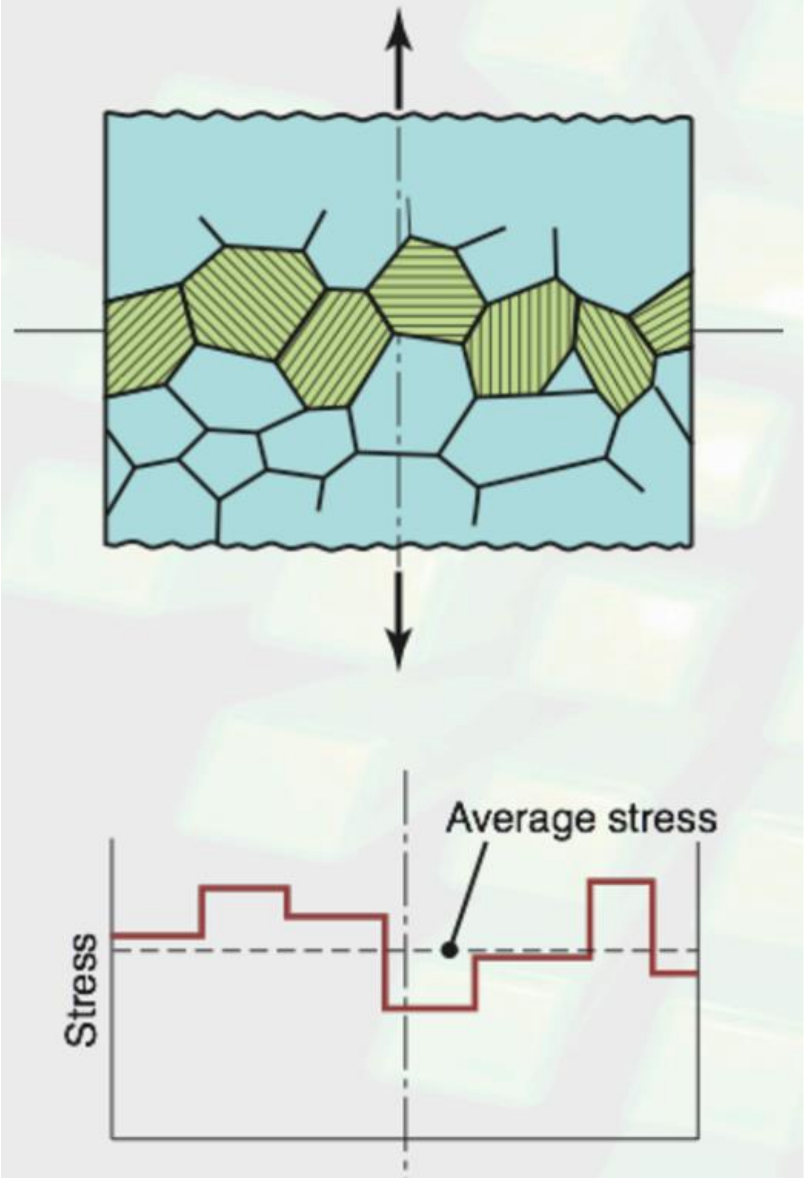
1. Higher forces are required for deformation
2. Heavier and more powerful equipment is required
3. Less ductility is available
4. Metal surfaces must be clean and scale-free
5. Undesirable residual stresses may be produced
6. Strain hardening occurs (may require intermediate annealing or in some cases material is not ductile enough to be processed)

Cold forming processes, in general, are better suited to large-scale production of parts because of the cost of the required equipment and tooling

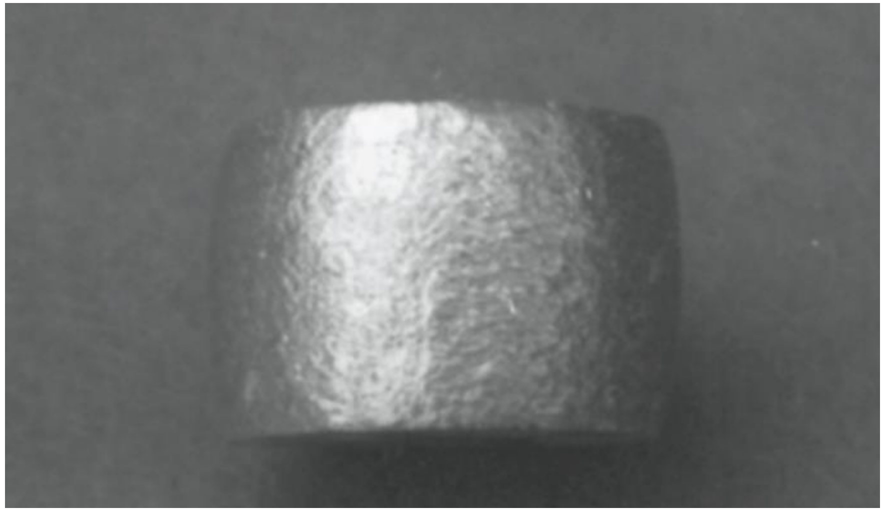
Some more on Cold Working

- Causes sub-microscopic breaking up of grain structure due to interactions of moving dislocation which lead to work hardening and low ductility
- All metals affected in similar way
- No more equiaxed grains, unless annealed after working
- Properties predictable from simple relations we have derived so far
- There is a limit to grain size which can be cold worked for making useful components
- When no. of grains too few, flow becomes irregular
- Flow is particularly irregular for hexagonal metals which have fewer slip planes e.g. Zn and Mg alloys
- Free surface develops an irregular outline ‘Orange peeling’

Irregular flow and Orange-peel effect:



Variation of tensile stress across a polycrystalline metal specimen with very few grains across the cross section



Orange Peel effect: Surface roughness on the cylindrical surface of an aluminum specimen subjected to compression

Hot Working

1. High temperature decreases the flow stress, it can be utilized to decrease the force and energy spent on deforming

2. Hot Working is defined as deformation process at temperatures above the recrystallization temperature (>0.5Tm), where new and recrystallized grains form during deformation

3. The old grain structure deformed by previously carried out mechanical working no longer exist, instead new crystals which are strain-free are formed which give better mechanical properties to the finished parts

4. In hot working, the temperature at which the working is completed is critical since any extra heat left in the material after working will promote grain growth, leading to poor mechanical properties of material

Hot Working

In comparison with cold working, the advantages of hot working are:

1. No strain hardening
2. Lesser forces are required for deformation
3. Far greater ductility of material is available, and therefore more deformation is possible.
4. Favorable grain size is obtained leading to better mechanical properties of material
5. Equipment of lesser power is needed
6. No residual stresses in the material
7. Work part shape can be substantially altered
8. Not-so-ductile materials can also be deformed (e.g. Mg-alloys)
9. Strength properties are isotropic

Hot Working

Some drawbacks of Hot Working:

1. A lot of energy is consumed in heating
2. Lubrication is more difficult
3. Oxidation and increased reactivity of the work metal
4. Reduced tool life because of increased wear rate at high temp
5. Lack of dimensional control of the finished component, because of the thermal expansion
6. Poor surface finish
7. Lack of work-hardening is undesirable where the strength level of a cold-worked product is needed

Some More on Hot Working

- Hot working is an interaction of two competing phenomena with inverse effects, hence very complex
- Properties derived for cold working are not completely true for hot working as along with dislocation generation, there is dislocation annihilation taking place
- Main reason for hot working is economics (large ingots are deformed by rolling, extrusion or forging whilst in the soft state)
- Usually requires secondary finishing process by cold working or machining.
- Important for cast-structures as there microstructure is highly oriented and certain amount of hot-working is required to break and refine these structures
- Diffusion of alloy constituents is facilitated and brittle films or particles of hard constituents are broken and distributed more evenly
- Most hot working are compressive in nature, so that cracks, cavities, and other defects are closed up and welded together
- Hot working can be characterized by the absence of strain-hardening after working and cooling
- Interplay of strain-hardening and softening by recovery and recrystallization: hence time is paramount as hardening is instantaneous but softening is time dependent
- Hence strain-rate is also very important
- Hot working may be viewed as a superimposition of working and annealing, so that maximum production efficiency is obtained
- Hot working is sometimes also required to suppress phase changes or precipitation (e.g. Inconel-718)
- Hot working if not done properly can lead to coring and segregation

Warm Working

Metal deformation carried out at temperatures intermediate to hot and cold forming is called Warm Forming or Working. Usually the temperature is above 0.3Tm and below recrystallization temperature (~0.5Tm).

Compared to cold forming, warm forming offers several advantages.

These include:

- Lesser loads on tooling and equipment
- More intricate geometries possible
- Greater metal ductility
- Fewer number of annealing operation (because of less strain hardening)

Warm Working

Compared to hot forming, warm forming offers the following advantages:

- Lesser amount of heat energy requirement
- Better precision of components
- Lesser scaling on parts
- Lesser decarburization of parts
- Better dimensional control
- Better surface finish
- Lesser thermal shock on tooling
- Lesser thermal fatigue to tooling, and so greater life of tooling.