MSE 528 - HEAT TREATMENT OF STEEL

Purpose

The purposes of this experiment are to:

- Investigate the processes of heat treating of steel
- Study hardness testing and its limits
- Examine microstructures of steel in relation to hardness

Background

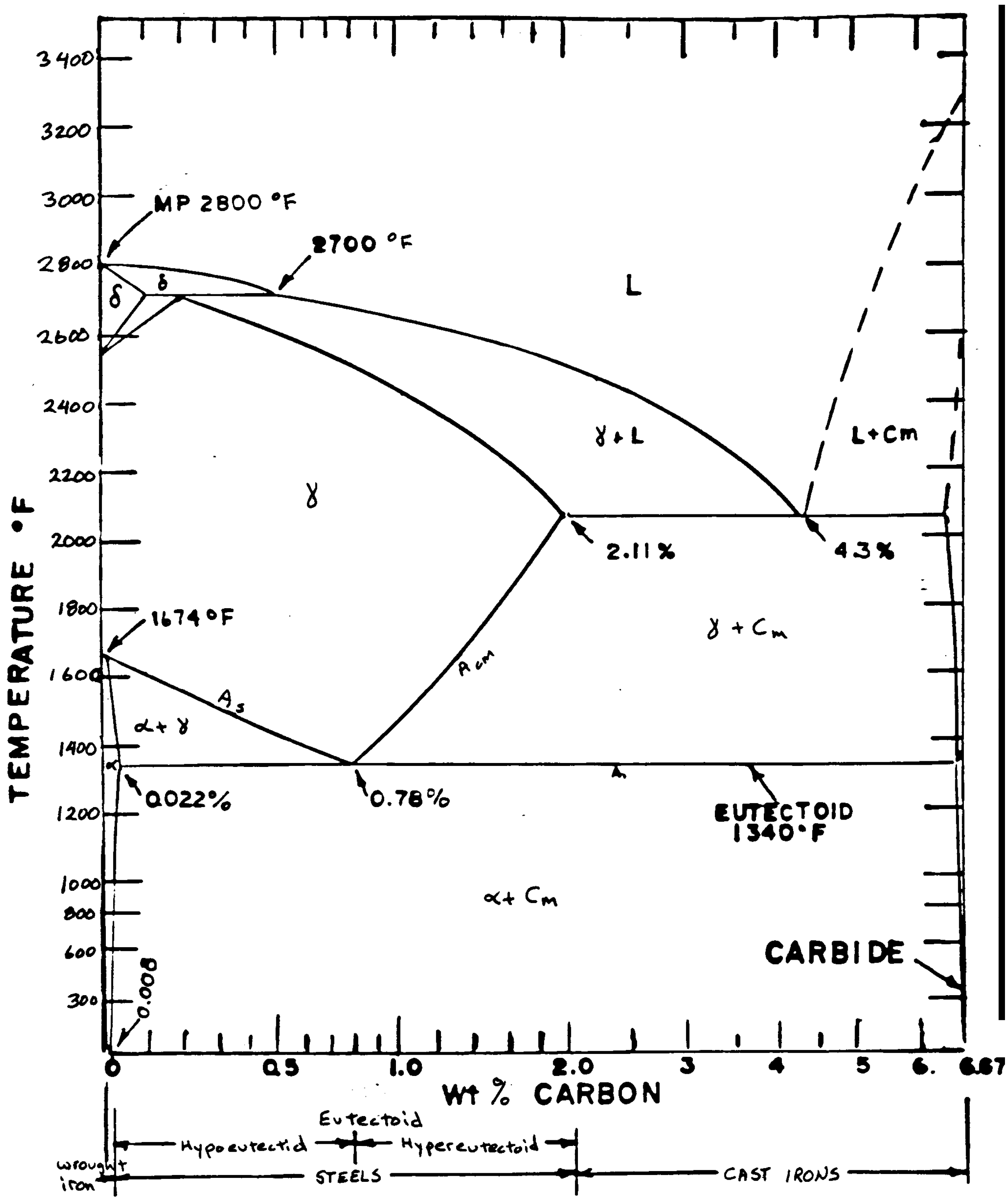
To understand heat treatment of steels requires an ability to understand the Fe-C phase diagram shown in Figure 6-1. Steel with a 0.78 wt% C is said to be a **eutectoid** steel. Steel with carbon content less than 0.78 wt% C is **hypoeutectoid** and greater than 0.78 wt% C is **hypereutectoid**. The region marked austenite is face-centered-cubic (FCC) and ferrite is body-centered-cubic (BCC).

There are also regions that have two phases. If one cools a hypoeutectoid steel from a point in the austenite region, reaching the A_3 line, ferrite will form from the austenite. This ferrite is called **proeutectoid** ferrite. When A_1 is reached, a mixture of ferrite and iron carbide (cementite) forms from the remaining austenite. The microstructure of a hypoeutectoid steel upon cooling would contain proeutectoid ferrite plus pearlite (α+ Fe_3C).

The size, type and distribution of phases present can be altered by not waiting for thermodynamic equilibrium. Steels are often cooled so rapidly that metastable phases appear. One such phase is **martensite**, which is a body-centered tetragonal (BCT) phase and forms only by very rapid cooling.

Much of the information on non-equilibrium distribution, size and type of phases has come from experiments. The results are presented in a time-temperature-transformation (TTT) diagram shown in Figure 6-2. As a sample is cooled, the temperature will decrease as shown in curve #1. At point A, pearlite (a mixture of ferrite and cementite) will start to form from austenite. At the time and temperature associated with point B, the austenite will have completely transformed to pearlite. There are many possible paths through the pearlite regions. Slower cooling causes coarse Pearlite, while fast cooling causes fine pearlite to form.

Cooling can produce other phases. If a specimen were cooled at a rate corresponding to curve #2 in Figure 6-3, martensite, instead of Pearlite, would begin to form at M_s temperature (point C), and the pearlite would be completely transformed to martensite at temperature M_s. Martensite causes increased hardness in steels.



α = ferrite (BCC iron) δ = delta ferrite (BCC iron)

γ = austenite (FCC iron) Fe_3C = iron carbide = cementite (orthorhombic)

Figure 6-1. Iron - Carbon Phase Diagram

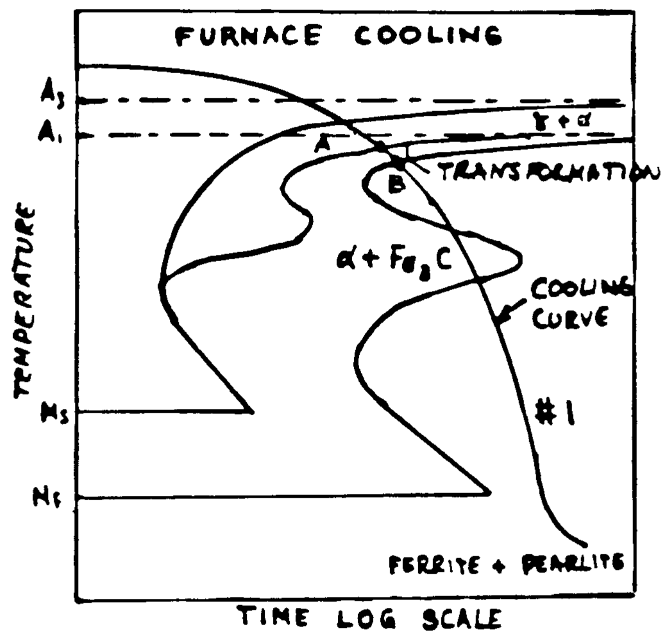


Figure 6-2. Typical TTT Curve for a Steel

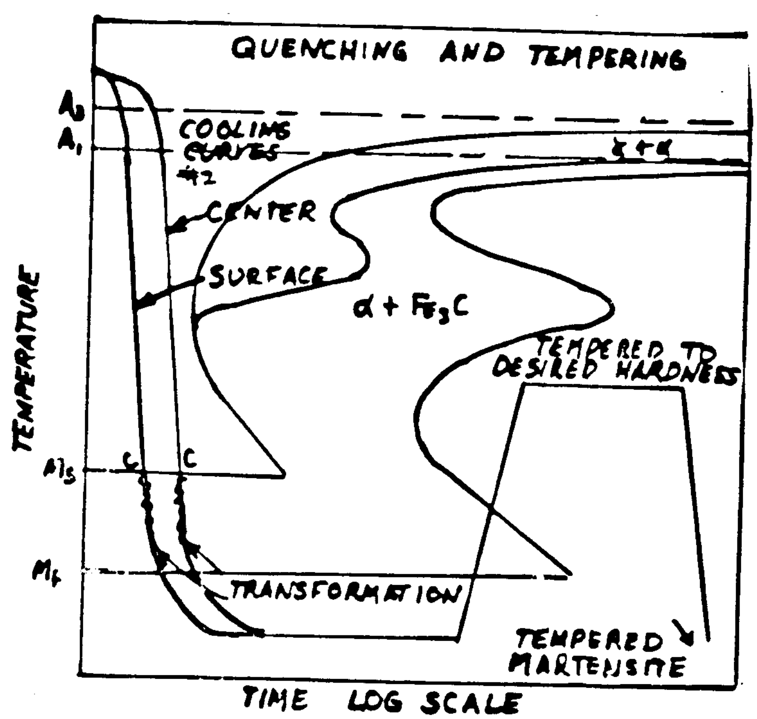


Figure 6-3. Non-Equilibrium Cooling to Obtain Martensite

Unfortunately, hardness in steels also produces brittleness. The brittleness is usually associated with low impact energy and low toughness. To restore some of the toughness and impact properties it is frequently necessary to "temper" or "draw" the steels. This is accomplished by heating the steel to a temperature between 500°F (260°C) and 1000°F (540°C). Tempering removes some of the internal stresses and introduces recovery processes in the steel without a large decrease in hardness or strength.

To obtain the desired mechanical properties it is necessary to cool steel from the proper temperature at the proper rates and temper them at the proper temperature and time. Isothermal transformation diagrams for SAE 1045 steel are shown in Figure 6-4.

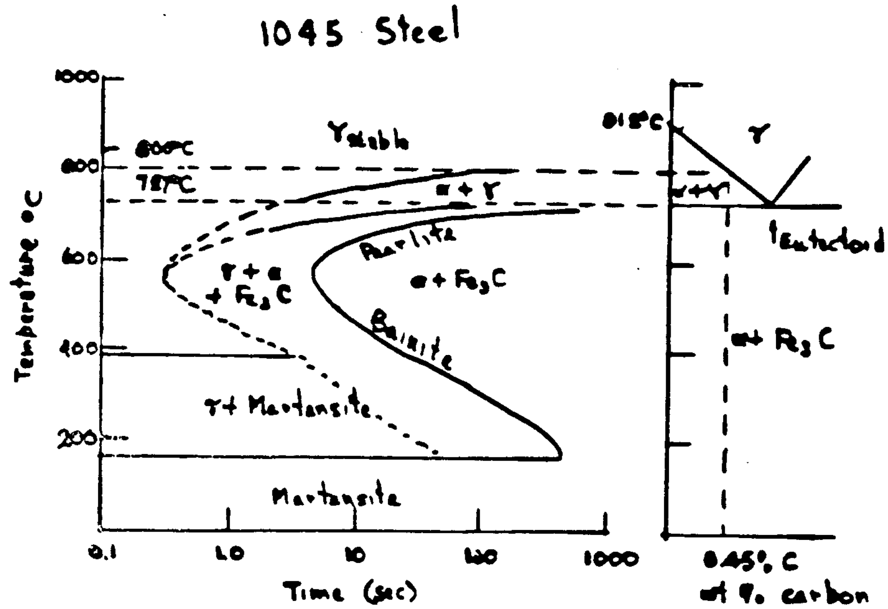


Figure 6-4. TTT Curve for 1045 Steel

Heat Treatment of Steels

Common steels, which are really solid solutions of carbon in iron, are body-centered-cubic. However, the carbon has a low solubility in bcc iron and precipitates as iron carbide when steel is cooled from 1600°F (870°C). The processes of precipitation can be altered by adjusting the cooling rate. This changes the distribution and size of the carbide which forms a laminar structure called pearlite during slow cooling processes.

If a steel is quenched into water or oil from 1600°F (870°C) a metastable phase called martensite forms, which is body-centered-tetragonal. This phase sets up large internal stresses and prevents carbide from forming. The internal stresses produce a high hardness and unfortunately, low toughness. After cooling, to restore toughness, steels are tempered by reheating them to a lower temperature around 800°F (426°C) and cooling. The tempering relieves the internal stresses and also allows some iron carbide to form. It also restores ductility.

Procedure

You are provided with **6 specimens of SAE 1045 steel** for your study. **Measure the hardness of all specimens using the R_A scale.**

1. Heat four specimens in one furnace at 1600 $\pm$ 25°F (**870 $\pm$ 15°C**) for 1/2 hour.
2. Put the other 2 specimens in a separate furnace at the same temperature for 1/2 hour.
3. Remove one specimen from the furnace with 2 specimens and cool it in air on a brick.
4. Turn off the furnace with the one remaining specimen. Allow the sample to remain in the furnace for one hour. The **air-cooled** and **furnace-cooled** specimens can be cooled in water after one hour. **Why?** *(Answer this in your write up)*.
5. Remove the **four specimens** and quickly drop them into **water**; the transfer should take less than one second. A little rehearsal could help. Be careful not to touch the specimens before they are cooled in water.
6. Measure Rockwell hardness of the quenched specimens before the next step.
7. Temper 1 each of the quenched specimens for 30 minutes at 600°F (315°C), 800°F (430°C), and 1000°F (540°C). After tempering, the specimens can be cooled in water.
8. Measure hardness of <u>all 6 samples</u> using the **Brinell (3000 kg) and Rockwell A** or C scales.

Data Analysis

1. If more than one impression is made per sample, a**verage the Brinell diameters** for each specimen.
2. **Compute the Brinell hardness numbers** and compare with the numbers read from a conversion chart for Rockwell A or C to Brinell.
3. Graph BHN (x-axis) versus Rockwell Hardness numbers (y-axis).
4. Graph Rockwell A or C hardness vs. tempering temperature (°C).
5. Compute the ultimate tensile strength (psi) of all specimens from the average BHN for each specimen using:

$$\sigma_{ult} = 500 \times \text{B.H.N.}$$

Write Up

Prepare a memo report that includes the following information.

Memo Report includes:
1. Discuss why the air-cooled and furnace-cooled specimens can be quenched in water after one hour.
2. Compare Brinell numbers (BHN) found from measured diameters with a **conversion chart** for Rockwell A or C (6 specimens). Go to a website or reference book to find this information; include this data in your tables.
3. Include tables (results and data measured) for BHN and R_A. Be sure to include measured values from Omnimet computer software.

4.	**Graph** BHN (x-axis) vs. Rockwell A or C (y-axis).
5.	**Graph** Rockwell A or C hardness vs. tempering temp.
6.	Calculate σ_{ult} for all specimens from the average BHN for each specimen.
7.	What is the purpose of quenching and tempering steel.
8.	Discuss the sources of error for the various hardness testers; compare consistency of test results and accuracy (Rockwell vs Brinell). Which hardness test appears to be most accurate?
9.	Discuss factors that probably contributed to the scatter in the hardness data and errors in the experiment (their sources)
10.	Using the inverse lever law, calculate the amount of carbide (Fe_3C) present at 1338^{o}F for SAE 1045. Use the phase diagram included in the lab description and show calculations.
11.	Discuss the expected microstructure for each heat treatment process.
12.	Discuss the correlation between microstructure and hardness.

Glossary of Terms
Understanding the following terms will aid in understanding this experiment.

Austenite. Face-centered cubic ( ) phase of iron or steel.

Austenitizing. Temperature where homogeneous austenite can form. Austenitizing is the first step in most of the heat treatments for steel and cast irons.

Annealing (steel). A heat treatment used to produce a soft, coarse pearlite in a steel by austenitizing, then furnace cooling.

Bainite. A two-phase micro-constituent, containing a fine needle-like microstructure of ferrite and cementite that forms in steels that are isothermally transformed at relatively low temperatures.

Body-centered cubic. Common atomic arrangement for metals consisting of eight atoms sitting on the corners of a cube and a ninth atom at the cubes center.

Cementite. The hard brittle intermetallic compound Fe_3C that when properly dispersed provides the strengthening in steels.

Eutectoid. A three-phase reaction in which one solid phase transforms to two different solid phases.

Face-centered cubic. Common atomic arrangement for metals consisting of eight atoms sitting on the corners of a cube and six additional atoms sitting in the center of each face of the cube.

Ferrite. Ferrous alloy based on the bcc structure of pure iron at room temperature.

Hypereutectoid. Composition greater than that of the eutectoid.

Hypoeutectoid. Composition less than that of the eutectoid.

Martensite. The metastable iron-carbon solid solution phase with an acicular, or needle like, microstructure produced by a diffusionless transformation associated with the quenching of austenite.

Normalizing. A simple heat treatment obtained by austenitizing and air cooling to produce a fine pearlite structure.

Pearlite. A two-phase lamellar micro-constituent, containing ferrite and cementite, that forms in steels that are cooled in a normal fashion or are isothermally transformed at relatively high temperatures.

Tempered martensite. The mixture of ferrite and cementite formed when martensite is tempered.

Tempering. A low-temperature heat treatment used to reduce the hardness of martensite by permitting the martensite to begin to decompose to the equilibrium phases.

References

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