MECHANICAL ENGINEERING LABORATORY
NEW JERSEY INSTITUTE OF TECHNOLOGY

Report Submitted by	Sundeep Singh (Team Leader)	Experiment No.	7
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Course & Section	ME 215-101 (2)	Instructor	Naruemon Suwattananont

Heat Treatment

Experiment Title

Performed by Group A2 With TA Abhishek

Group Members
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Students are not to write below this line

GRADING

Date Received ____________________

Days Late (if any) ____________________

☐ Abstract	☐ Data	☐ Discussion
☐ Introduction	☐ Calculations	☐ Conclusion
☐ Theory	☐ Curves	☐ Questions & Answers
☐ Procedure	☐ Sketches	☐ See Pages ________

Comments: ____

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(For further comments see inside cover)

Graded by: ______________ Grade: ______ Date Recorded: __________

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Abstract

The objective of Experiment 7, Heat Treatment, was to distinguish the effect of cooling speed and heating rate on the mechanical properties of high carbons and low carbon steel. The purpose of the Heat Treatment laboratory was to define the effect of heat treatment on the mechanical properties of carbon content steels. This was performed in the duration of two weeks using High Carbon percentage Steel, Low Carbon percentage Steel, multiple furnaces ranging from 200°C to 960°C, and the Rockwell hardness tester. In the first week, the heat treatment was performed on High Carbon percentage Steel and Low Carbon percentage Steel. During the second week, different medias for quenching were used for High Carbon Content Steel and the tempering process was performed on the water quenched High Carbon Content Steel samples. In theory, steels with higher carbon content have better mechanical properties, such as a higher hardness. Additionally, higher heating temperatures also lead to better mechanical properties. The results in the data sheets help support the theories and validate all the objectives. Overall, the experiment helps to strengthen and expand the students' knowledge on heat treatment.

Introduction

The Heat Treatment laboratory experiment was meant to reinforce the students' knowledge on the mechanical properties of carbon steels and how temperature plays a big role in changing the mechanical properties of the carbon steels. Some of the objectives of this laboratory experiment included studying the quench inability of steels, study the effects of heating temperature on martensite, study the effects of carbon concentration on martensite formation, and the effects of tempering on the mechanical properties. In theory, the higher the carbon content in the steel, the more hardness it has. The High Carbon Content Steel consisted from 0.80% to 2.0% carbon and the Low Carbon Content Steel consists from 0.05% to 0.25% carbon. Medium Carbon Content Steel consists from 0.4% to 0.6% carbon, but this will not be used for this laboratory experiment.

Anything above 2.1% of Carbon is no longer considered steel, it is considered cast iron. The importance of this laboratory experiment is to show how different temperatures and different carbon contents can drastically affect the mechanical properties of a material. The carbon steel samples were placed in different furnaces set at different temperatures. In theory, there should be a trend between high temperature and high hardness and much of this laboratory experiment will focus around that. Additionally, the formation of martensite will only happen with temperatures above 750°C and less than 2% carbon content steel, which is what this experiment will be using at large.

Procedure

The lab was split into two weeks, labeled as Week 1 and Week 2. In Week 1 (Oct. 14), the primary focus was to about the differences in heat treatment between high carbon content steel and low carbon content steel at different temperatures. The teacher assistant, Abhishek, first gave students a PowerPoint presentation of the different materials, the machines used, and theoretical background. After this was done, we moved over to the Rockwell tester to measure three samples of High Carbon Content Steel. The average of the High Carbon Content Steel samples was taken. Then, three samples of the Low Carbon Content Steel were measured for hardness. The average of the Low Carbon Content Steel samples was taken before quenching. When this was complete, one sample of Low Carbon Content Steel and one sample of High Carbon Steel was placed in furnaces measuring 960°C, 500°C, and 200°C for 20 minutes. After the 20 minutes were up, all the samples were water cooled and sanded down in order to a smooth surface for the hardness testing using the Rockwell tester. The samples of High Carbon Content Steel and Low Carbon Content Steel were measured for hardness and the average was taken for each respective sample.

During Week 2 (Oct. 21) of the lab, the students only dealt with High Carbon Content Steel. For the five samples of High Carbon Content Steel provided, the hardness of each sample was recorded multiple times using the Rockwell hardness tester. For each sample, the average hardness was written down. All five of the samples were placed in a furnace at 960°C for 15 minutes. When the 15 minutes were up, the first three samples were quenched in water, the fourth sample was quenched in oil, and the fifth sample was air cooled. When the samples cooled down and were safe to handle, the hardness of each sample was recorded multiple times and the average of each sample was taken. Moving on, for the three samples that were quenched with water, the first one was placed in a 500°C furnace, the second on was placed in a 400°C furnace, and the last one was placed in a 200°C furnace for 20 minutes. When the time was up, the sample was water cooled and the tempering process was complete. The hardness of each sample was taken multiple time and the average for each sample was written down.

Data Sheets

Week 1:

R. Dubrovsky
ME 215, Engineering Materials & Processes

DATA SHEET FOR LAB. # 7

	GROUP MEMBERS Week 1	Week 2
1	Anmol S.	
2	Theodore N.	
3	Petros A.	
4	Chris C.	
5	Ertugrul A.	
6	Sim S.	
7	Sundeep S.	
8		

GROUP:

Group Leader: Sundeep S.

Weeks:	Week 1	Week 2
Instructor's Approval	[signature]	
DATE:	10/14	

TABLE 7-1

Hardness / Steel	Before Quenching Scale B	Before Quenching HRc Scale C	After Quenching Temperature, °C 960	500	200
High Carbon Content	X	20.0 19.8 17.9	59.9	22.2	20.5
Low Carbon Content	X	8.8 8.6 9.0	14.3	8.7	8.3

H.C. 20.2
19.5
X 17.6 → error
20.2
19.8
20.3
19.4
18.3
X 16.4 → error
18.1
X 10.6 → error
X 16.8 → error
17.4

TABLE 7-2

WEEK TWO Hardness / Steel	HR Before Quenching HRb	Scale C HRc	HRc After Quenching Media Water	Oil	Air	HRc After Tempering Temperature 500 °C	400 °C	200 °C
High Carbon Content								

LC:
8.7
X 6.4 → error
7.9
9.8

8.3
8.9
8.6

9.0
9.2
8.7

L.C. (960°)	(500°)	(200°)
15.9	8.4	X 5.6
X 20.6 → error	9.4	7.8
13.2	8.3	8.1
13.7		9.0

H.C. (960)	(500°)	(200°)
59.3	22.3	20.0
60.0	22.0	20.4
60.5	22.4	21.0

High Carbon Content Steel before Quenching

	Sample 1	Sample 2	Sample 3
Trial 1	20.2	19.8	18.3
Trial 2	19.5	20.3	18.1
Trial 3	20.2	19.4	17.4
Average	20.0	19.8	17.9

Low Carbon Content Steel before Quenching

	Sample 1	Sample 2	Sample 3
Trial 1	8.7	8.3	9.0
Trial 2	7.9	8.9	9.2
Trial 3	9.8	8.6	8.7
Average	8.8	8.6	9.0

High Carbon Content Steel After Quenching

	Sample 1 (960°C)	Sample 2 (500°C)	Sample 3 (200°C)
Trial 1	59.3	22.3	20.0
Trial 2	60.0	22.0	20.4
Trial 3	60.5	22.4	21.0
Average	59.9	22.2	20.5

Low Carbon Content Steel After Quenching

	Sample 1 (960°C)	Sample 2 (500°C)	Sample 3 (200°C)
Trial 1	15.9	8.4	7.8
Trial 2	13.2	9.4	8.1
Trial 3	13.7	8.3	9.0
Average	14.3	8.7	8.3

Week 2:

DATA SHEET FOR LAB. # 7

	GROUP MEMBERS		GROUP:	Group Leader: Sundeep S.	Weeks:	Week 1	Week 2
	Week 1	Week 2			Instructor's Approval		
1		Petros A.					
2		Ertugrul A.					
3		Theodore N.					
4		Chris C.					
5		Anmol S.					
6		Sim S.					
7		Sundeep S.			DATE:		10/21
8							

TABLE 7-1

Hardness / Steel	Before Quenching		After Quenching		
		HRc	Temperature, °C		
	Scale B	Scale C	960	500	200
High Carbon Content					
Low Carbon Content					

S1 – 500°
47.6
48.7
48.5
47.3
47.4
47.1
57.3
56.8
56.2

TABLE 7-2

WEEK TWO	HR Before Quenching		HRc After Quenching			HRc After Tempering		
Hardness / Steel		Scale C	Media			Temperature		
	~~HRb~~	HRc	Water	Oil	Air	500 °C	400 °C	200 °C
High Carbon Content		20.4	57.8	59.0	36.93	47.6	47.3	57.3
		16.4	60.1			48.7	47.4	56.8
		17.7	58.5			48.5	47.1	56.2
		20.800			Avg:	48.3	47.3	56.8
		17.933						

1st	15 min
19.6	58.7
20.3	58.2
21.2	56.5
16.6	59.8
15.5	60.4
17.1	60.0
18.2	57.4
17.5	57.9
17.3	60.3
	Oil
21.5	57.8
20.8	59.4
20.1	59.8
	Air
17.9	39.7
18.0	36.9
17.9	34.2

High Carbon Content Steel before Quenching

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Trial 1	19.6	16.6	18.2	21.5	17.9
Trial 2	20.3	15.5	17.5	20.8	18.0
Trial 2	21.2	17.1	17.3	20.1	17.9
Average	20.4	16.4	17.7	20.8	17.9

High Carbon Content After Heating to 960°C for 15 minutes and Quenching with Water

	Sample 1	Sample 2	Sample 3
Trial 1	58.7	59.8	57.4
Trial 2	58.2	60.4	57.9
Trial 3	56.6	60.0	60.3
Average	57.8	60.1	58.5

High Carbon Content After Heating to 960°C for 15 minutes and Quenching with Oil

	Sample 4
Trial 1	57.8
Trial 2	59.4
Trial 3	59.8
Average	59.0

High Carbon Content After Heating to 960°C for 15 minutes and Air Cooled

	Sample 4
Trial 1	39.7
Trial 2	36.9
Trial 3	34.2
Average	36.9

High Carbon Content After Tempering

	Sample 1 (500°C)	Sample 2 (400°C)	Sample 3 (200°C)
Trial 1	47.6	47.3	57.3
Trial 2	48.7	47.4	56.8
Trial 3	48.5	47.1	56.2
Average	48.3	47.3	56.8

Results and Calculations

$$BHN = \frac{7300}{130 - R_b}$$

For 40< R_b<100

$$BHN = \frac{1520000 - 4500R_c}{(100 - R_b)^2}$$

For 10< R_c<40

$$BHN = \frac{25000 - 10(57 - R_c)^2}{100 - R_c}$$

For 40< R_c<70

- BHN = Brinell Hardness Numbers
- R_b= Hardness Number on B scale of Rockwell Tester
- R_c= Hardness Number on C scale of Rockwell Tester

Discussion

The results calculated for Weeks 1 and 2 were approved and signed by the teacher assistant. Additionally, the results calculated helped confirm the objectives of the lab. The objective of the lab was to define the influence of cooling speed and heating rate on the mechanical properties of the carbon steel. Additionally, some other objectives of the lab included studying the effects of carbon concentration on martensite formation, to study the effect of heating temperature on martensite formation, and to study the effects of tempering on the mechanical properties of the carbon steels. As seen in the data sheet, before and after quenching, the steel with the higher carbon percentage has a significantly higher hardness. Adding onto that, only the carbon steel with high carbon concentration was able to achieve a martensite formation, proven by the incredibly high hardness. However, this only occurred at a high temperature of 960°C, showing that there is a relationship between higher carbon percentage and martensite formation and higher temperature and martensite formation.

Furthermore, during Week 2's experiment, a relationship between cooling rate and hardness can be described as the slower the cooling rate is, the less hardness the steel will have, seen in table 7-2 where air cooling the same carbon steel sample has a smaller hardness than the much faster water cooled carbon steel sample. Some of the data acquired in the "HRc after Tempering" section in Table 7-2 may not be reliable because there should be a decreasing trend between temperature and hardness after tempering, but this trend is not present. Some possible reasons for this could have been an error in the stop watch while keeping note of the time, or an error in the hardness testing machine.

Conclusion

The purpose and objective of Experiment 7, Heat Treatment, was to define the effects of heat treatment on the mechanical properties of the given carbon steel samples. Throughout the two weeks, the main objectives of this laboratory experiment were for students to learn about the effect of carbon concentration on martensite formation, the effect of heating temperature on martensite formation, and the effect of tempering on the mechanical properties of the carbon steels. The results shown in the data sheets above generally prove the objectives to be correct with some acceptations seen in the “HRc After Tempering” section in Table 7-2. Furthermore, the results prove that heat treatment has a large influence over the hardness of the carbon steel sample and that the carbon percentage content also has a large influence on the hardness of the carbon steel sample. Additionally, the results in the laboratory experiment help prove the relationship between heating temperature on martensite formation and the effect of carbon concentration on martensite formation. Over the two weeks conducting this laboratory, the objectives were accomplished and validated.

Questions and Answers

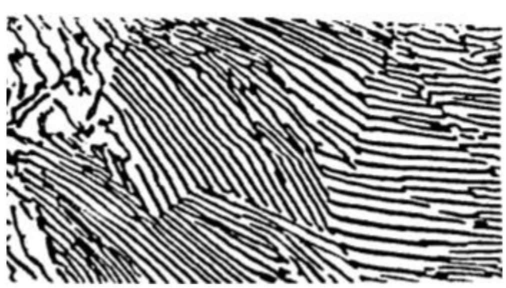
1. Explain why the specimens of steel 1045, after being heated to 700°C and 960°C and then quenched from that temperature, have different hardness. Indicate the differences of obtained microstructure of these specimens after quenching.

    The carbon content of steel 1045 is about 0.45% and as seen in the equilibrium diagram, steel 1045 becomes austenite after reaching 960°C and being quenched. In comparison after reaching 700°C and being quenched, it becomes cementite. Austenite has much better mechanical properties, explaining why the hardness after being heated to 960°C and being quenched is much higher than being heated to 700°C and being quenched (Otero).

2. Explain why the specimens of steel 1025 and 1060, after being heated to 960°C and then quenched from that temperature, have different hardness. Indicate the differences in the microstructure of these steels after quenching.

    Steel 1025 has about 0.25% carbon and Steel 1060 has about 0.60% carbon. Generally, the more carbon content percentage there is in steel, the greater the hardness is. However, after being heated at 960°C and quenched, both steel 1025 and steel 1060 will have the austenite microstructure.

3. Is it possible to get the structure shown below by water quenching from an austenite state?



Yes, it is possible to get the structure above by water quenching from an austenite state, the above structure is a pearlite structure.

4. If the hardness of two metals were known, one by a Brinell number and the other by a Rockwell number, would converting one to the other system give a valid comparison of the hardness of the two metals?

    The Brinell number and the Rockwell number both use the Rockwell Tester, but use different scales of the Rockwell tester, meaning that they can be converted using a conversion factor.

5. What is the average hardness of a pearlite structure?

    The average hardness of a pearlite structure is 269 Brinell (Property).

6. Is cementite harder than pearlite? If your answer is negative, give an explanation.

    Cementite has more carbon content percentage than pearlite and carbon content percentage correlates with hardness, meaning that cementite is harder than pearlite.

7. Is it true that the structure of hardened steel depends on the steel composition and hardening conditions?

    The structure of hardened steel does depend on the steel composition because the higher the percent carbon content is, the more hardness the material will have. Additionally, the hardening condition also play a factor such as the media used to quench the material. For instance, air cooling the material will yield a smaller hardness than water or oil quenching the material.

8. What does the casehardening process mean?

    The casehardening process is a process that increases the hardness of a material by adding a thin layer of a metal with a high percent carbon content to the outside surface (Zimmerman).

9. Define the following heat treatment processes:
   a. Normalizing: Steel is heated 30-50°C above the transformation line and then cooled in air.
   b. Full Annealing: Steel is heated 30-50°C above the transformation line and then cooled in a furnace.
   c. Process Annealing: The steel is heated near, but below the transformation line and then cooled.

   How can these processes be performed and what changes in mechanical properties can they provide?

   These processes can be performed using a furnace. Full Annealing results in coarse pearlite, normalizing results in fine pearlite, and process annealing results in recrystallization which reduces strain hardening effects.

10. What is martensite?

    Martensite is when no diffusion occurs during the transformation and the crystal structure changes from Face Centered Cube to Body Centered Tetragonal which increases strength, hardness, and brittleness.

11. What is the purpose of tempering?

    The purpose of tempering is to give the steel necessary ductility and fracture resistance and relax undesirable residual stress.

References

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