MSE 528 - HARDENABILITY OF STEELS

Purpose
This experiment is aimed at understanding the effect of cooling rate on the hardness of two steels. The experiment also shows why adding alloying elements other than carbon enables a part to be heat-treated more uniformly and to a greater depth.

Background
The background for **heat treatment of steels** describes why the rate of cooling affects hardness but it does not explain why some parts that are heat-treated do not reach a high hardness. This problem, which is very real, is not well understood by the average engineer.

In a practical sense it is not possible to heat-treat all parts to the same degree. The difference is due to the thickness or volume effect. Basically, when a part is quenched in water or some other fluid, the heat must be conducted out through the surface. This leads to a temperature gradient dt/dx between the surface and the center of the part being heat-treated. The temperature gradient varies with time.

The temperature gradient is less steep between the center and the edge at later times. Therefore, the temperature of the center lags in time behind the temperature of the surface. If we were to plot a time profile of the center and the edge temperatures as shown in Figure 7-1, the time to reach a given temperature T_2 is definitely longer in the center than at the edge. This means that cooling rate varies as a function of depth. The greater the depth the slower the cooling rate.

The situation with respect to the cooling rate can lead to a different hardness in the center than at the edge. The edge could transform to martensite and the center to pearlite or bainite.

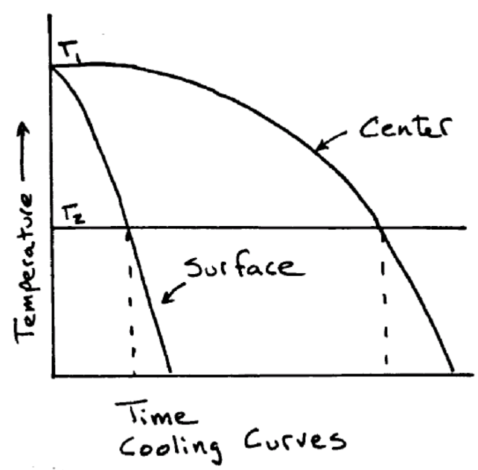

Fig. 7-1
Cooling Curves for the Surface and Center of a Quenched Specimen

In selecting a steel, the ability to cool the center depends upon the thickness of the part. The thicker the part, the slower the cooling rate at the center. For a given thickness, one must select a steel that can be hardened in the center if that is desired. The cooling rate in this case is fixed. The center part of steel can be hardened by shifting the time-temperature-transformation diagram through alloying. Figure 7-2 shows that alloying elements added to plain carbon steel can shift the nose of the TTT curve to longer times and raise the M_s temperature. This means a slower cooling rate can be used to reach the martensitic state. A slower cooling rate means a thicker part can be heat-treated.

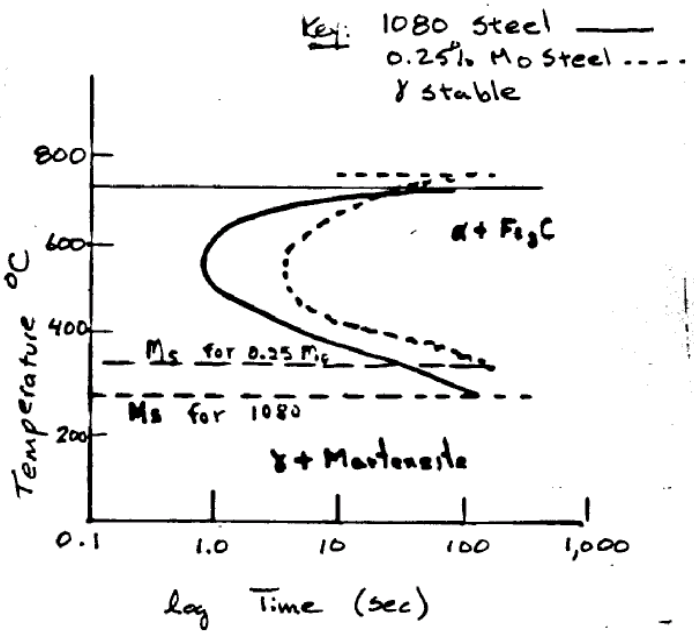

Fig. 7-2
Time-Temperature-Transformation Chart for Two Steels

To obtain standardized data on the hardness of steels as functions of cooling rates, the Jominy End Quench test was developed. In the test, water is sprayed on one end of a bar of steel while it is hot. This leads to a one dimensional heat transfer cooling. Except near the surface of the bar the temperature is controlled by heat flow along the length of the bar (like thickness in the part).

Moving axially away from the quenched end of the bar, the temperature and the rate of change of temperature are changing. The temperature is higher and the cooling rate is lower. If surface hardness is measured as a function of distance from the end, a hardness profile can be obtained which applies to any part made from the same steel, as shown in Figure 7-3.

<u>Procedure</u>
You will be given two steels: (type 1045) and a low-alloy steel (type 4143). Before heating the specimens, practice mounting the specimens in the rack and adjusting the water flow to spray the end of the specimens.

Stamp each specimen for identification and measure the hardness on the **Rockwell A** scale. Check to make sure the fork is secure and put the specimen in the furnace at 1600 $\pm$ 25°F (870 $\pm$ 45°C) for 45 minutes. While you are waiting for the specimens, examine the microstructure of the alloy steel and carbon steel specimens provided by your instructor. At the end of the austenitizing treatment above remove one specimen and carefully, but rapidly, place the specimen in the holder with the water turned on.

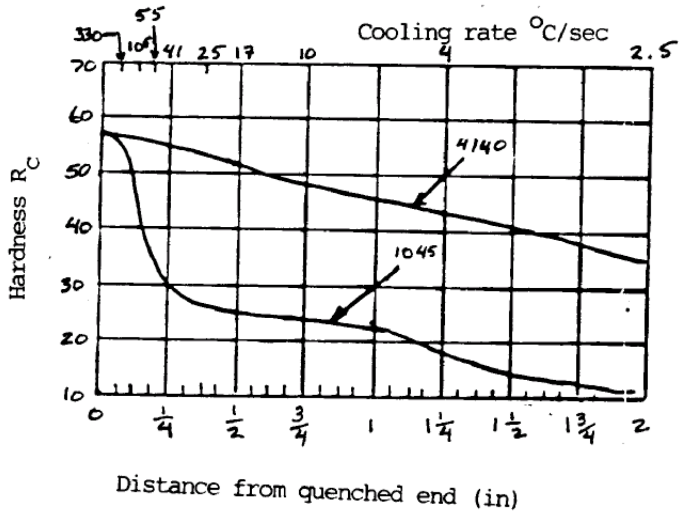

Fig. 7-3
Hardness as a Function of Distance from Quenched End for Two Steels

<u>Methods of Test</u>

The standard method for the Jominy test is ASTM - A255. The test consists of austenitizing at 50˚F (90˚C) above the solvus line on the Fe-C phase diagram that separates γ from $\gamma + \alpha$. The specimen is then removed from the furnace and is placed in the cooling tower. The time spent transferring the specimen from the furnace to the fixture should not be more than 5 sec. The fixture is constructed so that the specimen is held 1/2 inch above the water opening with the column of water directed only at the bottom of the bar. The water opening is 1/2 inch in diameter and the flow adjusted to cause the column to rise 2-1/2 inches without the specimen in place. The test piece is held in the fixture for 10 minutes before quenching in cold water.

After cooling, **one flat surface 0.025 inches deep is ground along the length** of the bar. **Rockwell A** hardness measurements are taken every **1/16 inch for the first inch** and every **1/8 for the next inch** and **1/4 for the next 2 inches**. After hardness measurements are completed, the results should be compared to the New Metals Handbook (Vol. 1)

Glossary of Terms

Understanding the following terms will aid in understanding this experiment.

Hardenability. The ease with which a steel can be quenched to form martensite. Steels with high hardenability form martensite even on slow cooling.

Hardenability curves. Graphs showing the effect of cooling rate on the hardness of a steel.

Jominy test. The test used to evaluate hardenability. An austenitized steel bar is quenched at one end only, thus producing a range of cooling rates along the bar.

Quenching. Rapidly cooling a material to some lower temperature by immersion in a liquid bath or gaseous stream. For example quenching steel in a pail of water.

Temperature gradient. A difference in temperature across some distance, for example between one end of the Jominy bar and the other.

Lab book

In Excel, p**lot the hardness as a function of distance from the quenched end** for both alloys; overlay the curves on the same graph. Discuss the effects of alloying on hardenability. Discuss the shift in the TTT curve due to alloying. Include these in your lab book.

References

ASM Vol. 1, Properties of Iron and Steel, 1977.

D. Callister Jr, Fundamentals of Materials Science and Engineering, J. Wiley & Sons, NY, 3rd Ed. 2008.

Flinn and Trojan, Engineering Materials and Their Applications, Chapter 6