Material Science – ENGG*2120: Winter 2020

LAB SUBMISSION COVER SHEET

Lab Performed: Impact Lab

Date Performed: March 31st, Tuesday

Date Submitted: April 7th, Tuesday.

Group Number: 04

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GROUP PARTICIPATION EVALUATION FORM

*****ALL GROUP MEMBERS MUST SIGN TO RECEIVE THEIR MARKS*****

By signing the cover sheet each member is stating that they made a significant contribution to the writing of this lab report and that the distribution of sections completed is accurate.

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Huda Ameer		Results
Nasiba Alchach		Discussion 1, 2, 3
Nishat Tamanna Haque Mamun	Nishat	Summary, Introduction, Conclusion
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University of Guelph

ENGG*2120: Material Science

Lab 4: Heat Treatment of Steels

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Summary

The aim of this lab is to classify the process of heat treatment on samples of steel alloys. In order to further understand the impact of heat treatment on toughness of steel alloys, two different steel alloys were heat treated. Heat treatment and alloy elements may be used for the modification of the steel microstructure which impacts steel's properties as well, for example ductility and toughness. Knowing the impact of alloys on steel properties can be enabled to monitor what the end outcome is and hence makes steel alloys more desirable for certain applications.

Heat treatment includes quenching and tempering. Quenching is the fast cooling of an alloy. And the tempering of steel is under the temperature of the eutectoid. AISI-1045 and AISI-4140 are samples of plain carbon steel used in this experiment. Such experiments are used to demonstrate the impact of alloying elements on heat treatment.

In this procedure AISI - 1045 with 0.45% carbon content and AISI - 4140 with 0.40% carbon composition were thermally treated with manganese, silicone, chromium and molybdenum. Such observations also demonstrate how the alloy components influence the heat treatment because the alloy contents of the 4140 are greater than 1045 [1].

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1.0 Introduction

The object of this experiment was, under methods of quenching, to heat different samples of plain carbon steel. The data obtained from this experiment would then be used for the properties evaluation and study of these samples of steel after treatment.

An alloy is a metal composed of at least one other or non-element element. Steel is an alloy that, due to its strong tensile strength and low cost, is commonly used in construction, transportation, tools and appliances. The alloys are composed mostly of iron, carbon and other elements such as Si, Mn, Mo, Cr, Ni. Steel may be rendered strong and brittle or soft and ductile by manipulating the microstructure of steel by heat treatment and alloy combinations [2].

The steel body-centered cubic structure is converted into a face-centered cubic structure (FCC) or austenite structure that increases carbon solubility when heat-treated which improves carbon solubility. It enables the breakdown of any remaining iron carbide or cementite resulting in a homogeneous austenite process. Nevertheless, the arrangement is converted from the FCC to the BCC through steel cooling. An iron carbide known as cementite forms when there is an insufficient amount of time for the steel to cool. The cooling and heating intensity of the steel has an effect on the structure. For example, when cooled gradually, the pearlite structure results in a structure of mild strength and reasonable ductility; but, when rapidly cooled and referred to as quenching, it produces an incredibly hard and brittle martensite framework. Martensite steel is reheated in a process called tempering to increase ductility and relieve residual stress [2].

2.0 Experimental Apparatus and Procedures

The experiment apparatus and procedures used for this lab are outlined in the ENGG*2120 Lab Manual [2].

3.0 Results

Figure 1. *Iron-Carbon Phase Diagram*

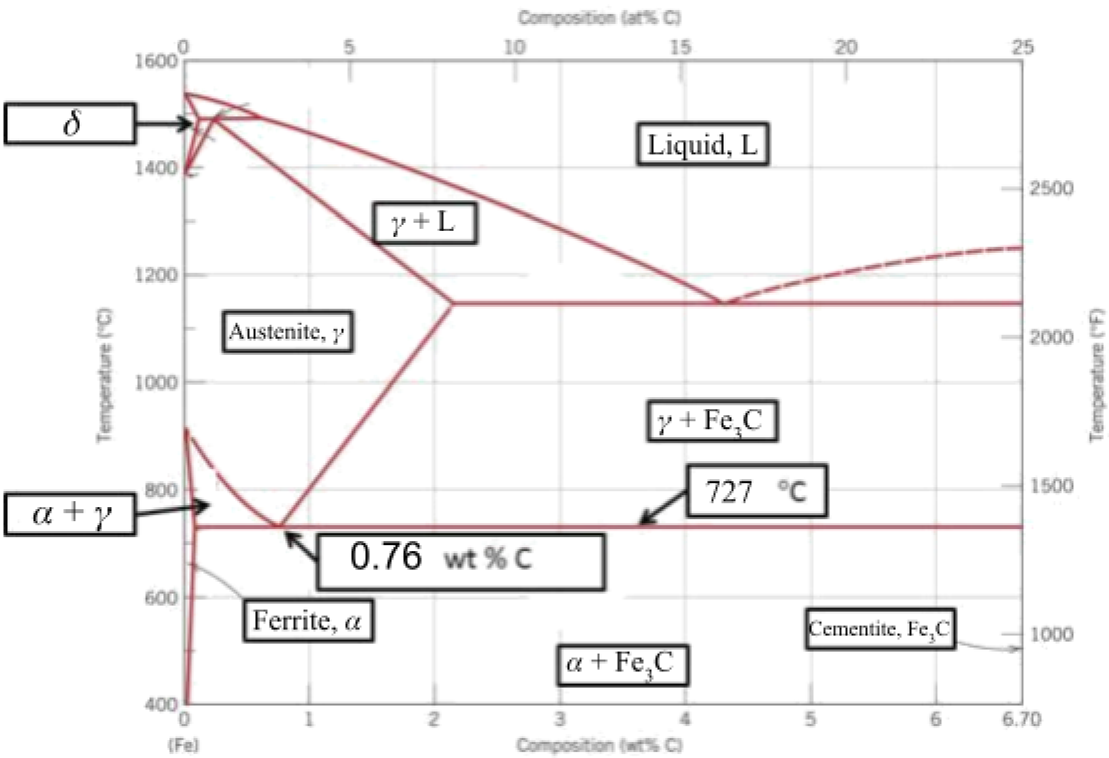


Table 1. *Hardness Results for 4140 and 1045 Steel for different treatments*

As Received		Air Quenched	
4140	1045	4140	1045
		No Temper, Let cool for 20 min	
84.45	79.08	12.43	65.70
86.42	81.42	29.39	76.52
88.67	81.39	27.03	77.14
		29.12	
B	B	C	B

Oil Quenched		Water Quenched	
4140	1045	4140	1045
No Temper			
36.92	72.99	49.28	13.59
46.61	80.56	48.97	15.38
51.46	87.18	55.11	19.26
20 min tempered @400℃			
40.71	81.26	39.19	15.70
42.89	80.09	33.16	20.52
43.97	82.42	39.78	15.95
		41.52	
40 min tempered @400℃			
27.53	80.57	29.65	18.17
45.17	82.30	32.49	16.97
45.35	82.70	31.40	15.64
47.44			
C	B	C	C

Table 2. *Hardness Results in B scale (HRBW) for different treatments*

As Received		Air Quenched	
4140	1045	4140	1045
		No Temper	
		Let cool for 20 min	
84.45	79.08	91	65.70
86.42	81.42	104	76.52
88.67	81.39	103	77.14
		104	

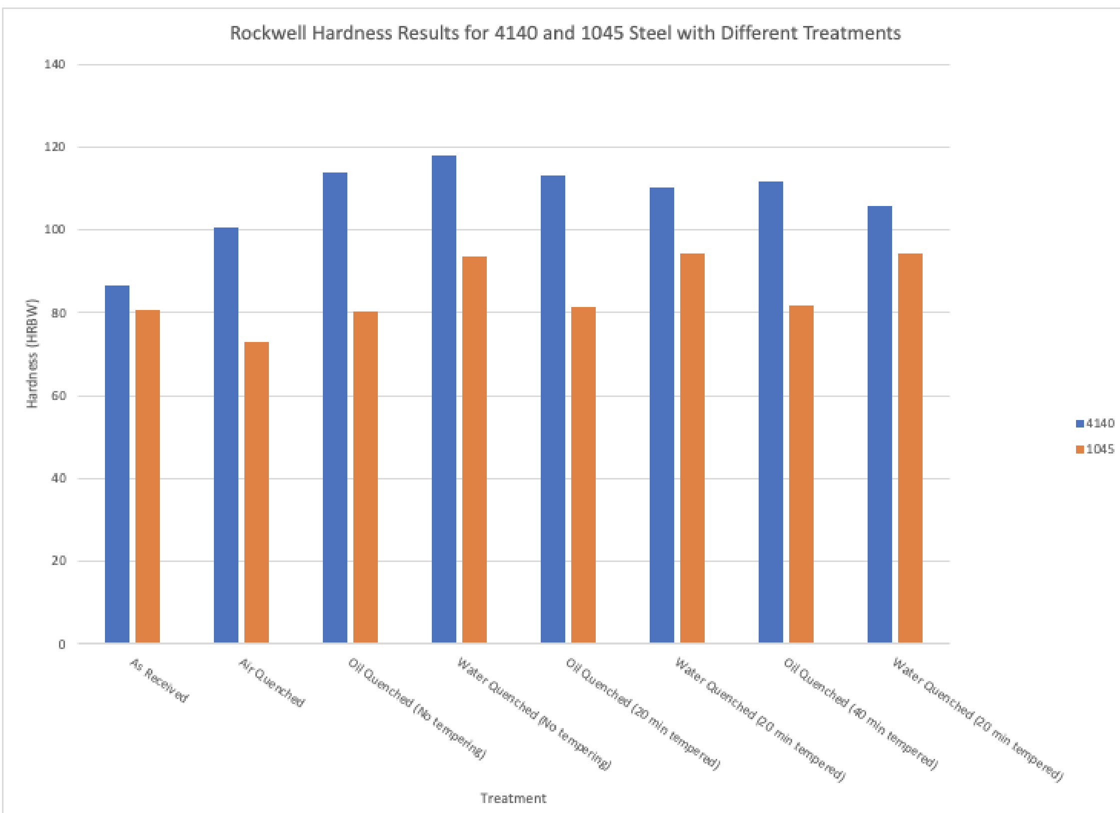
Oil Quenched		Water Quenched	
4140	1045	4140	1045
No Temper			
109	72.99	117	92
115	80.56	117	93
118	87.18	120	96
20 min tempered @400℃			
111	81.26	111	93
114	80.09	107	97
114	82.42	111	93
		112	
40 min tempered @400℃			
103	80.57	104	95
114	82.30	107	95
114	82.70	106	93
115			

Table 3. *Average Hardness Results in HRBW for different treatments*

As received		Air Quenched		Oil Quenched		Water Quenched	
4140	1045	4140	1045	4140	1045	4140	1045
86.51	80.63	100.5	73.12	114	80.24	118	93.67
Oil Quenched (20 min tempered)		**Water Quenched (20 min tempered)**		**Oil Quenched (40 min tempered)**		**Water Quenched (40 min tempered)**	
4140	1045	4140	1045	4140	1045	4140	1045
113	81.26	110.25	94.33	111.5	81.86	106.67	94.33

*Note: All Conversions made from the C scale to the B scale were done using [3].

Figure 2. *Graph of Hardness Results*



As can be seen in Figure 2, the same trend can be seen with all treatments, that the hardness of AISI-4140 steel is higher than that of 1045. 4140 steel has a higher alloy content than 1045, as can be depicted by their names. A steel following the naming convention of 10xx is a Plain Carbon Steel, while a steel with a 41xx is a Chromium Molybdenum Steel [4], alluding to the fact that the 4140 steel has more alloy content than the 1045 Steel. This means that a higher alloy content increases the hardenability of the steel.

Water Quenching with no tempering appears to be the heat treatment which produces the hardest steels. This is due to this treatment having the fastest rate to cool off, because of the water aspect, which forms martensite, making the steel extremely hard [2]. In the case of AISI-1045 steel, the treatment which produces the softest steel is Air Quenched, while for 4140 is As Received. The reason for Air Quenching producing the softest 1045 steel can be because it took a longer time to cool off, causing pearlite to form, increasing the ductility [2].

An increase in the time of tempering will decrease hardness. As seen in Table 3, as the samples go from no tempering to 20 minutes tempered and then 40 minutes tempered, the hardness decreases along with it.

Figure 3. *AISI-1045 Normal Micrograph*

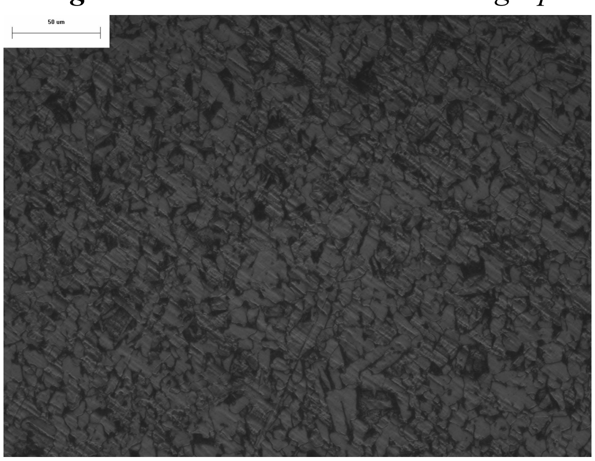


Figure 4. *AISI-1045 Tempered Micrograph*

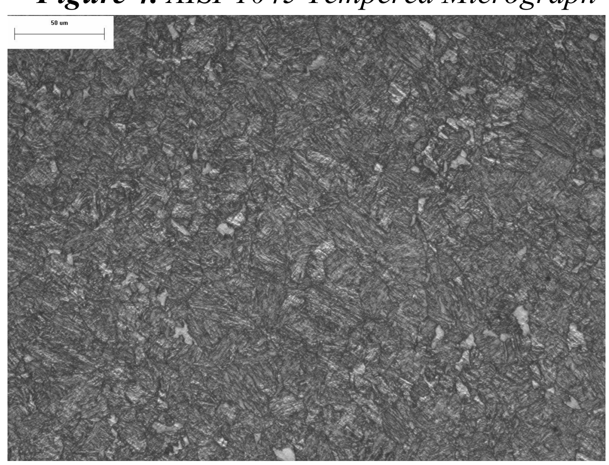


Figure 5. *AISI-1045 Air Quenched Micrograph*

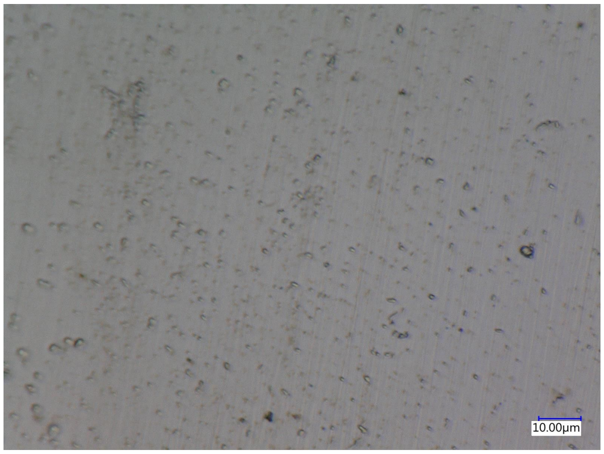
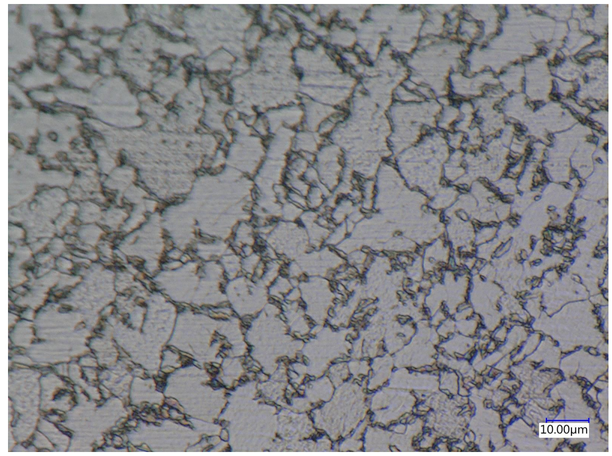


Figure 6. *AISI-1045 Water Quenched Micrograph*



As can be seen in figures 3, 4, 5, and 6, all the micrographs are visually different for each different quenched treatment. Figure 6 depicts the micrograph of the water quenched steel, and it can be seen that the steel appears to be hard and brittle, in comparison to Figure 5, the air quenched sample, which has a smoother looking surface. Water quenching causes martensite to form, causing the BCC structure to turn into BCT structure. It is because of the BCT structure that the steel is the hardest with this treatment. Figure 4 is the micrograph of the tempered steel, where the carbon from the BCT crystal is diffused to form ferrite and cementite. This explains why Figures 4 & 6 appear more similar than Figure 5, as the tempered steel has been heat treated twice and indicates the different structures contained [2].

4.0 Discussion

To minimize the sources of error, each sample was at least tested thrice and therefore a more accurate result was given by taking the average of the recorded trials. The AISI 4140 alloy steel resulted in 3 different Rockwell Hardness values of 100.5 HRBW, 114 HRBW and 118 HRBW. According to the results from the worksheet, little differences in the hardness of the steel is indicated when this type of steel is water quenched for 20 minutes and beyond.

The steel heat treatment method which produced the sample with the smallest Rockwell hardness value was the 1045 steel which underwent air quenching under no temper. This method had an average hardness of 73.12 HRBW, even lower than the as-received hardness for the steel which was 80.63 HRBW. Therefore, AISI 1045 is the softer steel and the microstructure possessed by this type of steel is body-centered cubic (BCC). On the other hand, AISI 4140 was considered the harder steel produced in this case due to lower carbon content [1] with a microstructure of body-centred cubic (BCC).

Annealing is a heat treatment method that brings a metal back to its state of equilibrium, making it smoother and more ductile. Another method of heat treatment is precipitation hardening, which produces uniformity in the grain structure of a metal and makes the steel less breakable.

Adding chromium will affect the characteristics of the steel by increasing its strength, hardness and its ability to be heat treated [5]. The addition of molybdenum will affect the steel by increasing its hardness and toughness. It will lower the quenching rate during the heat treatment process which will result in making a hard and strong steel [5].

The addition of some alloying elements will alter some of the steel's properties, i.e.: Steel's hardness and the microstructure of the compound since the physical structure of the compound will be changed due to the addition of some elements. For example, adding carbon to the steel would increase the steel's strength, hardness, and improve hardenability. But it could also increase the brittleness of the steel [6]. That said, there are quite a number of different alloys that improve the hardness of the steel, such as: Chromium (Cr), Molybdenum (Mo), Vanadium (V), Manganese (Mn) and Nickel (Ni) [5].

The average results calculated from the available results as shown in the table 3 illustrate that quenching with oil resulted in higher hardness values than when quenched with water for the 4140 samples except with no temper. Whereas, for 1045 steel, the data shows that water quenched steels are much harder than oil in all cases. However, it is understood that in steels, the faster the cooling rate the higher the hardness would be. Therefore, generally water quenched steels would be harder than oil quenched steel. This is mainly due to the fact that the thermal conductivity of water is higher than the thermal conductivity of oil and thus, the rate of cooling will be higher in water when compared to oil.

Oil quenching is used usually over water quenching, since quenching with water is much more rapid than quenching with oil. Oil has a higher boiling point than water causing a slower quenching rate and it cools rapidly and evenly therefore, reducing the risk of deformation, cracking and rough spots [7].

The major scheme of quenching is to harden and strengthen materials such as steel. That said, the steel becomes brittle. After the material has been quenched, tempering is used to achieve higher toughness and ductility by decreasing hardness. Tempering is achieved by heating the quenched steel. Tempering the quenched steel affects the ductility of the steel. The quenched steel becomes less brittle and more ductile without sacrificing too much hardness. Some of the disadvantages of quenching and tempering to harden steel is that during the heat treatment, the steel might get oxidized and in some cases the steel also might lose some of its properties. In addition, the process is considered to be time consuming [8].

The steel components should not quench and tempered after the components have been brazed. During the brazing process, the metals are heated and a filler metal to bond the components is inserted. In most cases the filler metal is a different type of steel than the part needed to be brazed. Due to this difference, if the braze gives way, it can be harmful. Quenching and tempering done after the brazing process could potentially result in unwanted effects and micro structural changes in the solidified metal filler. A possible alternative to this approach, could be to quench and temper the steels and secure the bond with a form of fastening [8].

Alloy steel is often used in civil application, for structures such airports, bridges, skyscrapers, etc [9]. Alloy steels provide the required strength in order to support the overall weight of structures. More specifically Nickel-Chromium-Molybdenum steel, which can be used in chemical process industries, allows for an increased corrosion resistance and toughness. Chromium Vanadium Steel alloy is used in cutting manufacturing as both Chromium and Vanadium improve the material [10]. The combination of the Chromium adding hardness, increased toughness and wear resistance, and the Vanadium increasing strength, toughness and shock resistance, allows for the use of the steel in the industry [2].

As the results were given, there is no personal experience for the determining the potential observed errors however, based on the experimental procedure there could be error in the transfer time between the heat treatment. As the steps needed to be completed as quickly as possible there could have been a human error in the transfer, allowing a change in temperature [1].

5.0 Conclusion

There are separate compositions of two metals which were used in this laboratory: AISI 1045 and AISI 4140. It is evident from the experiment that the two metals analyzed behaved differently. Since the introduction of iron alloying elements can contribute to a range of properties for steel that vary from growing strength to growing oxidation resistance. It is important to recognize the qualities of certain alloys that allow us to create the perfect steel alloy that is best fit for use. The iron-carbon phase diagram also enables to define the method in which the steel alloy should be effectively heat-treated to achieve the required amount of martensite. The strongest steel was AISI-4140 water quenched steel with a hardness of 118 HRBW, while the weakest steel was the 1045 air quenched steel with a hardness of 73.12 HRBW.

6.0 References

[1] "1045 vs 4140 Steel Comparison | Capital Steel & Wire", *Capitalsteel.net*. [Online]. Available from: https://www.capitalsteel.net/news/blog/1045-vs-4140-steel-comparison

[2] ENGG*2120 – Materials Science Laboratory Manual, School of Engineering University of Guelph, September, 2012.

[3] "Steel Hardness Conversion Table", SteelExpress Limited. [5 April 2020]. Available from: https://www.steelexpress.co.uk/steel-hardness-conversion.html

[4] "SAE/AISI Carbon Steel Naming Conventions", AZO Materials. [5 April 2020]. Available from: https://www.azom.com/article.aspx?ArticleID=6151

[5] Reshift Media. "5 Common Alloying Elements." *Metal Supermarkets - Steel, Aluminum, Stainless, Hot-Rolled, Cold-Rolled, Alloy, Carbon, Galvanized, Brass, Bronze, Copper*, 10 July 2019, [Online]. Available from: www.metalsupermarkets.com/5-common-alloying-elements/.

[6] Capudean, Bob. "Metallurgy Matters: Carbon Content, Steel Classifications, and Alloy Steels." *The Fabricators*, Aug. 2003, [Online]. Available from: www.thefabricator.com/thewelder/article/metalsmaterials/carbon-content-steel-classifications-and-alloy-steels.

[7] Webster, G. M., et al. "Quenchant Fundamentals: Condition Monitoring of Quench Oils." *Machinery Lubrication*. [Online]. Available from: https://www.machinerylubrication.com/Read/430/quench-oils

[8] "What Is Quenched and Tempered Steel?" *ShapeCUT*, 30 May 2019, [Online]. Available from: www.shapecut.com.au/blog/what-is-quenched-and-tempered-steel/.

[9] "Steel Alloys" Product Line Team *Economic Times.* Available from: https://economictimes.indiatimes.com/small-biz/productline/building-materials/alloy-steel-everything-you-need-to-know-about-alloy-steels-and-their-role-in-building-and-construction-industry/articleshow/70344024.cms?from=mdr

[10] MetalSupermarkets. [7 April 2020]. Available from: https://www.metalsupermarkets.com/alloy-steel-types/.