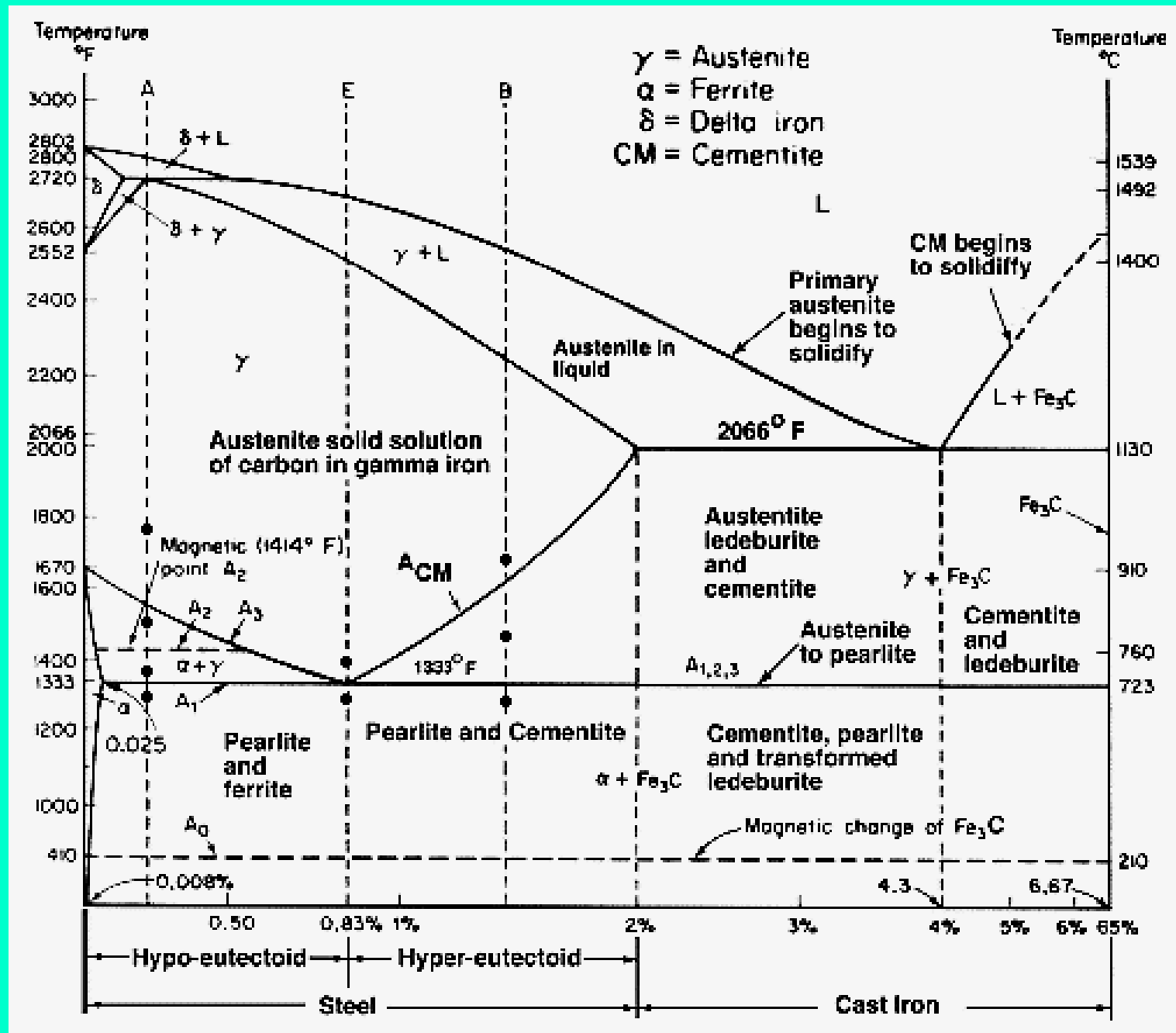


MEC 2309
Properties of Engineering Materials I

**HEAT TREATMENT
OF STEELS**

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INTRODUCTION



INTRODUCTION

- Machine components and structural members operate at extreme conditions of excessive mechanical loads, and high temperatures and pressure which induce stresses in the material.
- Similarly, metal working processes such as welding or cutting expose the material to some quantifiable amounts of heat which in turn induce thermal stresses in the material.

- As Materials Engineers, we are interested in the methods of enhancing the properties of material in order for them to support and withstand the desired working conditions as well as restoring the material to its original condition.
- Heat treatment is one method employed for this activity.
- The process of heat treating is the method by which metals are heated and cooled in a series of specific operations that never allow the metal to reach the molten state.

- The purpose of heat treating is to make a metal more useful by changing or restoring its mechanical properties.
- Through heat treatment, we can make a metal harder, stronger, and more resistant to impact.
- Also, heat treating can make a metal softer and more ductile.
- The one disadvantage is that no heat-treating procedure can produce all of these characteristics in one operation.

- Some properties are improved at the expense of others. E.g. hardening a metal may make it brittle or trying to soften it might make it weak.
- Heat treatment, therefore, involves trade-offs in the final properties that a material will have.
- The aim of the Materials Engineer is to get the optimum properties possible for a given application using a given material.

General Heat Treatment Process

Heat treating is accomplished in three major stages:

- **Stage 1 – Heating** the metal slowly to ensure a uniform temperature.
- **Stage 2 – Soaking** (holding) the metal at a given or required temperature for a given time.
- **Stage 3 – Cooling** the metal to room temperature

Successful heat treatment requires close control over all factors affecting the heating and cooling of a metal.

Stage 1: Heating

- The primary objective in the heating stage is to maintain uniform temperatures. If uneven heating occurs, one section of a part can expand faster than another and result in distortion or cracking.
- Uniform temperatures are attained by slow heating. The heating rate of a part depends on several factors. One important factor is the heat conductivity of the metal.
- A metal with a high-heat conductivity heats at a faster rate than one with a low conductivity.

Stage 2: Soaking

- After the metal is heated to the proper temperature, it is held at that temperature until the desired internal structural changes take place.
- This process is called Soaking. The length of time held at the proper temperature is called the Soaking Period.
- Soaking period depends on the chemical analysis of the metal and the mass of the part.

Stage 3: Cooling

- After a metal has been soaked, it must be returned to room temperature to complete the heat-treating process.
- To cool the metal, it can be placed in direct contact with a cooling medium composed of a gas, liquid, solid, or combination of these.
- The rate at which the metal is cooled depends on the metal and the properties desired.
- The rate of cooling also depends on the medium; therefore, the choice of a cooling medium has an important influence on the properties desired.

COMMON METHODS OF HEAT TREATING METALS

- The usual methods of heat-treating ferrous metals (metals with iron) are **annealing**, **normalising**, **hardening**, and **tempering**.
- Most non-ferrous metals can be annealed, but never tempered, normalised, or case-hardened.
- All these types of heat-treating processes are similar because they all involve the heating and cooling of metals.
- They differ in the heating temperatures and the cooling rates used and the final results.

TYPES OF HEAT TREATMENT

- We shall now look at these four basic types of heat treatment used today, namely: **annealing**, **normalising**, **hardening**, and **tempering**.
- We shall look at the techniques used in each process and how they relate to metal working
- Away we go.....!!!

Heat-treating: Annealing

- Annealing is a heat treatment process involving heating and cooling, usually applied to produce softening.
- The temperature of the operation and the rate of cooling depend upon the material being annealed and the purpose of the treatment.
- The term also refers to treatments intended to alter mechanical or physical properties, produce a definite microstructure, or remove gases.

(a) Full Annealing

- Full annealing is a softening process in which a steel is heated to a temperature above the transformation range and, after being held for a sufficient time at this temperature, is cooled slowly to a temperature below the transformation range.
- The steel is ordinarily allowed to cool slowly in the furnace, although it may be removed and cooled in some medium such as mica, lime, or ashes, that insures a slow rate of cooling.
- The temperature range normally used for full annealing is up to 10 °C above the critical line.

Optical view of microstructure of deformed iron at different annealing temperatures;

(A) as cold rolled,

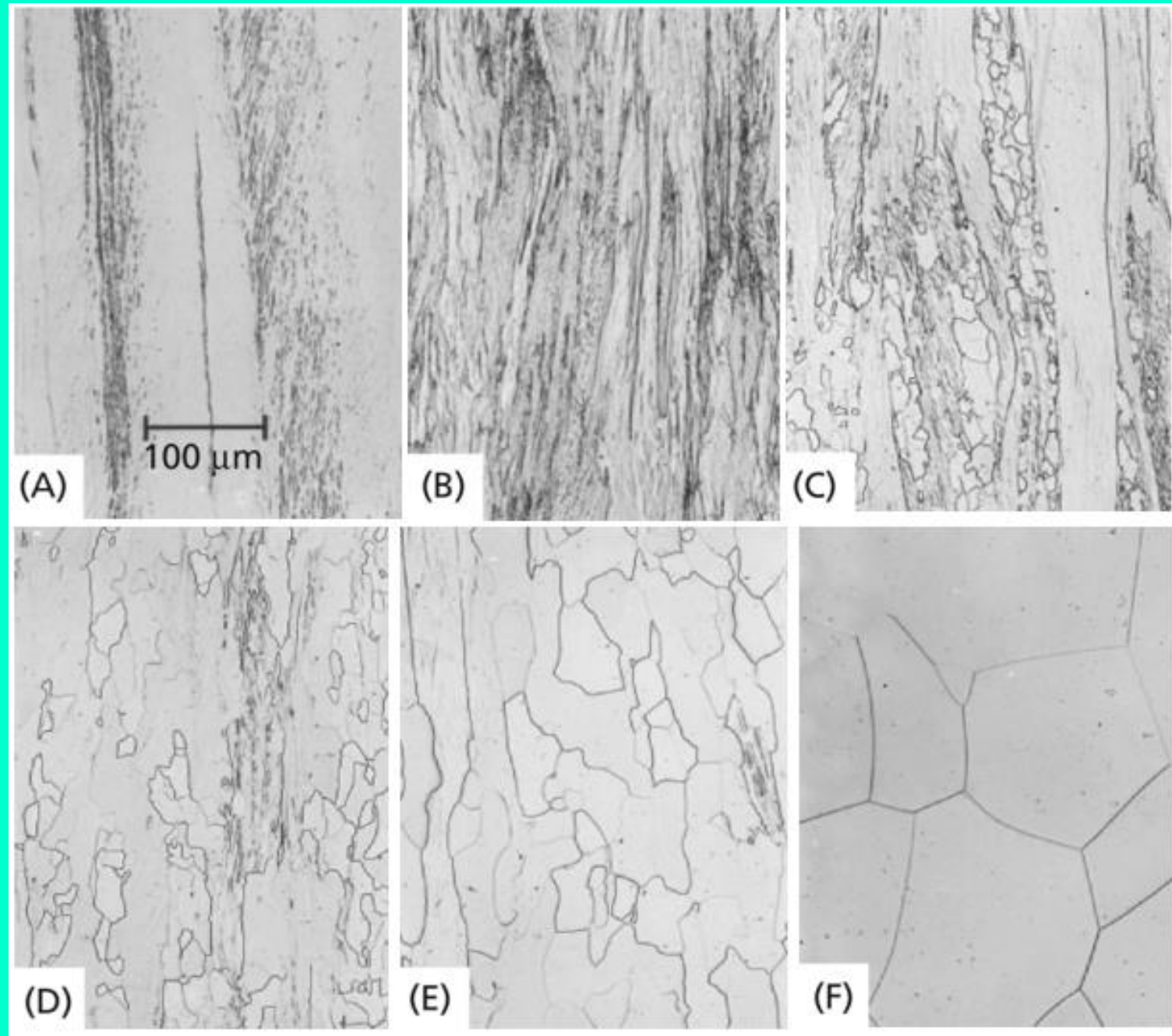
(B) annealed at 300 °C,

(C) annealed at 370 °C,

(D) annealed at 410 °C,

(E) annealed at 460 °C, and

(F) annealed at 650 °C.



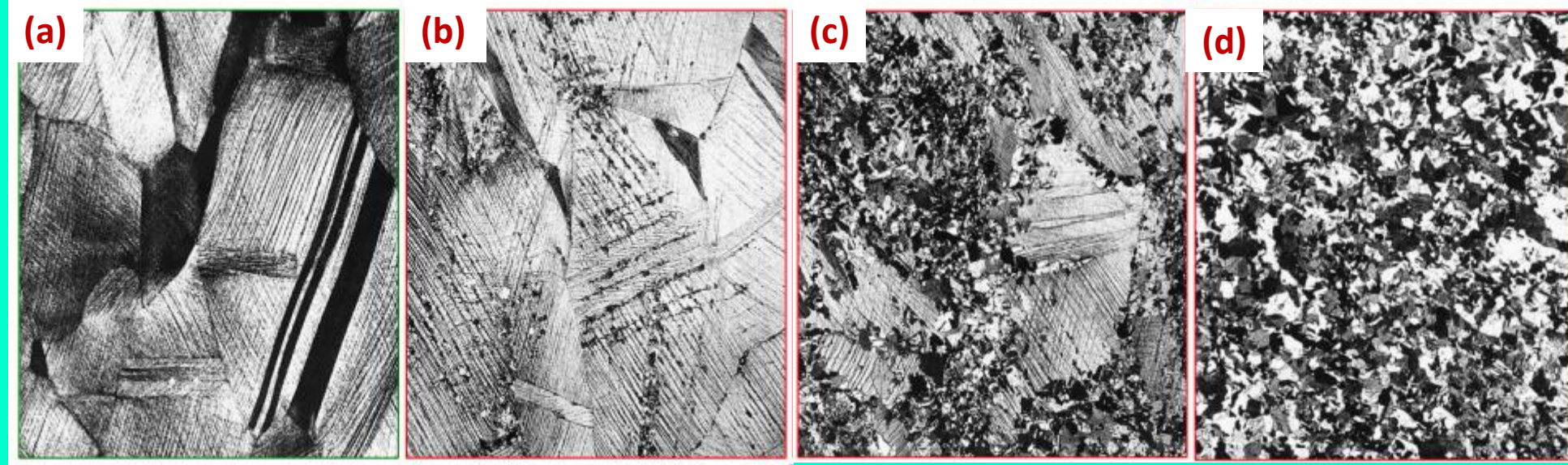
(b) Process Annealing

- Process annealing, frequently termed as stress-relief annealing, is usually applied to cold-worked low carbon steels (up to about 0.25% of carbon) to soften the steel sufficiently to allow further cold-working.
- The steel is usually heated close to, but below, the critical temperature.
- If the steel is not to be further cold-worked, but relief of internal stresses is desired, a lower range of temperature will suffice but the rate of cooling is immaterial.

Process Annealing

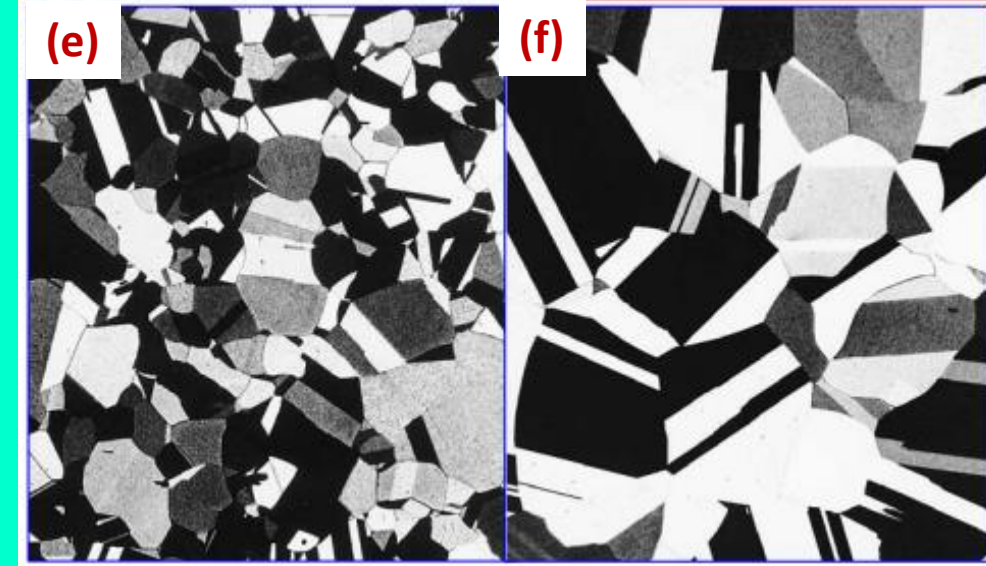
- This type of anneal will cause recrystallisation and softening of the cold-worked ferrite grains, but usually will not affect the relatively small amounts of cold-worked pearlite.

Recrystallisation



Photomicrographs showing several stages of the recrystallisation and grain growth of brass.

- (a) Cold-worked (33% CW) grain structure.
- (b) Initial stage of recrystallisation after heating 3s at 580 °C; the very small grains are those that have recrystallised.
- (c) Partial replacement of cold-worked grains by recrystallised ones (4s at 580 °C).
- (d) Complete recrystallisation (8s at 580 °C).
- (e) Grain growth after 15 min at 580 °C.
- (f) Grain growth after 10 min at 700 °C.



(c) Spheroidising

- Spheroidising is a process of heating and cooling steel that produces a rounded or globular form of carbide in a matrix of ferrite.
- It is usually accomplished by prolonged heating at temperatures just below the critical line, but may be facilitated by alternately heating to temperatures just above the critical line.
- The final step, however, should consist of holding at a temperature just below the critical as the rate of cooling is immaterial after slowly cooling to about 540 °C.

Spheroidising

- This treatment is usually applied to the high carbon steels (0.60% of carbon and higher).
- The purpose of the treatment is to improve machinability and it is also used to condition high-carbon steel for cold-drawing into wire.

Heat-treating: Normalising

- Normalising process is a heat treatment process for making material softer but does not produce the uniform material properties as produced with an annealing process.
- The steel is heated to a temperature above the critical line and then cooled in still air.
- The most common reason for the normalising process is to adjust mechanical properties to suit the service conditions.

- The other purpose of the normalising is:
 1. To relieve the internal stresses,
 2. To refine the grain structure, and
 3. To improve the machinability.
- Normalising involves heating steel to above 50°C above the upper critical (transformation) temperature, (for hypo-eutectoid steel) and to 50°C above the lower critical temperature (for hyper eutectoid steel), i.e. into the complete austenite range.
- The usual normalising temperature ranges from 815°C to 980°C , depending on the steel involved.

- Holding at this temperature for a shorter time to prevent grain growth and finally, cooling in air.
- The time allowed should be sufficient so that the temperature is equalised throughout the section, for complete transformation to austenite, i.e. austenitising of the steel.
- After austenising, the alloy is air-cooled to a temperature substantially below the transformation range.
- The air-cooling avoids excessive proeutectoid segregation. The cooling rate is usually in the range of 500 to 1000 °C/h.

- The structure produced by normalising is similar to that of annealing. But air cooling is faster than furnace cooling. Thus the normalised steels possess finer grains than annealed steels.
- The normalised structure of low-alloy steel consists of sorbite (fine pearlite) and fine ferrite.
- The increased rate of cooling in normalising results in high hardness and low ductility than annealed steel, i.e. machinability will be easy.

- Normalising is mainly to obliterate the effects of any previous heat treatment (including the coarse grained structure sometimes resulting from high forging temperatures) or cold-working and to ensure a homogeneous austenite on reheating for hardening or full annealing.
- It removes the internal stresses induced by heat treating, welding, casting, forging, forming, or machining.
- Normalised steels are harder and stronger than annealed steels

- The final microstructure consists of fine pearlite and an absence of massive proeutectoid ferrite. Normalising is commonly specified for plates of pressure vessel quality above 1½ inch in thickness.

Heat-treating: Hardening

- Steels can be hardened by the simple expedient of heating to above the transformation temperature, holding long enough to insure the attainment of uniform temperature and solution of carbon in the austenite, and then cooling rapidly (quenching).
- The hardening process allows the austenite to transform to martensite. Most alloys require rapid cooling (quenching) for hardening but a few can be air-cooled with the same results.

Hardening

- Hardening increases the hardness and strength of the steel, but makes it less ductile.
- Generally, the harder the alloy, the more brittle it becomes.
- To harden ferrous metals, the metal is rapidly cooled after thoroughly soaking it at a temperature slightly above its upper critical point.

Hardening

- In plain carbon steel, the maximum hardness obtained by heat treatment depends almost entirely on the carbon content of the steel.
- As the carbon content increases, the hardening ability of the steel increases;
- However, this capability of hardening with an increase in carbon content continues only to a certain point.
- In practice, 0.80 percent carbon is required for maximum hardness.

Case-hardening

- Case hardening is a process of hardening a ferrous alloy so that the surface layer or case is made substantially harder than the interior or core.
- The chemical composition of the surface layer is altered during the treatment by the addition of carbon, nitrogen, or both.
- The most frequently used case-hardening processes are carburising, cyaniding, and nitriding.

(a) Carburising

- Carburising is a process that introduces carbon into solid ferrous alloy by heating the metal in contact with a carbonaceous material to a temperature above the transformation temperature of the steel and holding at that temperature.
- The depth of penetration of carbon is dependent on temperature, time at temperature, and the composition of the carburising agent. After carburising, the steel will have a high-carbon case graduating into the low-carbon core.

(b) Cyaniding

- Cyaniding process involves the introduction of both carbon and nitrogen into the surface layers of the steel.
- Steels to be cyanided normally are heated in a molten bath of cyanide-carbonate-chloride salts (usually containing 30 to 95% of sodium cyanide) and then quenched in brine, water, or mineral oil.
- Steels can be cyanided also by heating to the proper temperature and dipping in a powdered cyanide mixture or sprinkling the powder on the steel, followed by quenching.

(c) Nitriding

- The nitriding process involves the action of introducing the steel in a nitrogenous medium, usually ammonia gas, at a temperature of about 500 to 540 °C, whereby a very hard surface is obtained.
- The surface-hardening effect is due to the absorption of nitrogen and subsequent heat treatment of the steel is unnecessary.

Heat-treating: Tempering

- After the hardening treatment is applied, steel is often harder than needed and is too brittle for most practical uses.
- Also, severe internal stresses are set up during the rapid cooling from the hardening temperature.
- To relieve the internal stresses and reduce brittleness, the steel is tempered after it is hardened.

Tempering

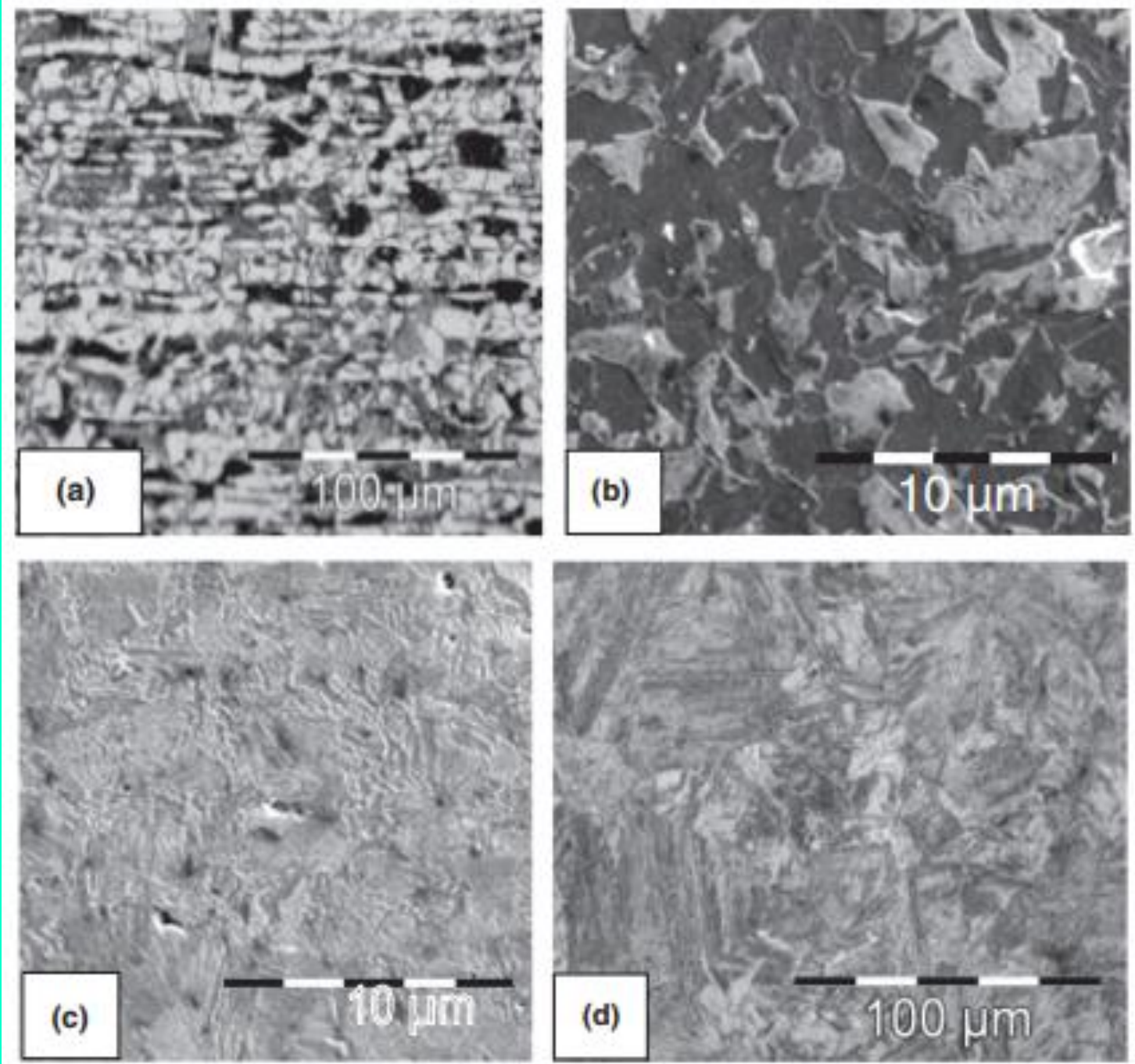
- Tempering (sometimes called drawing) is the process of reheating hardened (martensitic) or normalised steels to some temperature below the lower critical value before cooling.
- Tempering consists of heating the steel to a specific temperature (below its hardening temperature), holding it at that temperature for the required length of time, and then cooling it, usually in still air.

Tempering

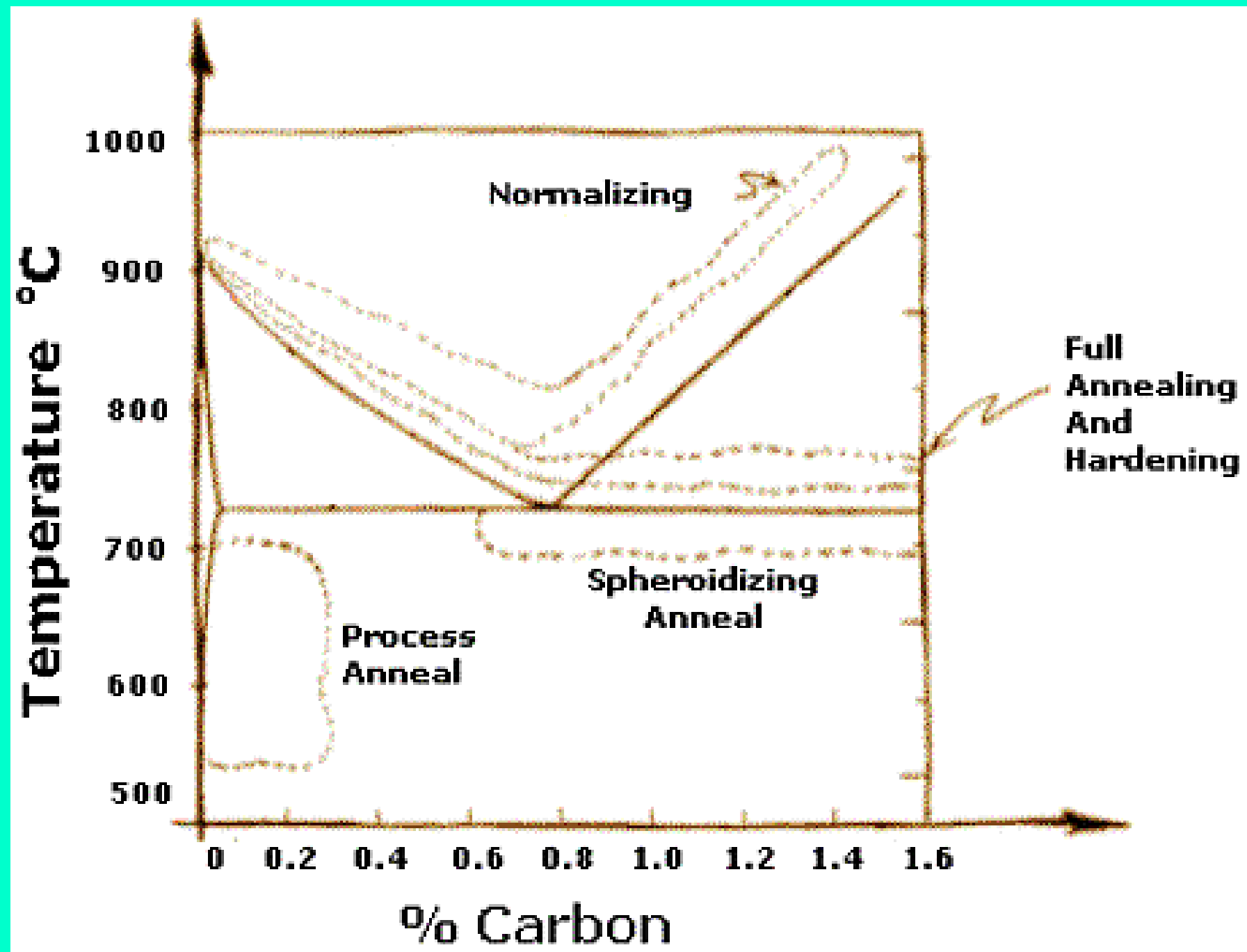
- During tempering process, martensite in hardened steel is gradually changed into a structure consisting of spheroids of cementite in a matrix of ferrite.
- These changes are accompanied by a decreasing hardness and increasing toughness.

Figure 1: Optical micrographs of banded structure of C-Mn-Cr-B steel sample:

- (a) As-received C-Mn-Cr-B steel sample,
- (b) Ferrite-pearlite aggregate of the sample cooled at $1\text{ }^{\circ}\text{C/s}$,
- (c) Bainitic structure of the steel subjected to cooling rate of $10\text{ }^{\circ}\text{C/s}$, and
- (d) Martensitic structure at cooling rate of $20\text{ }^{\circ}\text{C/s}$.



Heat treatment methods and the temperature they are done on the Fe-C phase diagram.



The End