Lab Experiment # 8

Quenching and Tempering of Steel

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Objective

The goal of the quenching and tempering of steel lab is to observe effects of the entire heat treatment process on the mechanical properties (hardness) and microstructures of a eutectoid steels. Hardness level will be observed on each step of the process to observe changes as well as the effects of different tempering temperature to observe optimal level to achieve required hardness levels.

Equipment/Materials

- Furnace
- Rockwell hardness tester
- 5 Steel Specimen (AISI 1095 Steel)

Experimental Procedure

1. Cut the AISI 1095 Steel into 5 specimens. And perform hardness test of each specimen and take average of all the measurements.
2. Setting one of the specimens aside, place the other specimens in the furnace at 830 degrees Celsius for around 45 minutes after temperature becomes steady
3. Quickly drop each specimen into large container of 2-4 liters of water for the quenching stage.
4. Measure the hardness of each of the specimen after quenching and take the average. Set one specimen aside.
5. Place the remaining 3 specimen into three resistance furnaces at 205, 360 and 540 degrees Celsius for around 45 minutes. Allow to cool after.
6. Measure the hardness of each of the remaining three specimens.
7. Compare the hardness change for the three different.

Experimental Results

	Rockwell hardness (HRC)
Non-heat treated	**20**
Quenched	**60**
Tempered (205^{o} C)	**55**
Tempered (360^{o} C)	**51**
Tempered (540^{o} C)	**38**

Figure 1: Values of Hardness under different stage of heat treatment and tempering temperatures.

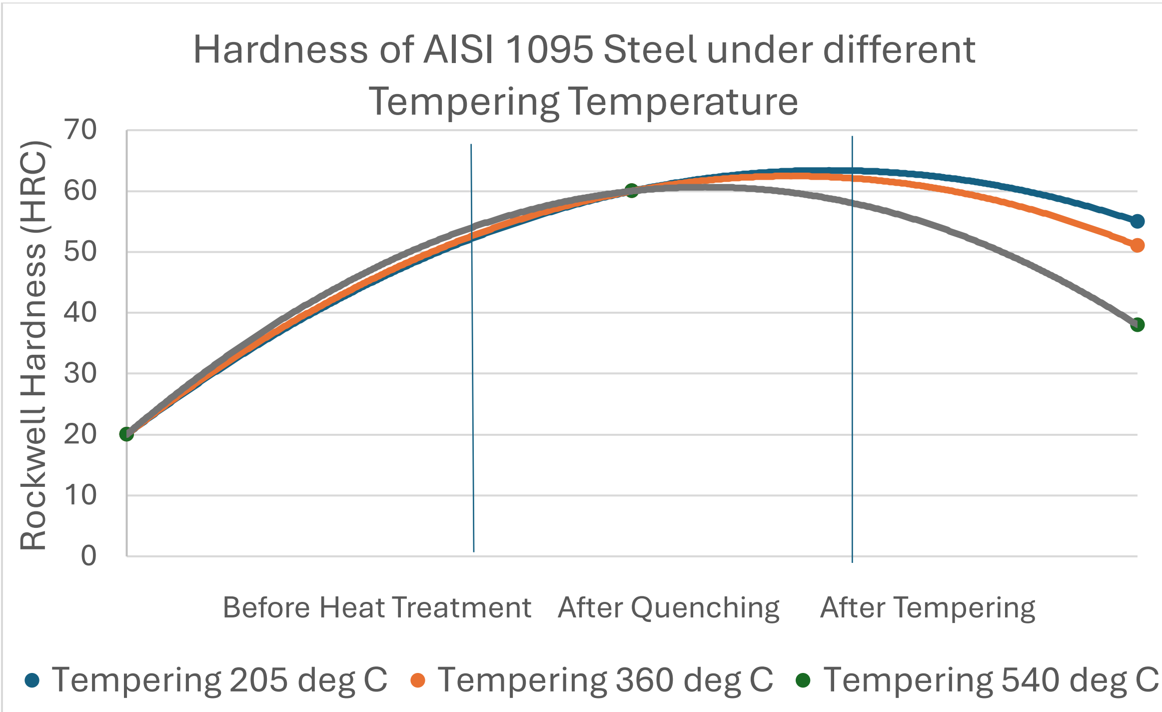


Figure 2: Hardness of Steel specimens under 3 different tempering temperature values prior to and after each stage of heat treatment.

Discussion of Results

Based on the data in figure 1, it can be observed that the tempering temperature has an inverse effect on the hardness of the steel specimen. At a temperature of 540 degree Celsius, the hardness value was seen to be the lowest while the 205-degree Celsius tempered specimen can be seen to have the highest hardness. This result can be justified by the fact that higher temperature is related to higher ductility, hence the lowering of the hardness. All the specimen reaches its peak hardness sometime after the quenching stage, where they are rapidly cooled.

Martensite is able to develop in the specimen during the quenching stage, resulting in the changes in hardness. However, such formation in high amounts may not be desirable due to the brittle behavior now exhibited by the material. Despite all the specimen decreasing in hardness after tempering, such process is necessary to restore ductility and therefore, the usability of the material. Introduction of small parts of $\alpha\ and\ Fe_3C$ is seen during the tempering process. The entire heat treatment process results in a change of phase, from Austenite to Ferrite/Cementite.

Conclusion

Tempering temperature is an important factor when it comes to the mechanical and microstructures of an material. It can be observed from this lab that higher tempering temperature yields the lowest final hardness values after the entire heat treatment process. However, depending on the application of the material, lower hardness may be sacrificed for the predictabilities of tempering to a more ductile material.

Review Questions

1. How do you describe the microstructure of the specimen before tempered?

Prior to tempering the specimen, during the quenching stage the microstructure are that of the martensite crystalline structure. Such structure is observed to be needle like and form through rapid cooling (the process of quenching).

2. Can you predict the mechanical properties of that specimen from the estimated microstructure?

The structure of a material directly affects their properties. Microstructures such as the martensite are associated with brittle mechanical behavior while ferrite is associated with mechanical properties like being softer and more ductile.

3. What happens to a specimen when it is placed in a furnace at 830 °C?

At 830 °C, the steel specimen used in the experiment reaches a point pass their eutectoid temperature and reaches the point of changing phases. At that point, the material shifts into the Austinite phase.

4. Why is the hardness of the quenched specimen so high? Is it related to the microstructure? If yes, in what way?

The quenching stage introduces martensite crystalline structures into the material, with a quicker rate introducing more martensite structures. Martensite is associated with the property of high hardness levels.

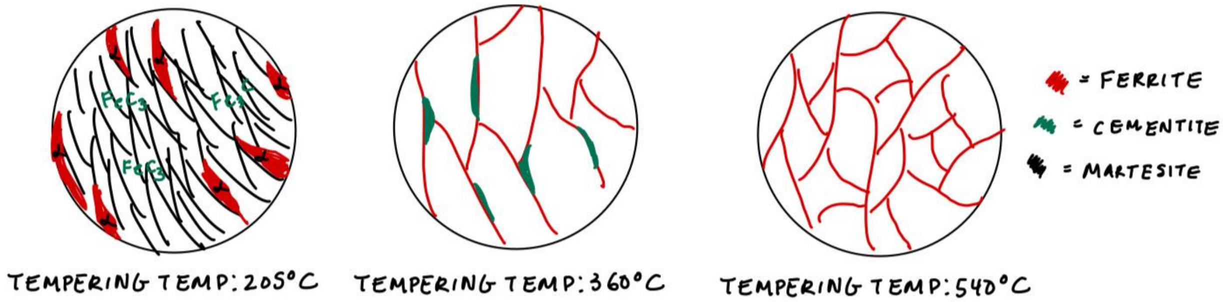
5. What happens to a quenched specimen during the tempering operations? What causes that change?

During the tempering stage, the specimen ductility is restored in partial, depending on the temperature. This change is due to the change in the presence of different amounts of ferrite/cementite. Higher temperature introduces more ferrite, which is associated with higerh ductility.

6. What are the effects of the tempering temperature on the mechanical properties (hardness, tensile strength, and ductility) of the tempered specimens?

Tempering temperature is seen to decrease hardness (as seen in this lab) but also reduce tensile and yield strength. Overall ductility is seen to have increased, which is due to lower carbon (higher ferrite) present in the specimen.

7. Describe the microstructure of each of the tempered specimens, and sketch them. What is the effect of the tempering temperature on the microstructure?



At Tempered (205° C), the specimen is still mostly in the martensite but small amounts of cementite and ferrite can be found. At Tempered (360° C), the structure is now in ferrite with small amounts of the cementite that can be found. At Tempered (540° C), the structure is now in ferrite, where the cementite can now grow into the ferrite matrices.

8. How do you explain the hardness versus tempering temperature graph in light of your observations of the microstructure of the tempered specimens?

Hardness levels after tempering is lowest in higher temperature due to the reduction of the martensite and increasing presence of structures associated with softness, ferrite.

9. What is the industrial significance of the hardness-tempering temperature plot

Depending on the application needed for a material, it may be important to find the ideal temperature needed to have certain mechanical prototypes (in this case, hardness). While not tempering at all may yield the highest hardness, it is more ideal to include higher ductility in the design as it can make the design more predictable during failure.

10. Can you anticipate the results if the same experiment were performed on AISI 1020 steel? Explain.

On a 1020 steel, the carbon content is seen to be much lower than that of 1095 steel. Steel will be observed to be hypoeutectoid instead of hypereutectoid which would change the temperatures needed to reach the same mechanical properties during tempering and quenching. 1020 steel would result in lower hardness at the same temperatures used for tempering in the 1095 steels specimens

11. What is the effect of carbon content on the mechanical properties of quenched and of tempered steels?

Higher carbon content can be seen through the phase diagram to change the temperature needed to heat treat the specimen and also the temperature needed for the quenching process to changes phases. The tempering of the steel would have a different scale in restoring ductility as well due to the shift of the vale on the x axis.

References

[1] CCNY ME 46100 Lab Report Preparation, CUNY blackboard website.

[2] CCNY ME 46100 Lab Manuals, CUNY blackboard website.
[3] CCNY ME 46100 Lab Data, CUNY blackboard website.