

# METALS

## Heat Treatment

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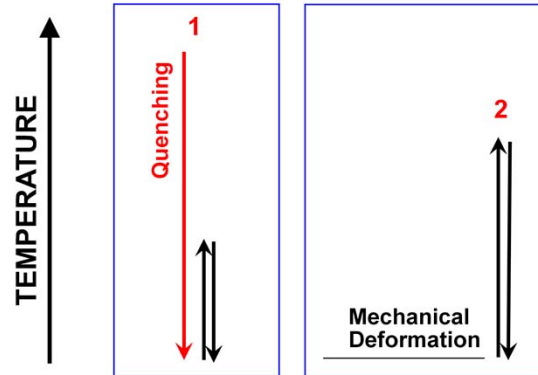


Keep remembering that properties depend on structure – and that we can alter the structure without changing the overall composition. Based on the way we cool materials and reheat them, we can affect the number of phases, types of phases, grain sizes, and grain shapes. All impact the properties. Because we use heat treatments in dentistry, it is important to understand why and when.

# INTRODUCTION

Objectives for heat treatment.

1. Control of phases forming in the microstructure.
2. Recovery from mechanical deformation.



The two main objectives for heat treatment are

- (1) to control the phases that form during solidification, and
- (2) to recover from the effects of mechanical deformation on the grains in the structure.

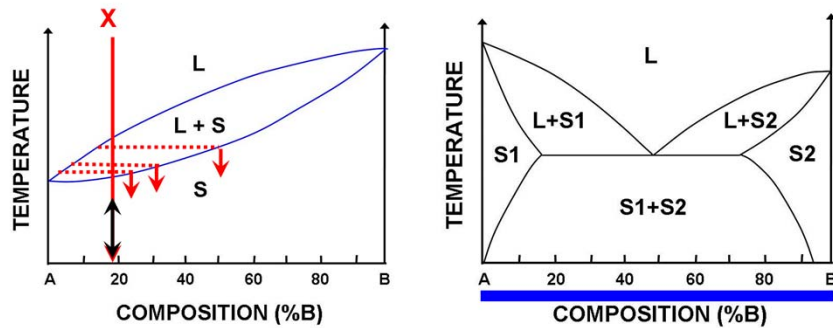
**[CLICK]** In the first case, the rate of cooling (quenching) and subsequent reheating can control the phases that exist.

**[CLICK]** In the second case, grains become deformed during fabrication procedures. They change shapes and become brittle. It is important to recover from those effects.

Now let's look at the details of each.

# CONTROL OF PHASES

Quenching and coring.



Equilibrium phase diagrams are maps of the phases that will exist at different temperatures – and assumes that you have enough time as required to get there. In the real world, often we are cooling too quickly. We may then need to reheat to allow the phases to get to equilibrium ones. Let's look at what this means for a couple of examples on each of the phase diagrams above.

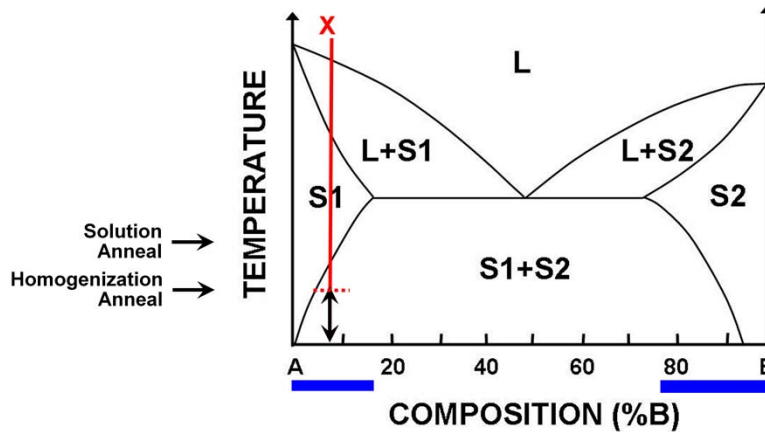
For composition X **[CLICK]**, cool from high temperatures when the system is liquid down to room temperature where the system is solid. (1) What is the overall composition? 81A-19B (2) How many phases are present? Even with fast cooling there is only one solid phase that ever forms. Because there is only one phase, we do not need to use tie lines or the level law in the solid region.

However, there is something else that happens which we are concerned about. Consider the composition as it cools quickly through the L+S region. **[CLICK]** What was the composition of the first solid that formed? You have to use tie lines. It is 49A-51B. **[CLICK]** As you continue to cool to convert half the liquid into solid, what is the average composition of the next solid? It should be 69A-31B. But there has not been time for the first solid to diffuse atoms into the new solid and average things out. The first solid remains at its original composition, and the new solid forms a different compositional layer on top. **[CLICK]** As you get close to 90% conversion to solid, this problem just gets worse. When all the solid is formed, the grains have varying compositions from the inside to the outside. We say the structure is CORED. How do you get rid of this later on? **[CLICK]** You can simply heat up the solid for a short period of time to a temperature in the one phase S region and diffusion will occur to average things back out. At temperatures of 50-100C below the solidus line, this will happen in about 20 minutes.

Where does coring occur on the EUTECTIC DIAGRAM to the right? **[CLICK]** You get coring any time you are cooling quickly through a two phase region that involves at least one solid phase. It occurs for every alloy composition across the diagram but not for the pure components of A or B.

# CONTROL OF PHASES

Annealing.



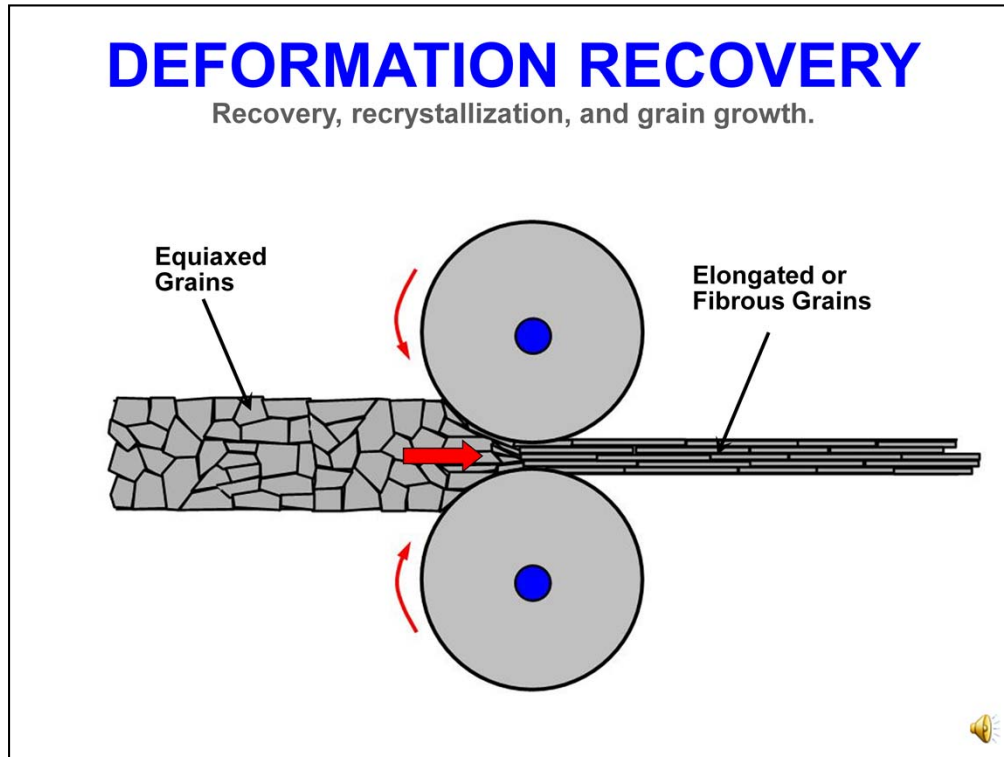
Rapid cooling can also prevent the formation of equilibrium phases altogether for certain composition ranges on the phase diagram. **[CLICK]** Lets look at the edges of the eutectic phase diagram. **[CLICK]** Choose one composition to follow. On rapid cooling it will be cored from going through the L+S1 region quickly. As we continue to cool it quickly down to room temperature, it would like to transform into S1+S2 phases but it does not have enough time to precipitation S2 out of the S1 and re-arrange the atoms to new compositions for the phases. So it remains S1. **[CLICK]** Later on we can get things back to equilibrium conditions – so that coring is eliminated, and the correct compositions and amounts of S1+S2 phases are present. **[CLICK]** We just heat up from room temperature for a short time below the temperature for the transformation. The system will have enough thermal energy to allow the process to happen.

Reheating a material to change its phases is generally called ANNEALING. The specific type depends on the events that are occurring. **[CLICK]** HOMOGENIZATION ANNEALING is heating to remove coring. If you have two phases, heat them up into a single solid phase region, and then quench, you will freeze in the single solid phase. This called a **[CLICK]** SOLUTION ANNEAL. It makes the material softer because there is only 1 phase that has to deform. A TEMPERING ANNEAL could involve a range of types of changes, but generally makes a material more ductile regardless of the mechanisms involved.

Now let's go on to the second major reason for heat treatments – recovery from plastic deformation.

# DEFORMATION RECOVERY

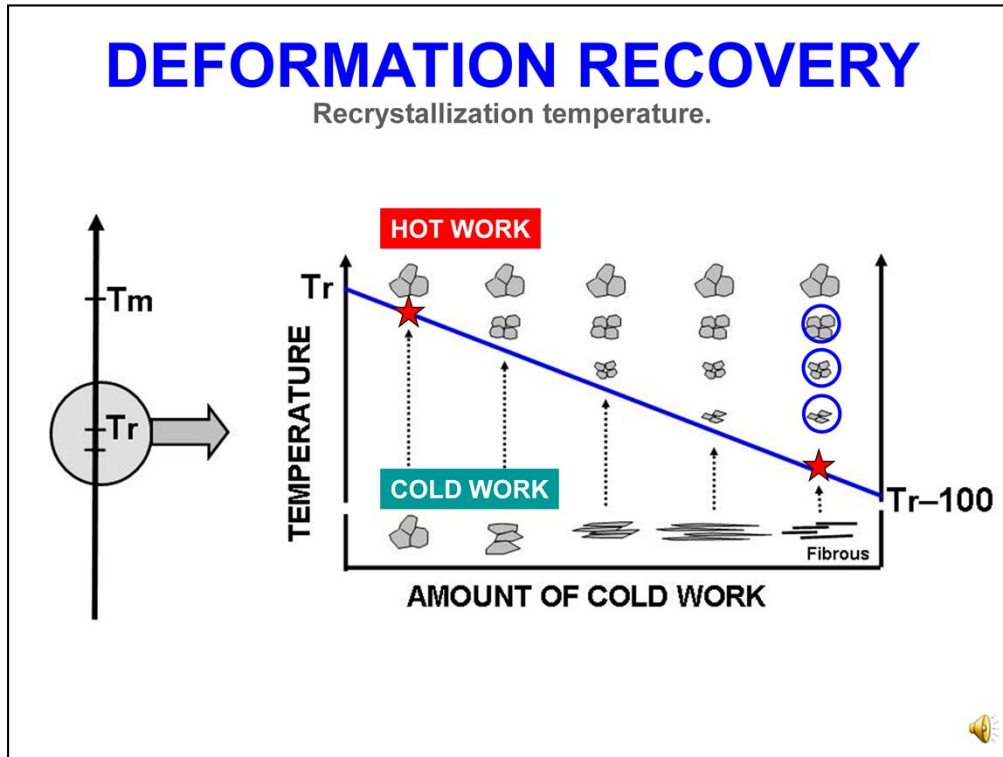
Recovery, recrystallization, and grain growth.



We will use as our model, a set of rolling wheels used to compress a thick sheet down into a much thinner configuration. **[CLICK]** As the metal sheet passes through the rollers, the grains are reshaped from **[CLICK]** EQUIAXED ones into **[CLICK]** ELONGATED or FIBROUS ones. Equiaxed means that the width across the grains is approximately the same in all directions. This is typically the equilibrium shape.

The newly deformed shape has different properties. To deform, many dislocations in the structure had to move – and in the process they became TIED UP around themselves or ran into grain boundaries. As fewer and fewer functional ones remain, the material becomes more and more brittle. This makes further fabrication likely to cause fracture. Therefore, to be able to continue the deformation process, we need to recover and generate new dislocations and potentially reform equiaxed grains again.

If we heat up the material, there is a point at which this happens, called the RECRYSTALLIZATION TEMPERATURE. We just need to get above that temperature. It is approximately 2/3rds of the melting temperature, and often is slightly less than that. It is not an absolute temperature. It depends on the amount of deformation (or WORK) that has been done to the material. More work tends to lower the  $T_r$ .



Let's examine the recrystallization temperature, or  $T_r$ , for different amounts of deformation (or WORK). Follow the blue line. **[CLICK]** At the far right there is lots of deformed structure and the  $T_r$  can be almost 100C lower than the far left with very little work. **[CLICK]** Work below the  $T_r$  is called COLD WORK. **[CLICK]**

When you heat above the  $T_r$ , at first the material RECOVERS **[CLICK]** and generates new dislocations. Next it RECRYSTALLIZES **[CLICK]** by nucleating new grains in the solid state. These continue their **[CLICK]** GROWTH and produce a structure that has properties of the system before deformation. The steps are (1) recovery, (2) recrystallization, and (3) grain growth.

To avoid having to go through recovery, recrystallization, and grain growth all of the time, you can simply heat the material above the  $T_r$  (where it is still solid) and deform it there. **[CLICK]** This is called HOT WORK. It spontaneously goes through the 3 steps. This is what a black smith does when he puts the iron part being shaped into the hot embers to heat it before it is pounded and hot worked.

If you trial seat a cast crown on a working die and bend the margins to get better adaptation, you are COLD WORKING the material. If you do this too much, then the margin becomes very brittle. If you reheat the crown above its  $T_r$  for a short period of time, it will recovery, recrystallize, and grow new grains.

# QUICK REVIEW

Review of heat treatments of metal alloys.

- **What are the 2 major REASONS for heat treatment?**  
(1) CONTROL OF PHASES, and (2) RECOVERY FROM DEFORMATION
- **What are CORED grains?**  
DIFFERENT COMPOSITION FROM INSIDE TO OUTSIDE OF GRAINS.
- **What HEAT TREATMENT removes coring?**  
HOMOGENIZATION ANNEAL
- **What happens on heating to temperatures above the  $T_r$ ?**  
RECOVERY, RECRYSTALLIZATION, GRAIN GROWTH
- **What is the  $T_r$  for an alloy that starts to melt at 1200K?**  
It is approximately 2/3rds the melting temperature or 800K = 527C
- **What is the name for DEFORMATION above  $T_r$ ?**  
HOT WORK



Here is a quick review of the concepts from this module.

**[CLICK]** (1) What are the 2 major REASONS for heat treatment?

**[CLICK]**

**[CLICK]** (2) What are CORED grains?

**[CLICK]**

**[CLICK]** (3) What HEAT TREATMENT removes coring?

**[CLICK]**

**[CLICK]** (4) What happens on heating to temperatures above the  $T_r$ ?

**[CLICK]**

**[CLICK]** (5) What is the  $T_r$  for an alloy that starts to melt at 1200K?

**[CLICK]**

**[CLICK]** (6) What is the name for DEFORMATION above  $T_r$ ?

**[CLICK]**



**THANK YOU**



THANK YOU.