

Isothermal Heat Treatments and TTT Diagrams

Isothermal Heat Treatment

Isothermal heat treatment involves rapidly cooling steel to a specific temperature below the austenite region, holding it until transformation is complete, and then cooling to room temperature. This approach produces more uniform microstructures than continuous cooling.

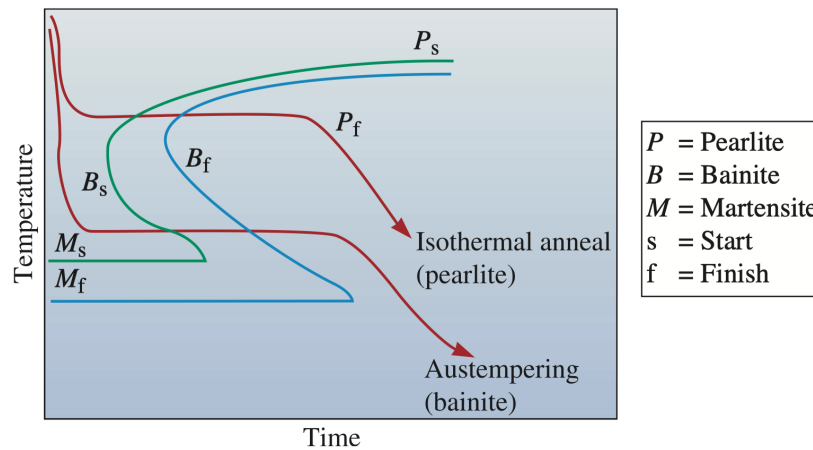


Figure 1. The austempering and isothermal annealing heat treatments in 1080 steel. (Adapted from Askeland & Wright, 2016).

Time-Temperature-Transformation (TTT) Diagrams

TTT diagrams represent the start and finish times of phase transformations in steels under constant (isothermal) temperatures. They help in visualizing transformation behavior of austenite over time.

- X-axis: logarithmic time (s).
- Y-axis: temperature (°C).
- Shows curves for start and end of transformations like pearlite and bainite.

Microstructures from TTT Transformations

- **Pearlite**: Forms at higher transformation temperatures; slow diffusion.
- **Bainite**: Forms below the 'nose' of the TTT curve; faster cooling required.
- **Martensite**: Non-diffusional shear transformation below M_s temperature; hard and brittle.

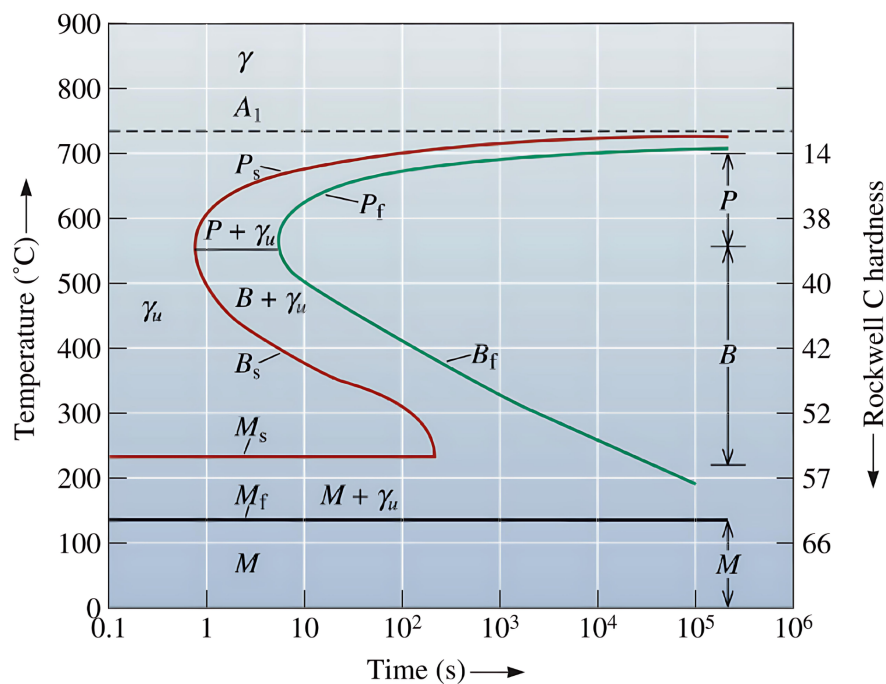


Figure 2. The time-temperature-transformation (TTT) diagram for a eutectoid steel, where P = Pearlite, B = Bainite, and M = Martensite. The subscripts “s” and “f” indicate the start and finish of a transformation. γ_u is unstable austenite. (Adapted from Askeland & Wright, 2016).

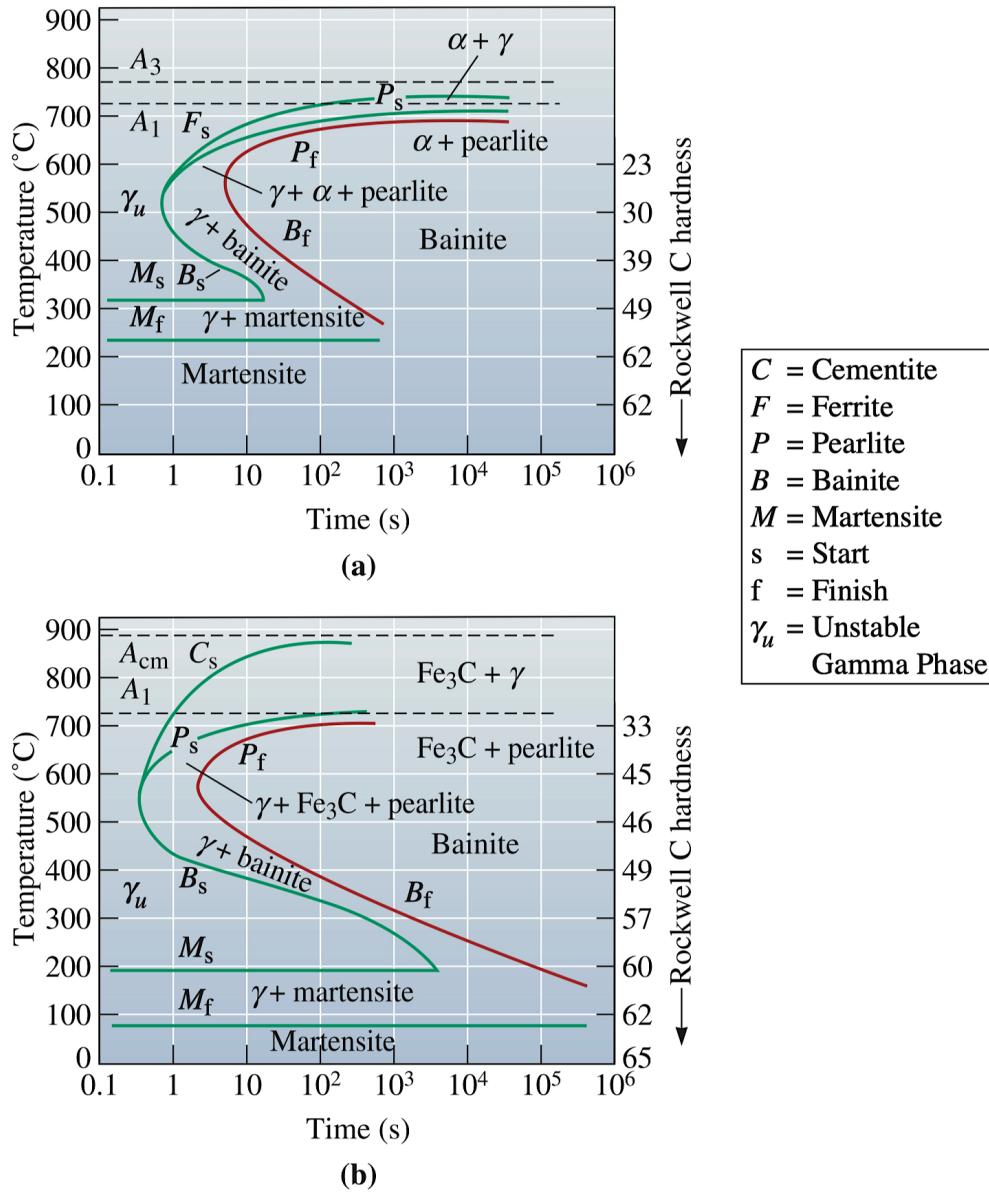


Figure 3. The TTT diagrams for (a) a 1050 and (b) a 10110 steel. Note unstable austenite. (Adapted from Askeland & Wright, 2016).

Austempering and Martempering

- **Austempering**: Austenitize → Quench to bainitic region → Hold → Cool to room temp.
- Produces bainite: high strength and toughness, less distortion.
- **Martempering**: Austenitize → Quench just above M_s → Equalize temp → Cool through martensitic range.
- Minimizes cracking and distortion.

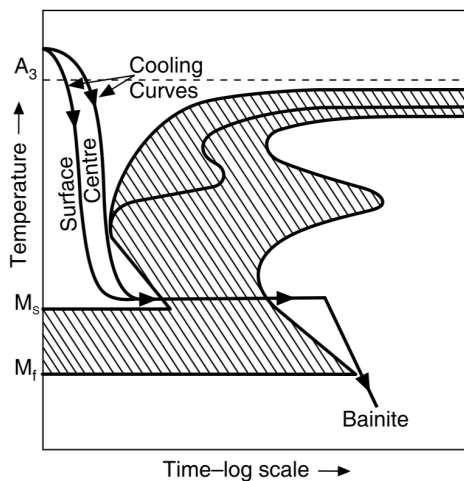


Figure 4. Austempering

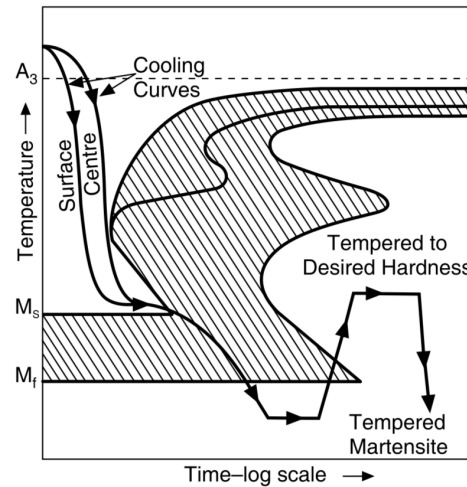
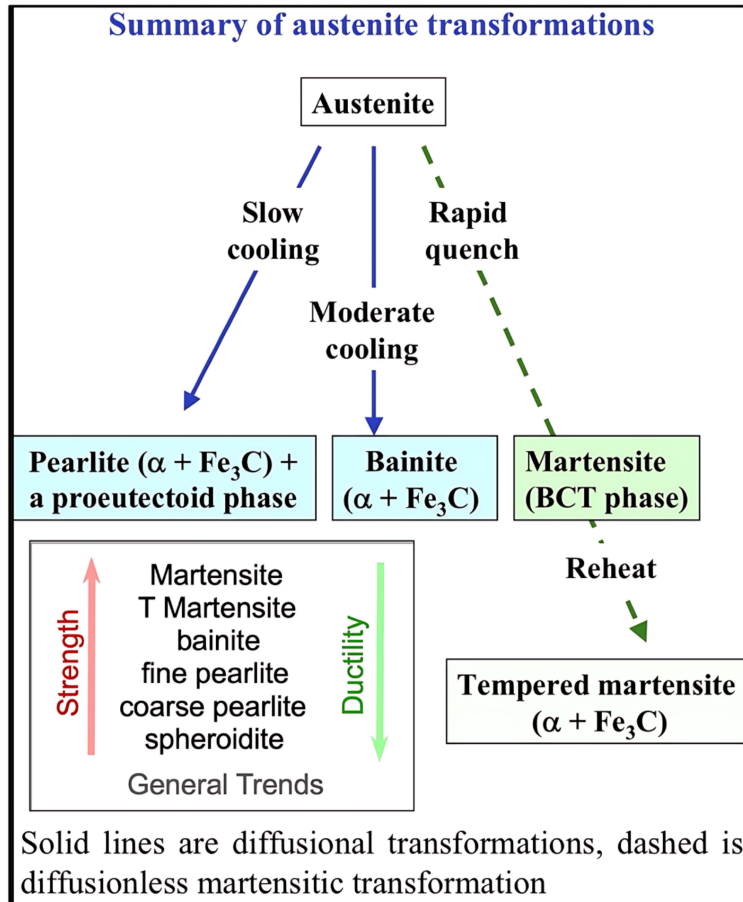


Figure 5. Martempering

Comparison of Isothermal Products

- **Pearlite**: Moderate hardness and ductility; lamellar structure.
- **Bainite**: Acicular structure; higher toughness than pearlite.
- **Martensite**: Hardest phase; requires tempering for ductility.



Summary

Isothermal heat treatments are valuable tools for controlling steel microstructures. TTT diagrams serve as essential references for selecting appropriate temperatures and times. Processes like austempering and martempering offer advantages in reducing distortion while achieving desired properties.

A heat treatment is needed to produce a uniform microstructure and hardness of HRC 23 in a 1050 steel axle.

SOLUTION

We might attempt this task in several ways. We could austenitize the steel, then cool at an appropriate rate by annealing or normalizing to obtain the correct hardness. By doing this, however, we find that the structure and hardness vary from the surface to the center of the axle.

A better approach is to use an isothermal heat treatment. From Figure 13-7, we find that a hardness of HRC 23 is obtained by transforming austenite to a mixture

of ferrite and pearlite at 600°C. From Figure 13-1, we find that the A_3 temperature is 770°C. Therefore, our heat treatment is

1. Austenitize the steel at $770 + (30 \text{ to } 55) = 800^\circ\text{C}$ to 825°C , holding for 1 h and obtaining 100% γ .

2. Quench the steel to 600°C and hold for a minimum of 10 s. Primary ferrite begins to precipitate from the unstable austenite after about 1.0 s. After 1.5 s, pearlite begins to grow, and the austenite is completely transformed to ferrite and pearlite after about 10 s. After this treatment, the microconstituents present are

$$\text{Primary } \alpha = \left[\frac{(0.77 - 0.5)}{(0.77 - 0.218)} \right] \times 100 = 36\%$$

$$\text{Pearlite} = \left[\frac{(0.5 - 0.0218)}{(0.77 - 0.0218)} \right] \times 100 = 64\%$$

3. Cool in air to room temperature, preserving the equilibrium amounts of primary ferrite and pearlite. The microstructure and hardness are uniform because of the isothermal anneal.

Interrupting Isothermal Transformations

Complicated microstructures can be created by changing the temperature during isothermal holding, a method known as interrupted isothermal transformation.

For example, consider 1050 steel austenitized at 800 °C:

- First, quench to 650 °C and hold for 10 seconds → ferrite + pearlite begin to form.

- Then quench to 350 °C and hold for 1 hour → remaining austenite transforms to bainite.

- Final microstructure: ferrite + pearlite + bainite.

If the process is stopped after 1 minute at 350 °C and then quenched

- Untransformed austenite converts to martensite, resulting in a complex microstructure:

ferrite + pearlite + bainite + martensite.

Note: Each change in temperature resets the transformation time on the TTT diagram. In practice, transitions are not instantaneous, which is why Continuous Cooling Transformation (CCT) diagrams offer more practical insights for real-world applications.

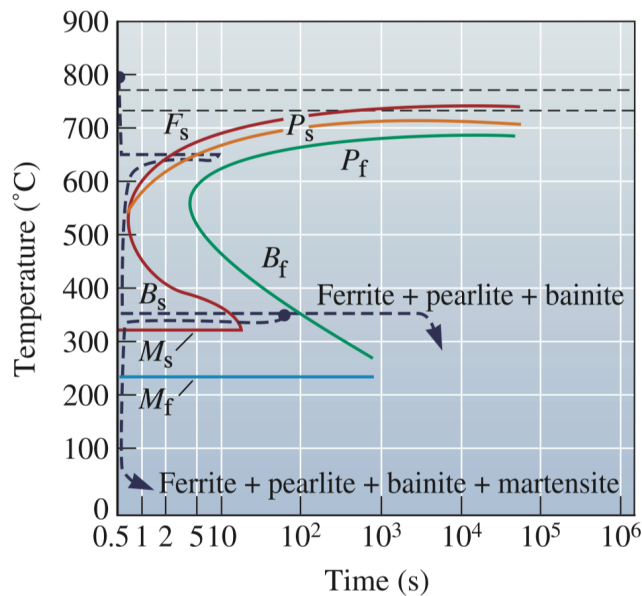


Figure 6. Producing complicated structures by interrupting the isothermal heat treatment of a 1050 steel.

Practice Problems: Time-Temperature-Transformation (TTT)

- Conceptual Questions:

1. A TTT diagram for eutectoid steel shows pearlite forming at $\sim 700^{\circ}\text{C}$ and bainite at $\sim 500^{\circ}\text{C}$.

Q: What would be the likely microstructure if the steel is held at 600°C for 30 minutes?

2. Explain how a TTT diagram is used to design an austempering process.

- Problem Examples:

3. Given: Austenitize at 850°C \rightarrow Quench to 650°C \rightarrow Hold 1 min \rightarrow Quench to room temp.

Q: Sketch the transformation path on a typical TTT diagram. Identify resulting microstructure.

4. A 1080 steel is cooled to 400°C . The TTT diagram shows that bainite starts forming after 30 s.

Q: What must be the minimum cooling time to avoid bainite formation?

Industrial Case Study: Unintended Bainite Formation

Case: Heat-treated steel components were designed to form fine pearlite for balanced strength and toughness but became unexpectedly brittle after heat treatment.

Cause: The isothermal holding temperature and time intersected the bainite region of the TTT diagram instead of the pearlite region, leading to bainitic transformation.

Lesson: Holding temperature and time, not just heat treatment type, determine the final phase and mechanical properties.