California State University, Long Beach

Department of Mechanical and Aerospace Engineering

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Lab Report
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Experiment Number: 2
Date Performed: 09 / 14 / 2022

Title: Metallographic Observation, Analysis and Hardness testing

Course Number: MAE 361
Section Number: Sec 03
Class Number: Eng 4 125

Instructor: Dr. Shamim Mirza

Objective:

The objective of this experiment is to be able to use different methods of heat treating in order to better understand how materials' (AISI/SAE 1018 and 1045) hardness will be affected. The different heat treating methods used were normalization, quenching, and tempering. The normalization was performed for 50 min at 850 and 900 Celsius for the 1045 and 1018 respectively. After, quenching was performed at the same time duration and temperature values by submerging the samples into water after. Then tempering was performed with 10min/20min/30min intervals with three different temperatures for each specimen: 200, 400, and 600 Celsius.

Apparatus:

Figure 1: Pace Technologies Nano 2000T Dual Grinder Polisher

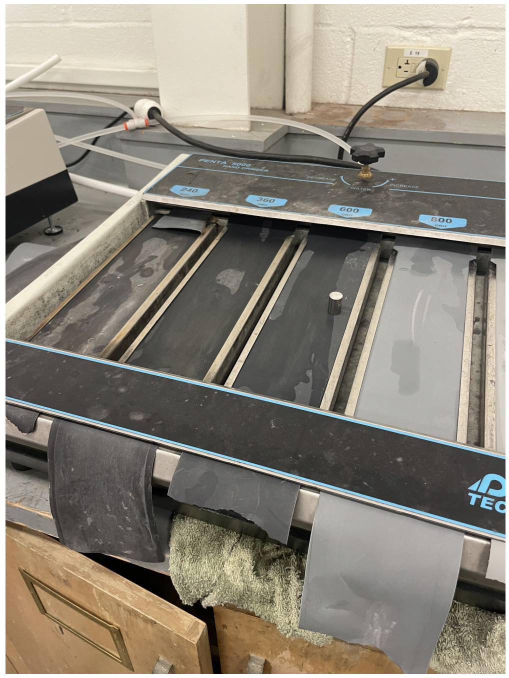

Figure 2: Pace Technologies Penta 5000 5-Station Hand Grinder

Figure 3: United Tru-Blue II Rockwell Hardness Testing System

Figure 4: Paragon HT14D - Heat Treating Furnace

Samples:

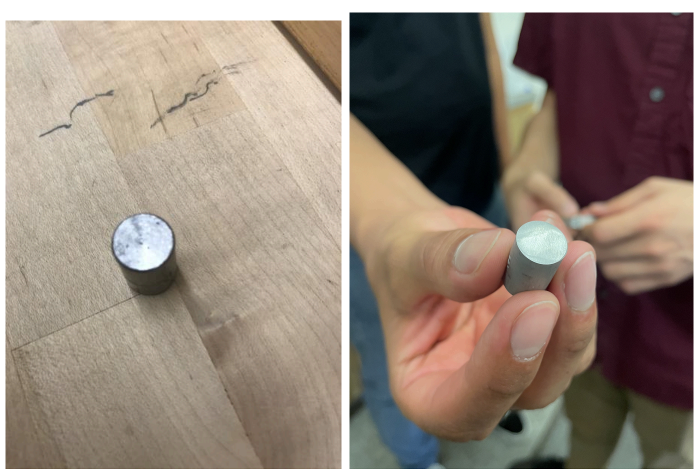

Figure 5: Raw 1045 and 1018 Steel Sample

Procedure:

The first step of the experiment is to grind both ends of the cylindrical 1045 sample or 1018 sample until they are smooth and polished. Our group specifically was given the 1045 sample to work with. This is done using the Penta 5000 hand grinder by grinding one side in a single direction starting at 240 grit roughness for about 1 minute. After grinding the side with 240 grit sandpaper, it is rotated 90 degrees and then grinded on 360 grit sandpaper in the same direction as before for another minute. This procedure is repeated using 600, 800, and 1200 grit sandpaper going from the lowest grit number to the highest. After polishing both sides of the 1045 sample, the sample is placed vertically on the Tru-Blue II hardness testing machine to determine its hardness value. The correct settings (a 1/32 inch diamond indenter, applying a load of 60 kilograms, using Rockwell Scale A) are inputted into the machine and the indenting tip is lowered close to the surface of the sample where it is almost touching. The button to start indenting is pushed giving a hardness value for the sample. This is done three times in three different areas of the sample's surface where they aren't too close to one another or too close to the edge of the surface, with the general rule of at least 5 diameters of the indenter tip.

The sample is then normalized via heating for 50 minutes at 850C or 900C for 1045 and 1018 respectively. After heating, the samples are to be taken out and "air-cooled" at room temperature. This was done by the professor beforehand to save time. The students took the samples and performed the polishing and testing cycle described above.

Next, quenching was performed via heating for 50 minutes at 850C or 900C for 1045 and 1018 respectively. After heating, the samples are instantly dropped into water to cool to room temperature.

Then, the samples were hardened by baking the samples at 200C, 400C, and 600C by baking them for 10 minutes, 20 minutes, and 30 minutes at each specified temperature. After each heat treatment session, the samples were air-cooled before doing a cycle of polishing and hardness testing described above.

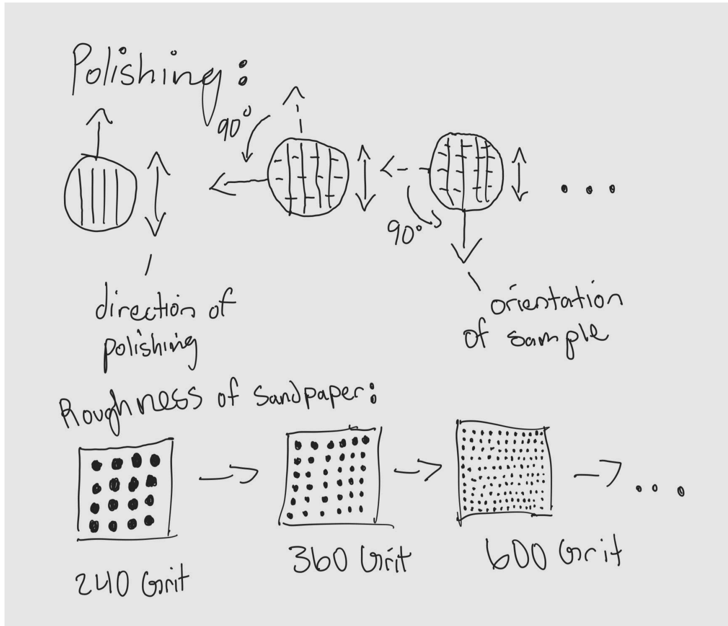

Figure 6: Polishing Sample Drawing

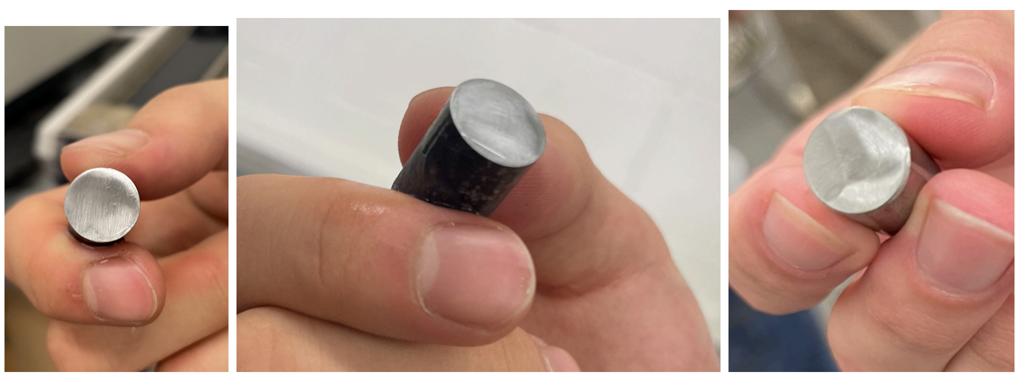

Figure 7: Polishing results between sandpaper grit and final result

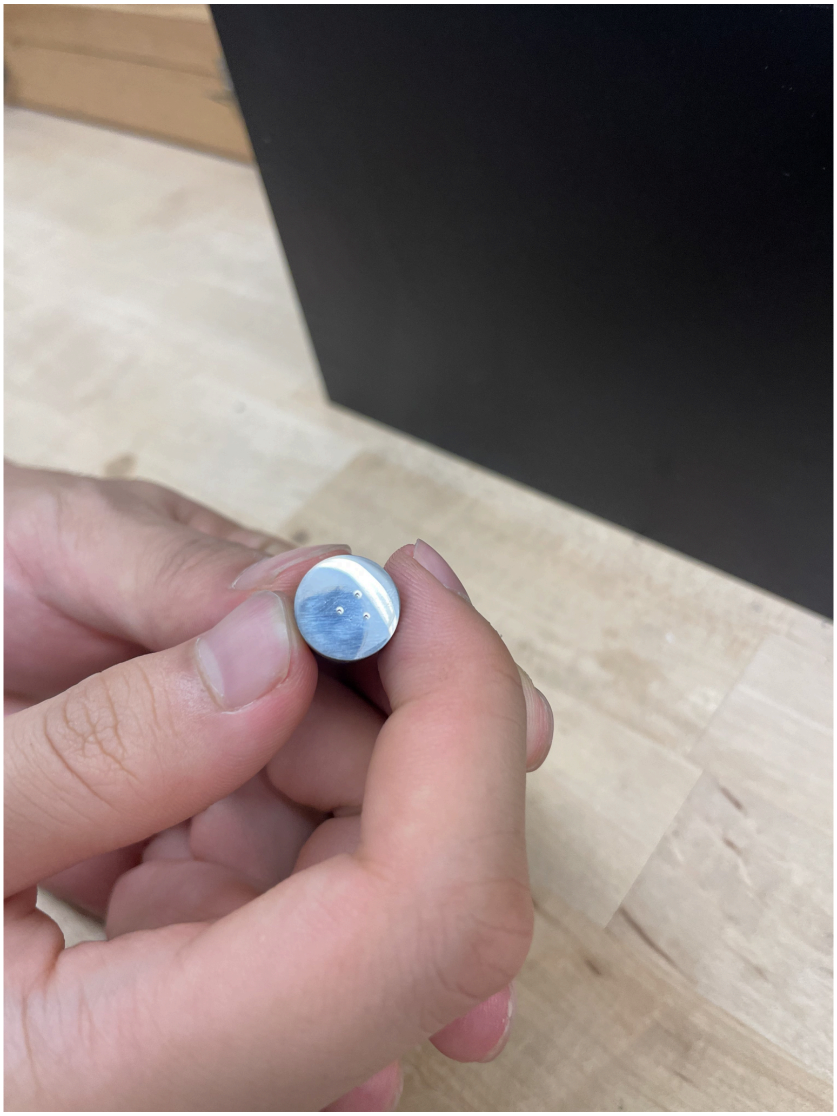

Figure 8: Sample after hardness testing

Test Results:

Table 1 : Raw Samples HRA Values

Raw Samples HRA				**Average HRA**
1018	57.06	58.11	58.35	57.84
1045	57.32	58.63	57.89	57.95

Table 2: Normalization HRA Values

Normalization								
1045			**Average 1045**		**1018**			**Average 1018**
51.24	46.2	51.04	49.32		42.53	44.27	45.48	44.65
50.66	42.7	51.09			42.76	46.22	45.54	
50.96	49.85	50.17			43.09	46.62	45.34	

Table 3: Quenching HRA Values

Hardening								
1045 at 850			**Average 1045**		**1018 at 900**			**Average 1018**
67.52	72.29	76.59	72.45		72.44	67.78	68.01	69.56
67.81	70.48	76.69			70.56	69.41	69.1	
69.83	71.96	78.89			66.65	72.99	69.11	

Table 4: Heat Tempering HRA Values

Heat Tempering	**Hardness (N/mm^2)**					
	200 C		**400 C**		**600 C**	
Sample	**1018**	**1045**	**1018**	**1045**	**1018**	**1045**
10 min	69.83	67.71	65.86	70.59	65.96	61.39
	70.38	66.81	65.23	69.54	64.5	61.21
	70.06	72.66	64.19	69.16	66.14	62.49
Average	**70.09**	**69.06**	**65.09**	**69.76**	**65.53**	**61.7**
20 min	70.8	78.52	65.47	71.36	58.02	60.05
	71.85	78.53	66.92	71.12	57.52	60.25
	71.89	78.43	66.04	71.81	57.95	60.39
Average	**71.51**	**78.49**	**66.14**	**71.43**	**57.83**	**60.23**
30 min	69.41	69.33	64.18	69.06	57.99	59.57
	71.11	70.62	65.61	70.79	57.35	60.03
	70.76	71.14	66.06	70.61	56.55	59.48
Average	**70.43**	**70.36**	**65.28**	**70.15**	**57.3**	**59.69**

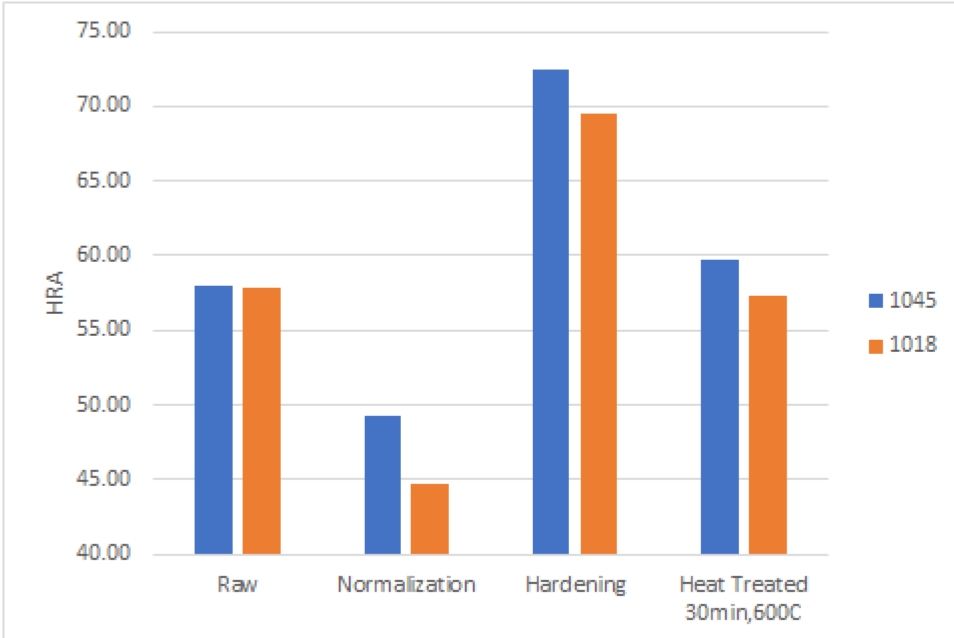

Figure 9: Tracking HRA Throughout Experiment

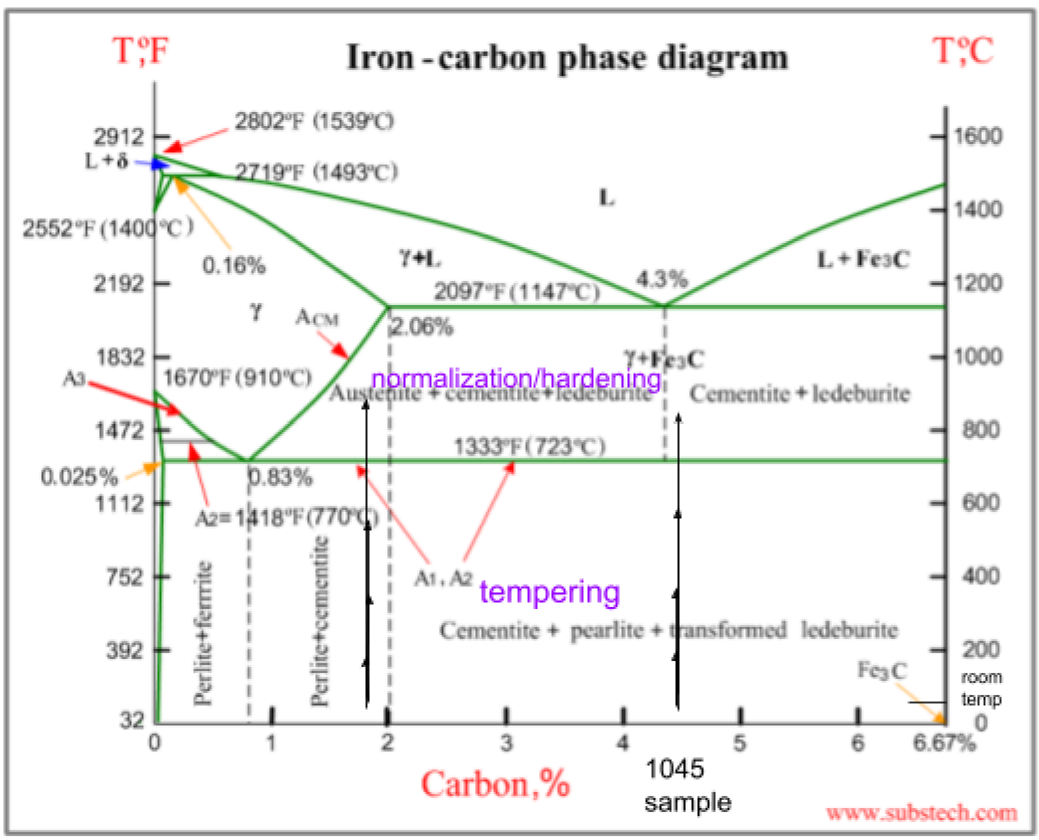

Figure 10: Phase Diagram Showing the Phase Changes of the Steel

Discussion:

The hardness of SAE 1018 steel was nearly always lower than SAE 1045 steel throughout the entirety of the experiment, but their difference differed with each heat treatment. The raw samples started off nearly identical, with sample 1045 being just slightly higher than 1018. After normalizing, both samples' hardnesses decreased with a 4.67 difference between them, sample 1045 being the greater one. After hardening, both samples’ hardnesses increased drastically with a 2.89 difference between them, sample 1045 remaining the greater one. Tempering at 200 ℃ for 10 minutes decreased the hardness of both samples slightly, resulting in a difference of 1.03, sample 1018 being the greater one this time. Tempering at 200 ℃ for 20 minutes resulted in the greatest hardness for both samples, with a difference of 6.89 between them, sample 1045 being the greater one. This heat treatment gave the two samples the greatest difference of hardness. Tempering at 200 ℃ for 30 minutes decreased both samples’ hardnesses with a 0.07 difference, sample 1018 being the greater one. Tempering at 400 ℃ for 10, 20, and 30 minutes resulted in both samples’ hardnesses decreasing, increasing, and then decreasing again respectively. The difference between samples for 10 minutes was 4.67, 20 minutes was 5.29, and 30 minutes was 5.29. Tempering at 600 ℃ for 10 minutes resulted in a slight increase for sample 1018 and substantial decrease for sample 1045, with a difference of 3.83, with the former being the greater. Tempering at 600 ℃ for 20 and 30 minutes resulted in a decrease both times, for both samples. The difference at both 20 and 30 minutes was 2.4.

Weakening or strengthening the samples wasn’t simply the cause of increasing the temperature, it was due to a phase change of the structure of the material. In this case, it was the heating of the steel to temperature in which austenite forms naturally. The results of our experiment are to be expected, as normalization recrystallizes the microstructure into a BCC structure which is less dense, allowing it to be more compressible, thus decreasing its hardness. The reason for this is because the less dense an object is, the easier it is to deform since hardness is just the resistance to deformation.

The increase in hardness from normalization to after hardening can be attributed to the quenching not allowing the atoms to fully reposition themselves the the BCC structure, inducing internal stresses which in turn increase the hardness. This also results in smaller grain size compared to that of the normalized, increasing the grain boundaries, which is another reason for the increase in hardness since the more grain boundaries the material has, the harder it will be.

Theoretically, the higher the temperature and the longer the time the material is being heat treated, the softer the material should be. Likewise, a material being heat treated at a low temperature for a short duration should result in a harder material than that previously mentioned. However, this is clearly not what we saw in our results. For both samples at 200 ℃ and 400 ℃, there was an increase in hardness for the 20 minute interval. It could be assumed that a group perhaps had gotten the wrong sample out of the oven, one in which had only been in there for a couple minutes. Another possibility is not allowing the material to air-cool, and instead quenching it, resulting in a harder material. That being said, the results for the 600 ℃

tests do follow the trend that was to be expected, as each greater time interval decreases the hardness of both materials.

The reference values for the hardness of SAE 1018 and SAE 1045, once converted to the correct scale, were found to 48.5 and 56.5. Both of our raw samples had a hardness of about 57, which is about 15% from the theoretical value for 1018. This discrepancy could be a result of inconsistent polishing technique, giving a poor surface to test the hardness.

Answers to Questions:

1)

Table 5: List of Average HRA

Hardness (N/mm^2)			
Sample 1018		Sample 1045	
Raw	57.84	Raw	57.95
Normalized	44.65	Normalized	49.32
Hardened	69.56	Hardened	72.45
Tempered at 200 ℃ for 10 minutes	70.09	Tempered at 200 ℃ for 10 minutes	69.06
Tempered at 200 ℃ for 20 minutes	71.51	Tempered at 200 ℃ for 20 minutes	78.49
Tempered at 200 ℃ for 30 minutes	70.43	Tempered at 200 ℃ for 30 minutes	70.36
Tempered at 400 ℃ for 10 minutes	65.09	Tempered at 400 ℃ for 10 minutes	69.76
Tempered at 400 ℃ for 20 minutes	66.14	Tempered at 400 ℃ for 20 minutes	71.43
Tempered at 400 ℃ for 30 minutes	65.28	Tempered at 400 ℃ for 30 minutes	70.15
Tempered at 600 ℃ for 10 minutes	65.53	Tempered at 600 ℃ for 10 minutes	61.7
Tempered at 600 ℃ for 20 minutes	57.83	Tempered at 600 ℃ for 20 minutes	60.23
Tempered at 600 ℃ for 30 minutes	57.30	Tempered at 600 ℃ for 30 minutes	59.70

2) The microstructure of the specimen is not given. However, it can be inferred from the composition of 1018 and 1045 that 1045 has a larger percentage of carbon in it. Mixtures of materials create smaller microstructures and harder materials. Pearlite consists of alternating layers of ferrite and cementite that forms during eutectoid transformation, this makes it very tough and wear-resistant. It is both stronger and lighter than pure ferric steel. Ferrite is a phase of Body-Centered-Cubic crystal structure and exists at low temperatures and low carbon content. It contains up to 0.0008% carbon at room temperature. This can be increased to a maximum of 0.022% by increasing the temperature to 727℃. This phase is magnetic below 768℃. Cementite is an iron carbide containing 6.70% carbon, is hard, and very brittle, making it suitable for strengthening steels. It decomposes extremely slowly at room temperature into iron and carbon. Proeutectoid ferrite is formed when steels which contain less than the eutectoid carbon content are air cooled. Forming above the eutectoid temperature, it has the same BCC structure as regular ferrite carbon steel.
3) It was important to grind 1/32 inch off the ends of the specimen because heating causes an oxide layer to form on the surface, thus it must be polished off to reveal the original surface.
4) Rockwell hardness scale A was used because it is used for harder materials and it has a good range of hardness, necessary for this particular lab since we are doing various heat treatments.
5) A higher temperature for austenitizing the SAE 1018 steel over the SAE 1045 steel is preferred because 1018 has a lower carbon composition, thus resulting in a higher transformation temperature.
6) Tempering time and temperature weakened the hardness of both 1045 and 1018 as the experiment went on. For both samples, their hardness was at its highest at the 20 minute mark, at 200 ℃. The samples were at their lowest at the 30 minute mark at 600 ℃. Overall, the greater the temperature, the weaker the material, and the longer the tempering time, after a certain point, the weaker the material as well.
7)

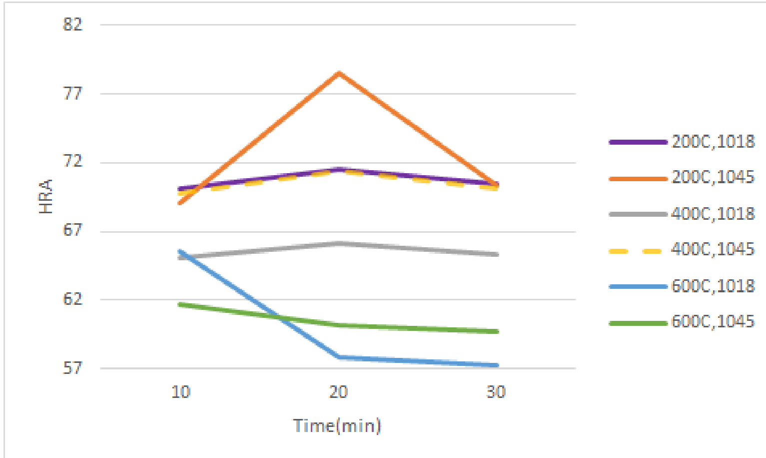

Figure 11: HRA Change over time

8) The microstructure that possessed the greatest hardness was observed to be the 1045 steel samples during the second heat treatment at 20 minutes. The microstructure that possessed the lowest hardness was observed to be the 1018 steel samples during the third heat treatments at 30 minutes overall.
9) If the austenitizing temperature was at 760C rather than 850C or 900C, the microstructure would have been different. The higher temperatures of 850C or 900C was needed for a more ductile material, based on the phase diagram. The microstructure would vary at 760C based on the duration, but would have lower hardness and be less ductile.
10) The quenching medium determines the speed at which the sample would cool at. Rapid quenching such as dunking the sample in something with high thermal heat capacity such as water bath allows for the microstructure of the steel to become harder and more brittle. The higher the temperature of the medium before quenching, the slower the material quenches, which may yield different results if for example, the sample were to be quenched in warm water rather than cold water.

Conclusions:

Multiple groups could have made mistakes when considering quenching or air drying for their samples at certain stages. The experiment could have been done with less error with more reminders between sections of heat treatment. Moreover, groups could have been forgetful and taken out the wrong sample. This could be avoided if there was more communication between students when moving samples. Additionally, students have inconsistent polishing techniques and can cause large variance in HRA values.

Heat treatments change the hardness of a material by affecting the grain structure. Increasing or decreasing hardness depends on the rate that the grains are cooled. Quenching cooled the steel fast and made it hard, while normalization and tempering made the steel soft due to longer air-drying rates where the grains were allowed to cool and settle into larger formations.

Due to larger carbon content, the grain structure of 1045 would be harder and be more difficult to change through heat treatment. This was evident in the lab with 1018 having a larger variance in HRA with each application of heat treatment.

References:

AISI 1018 Carbon Steel Brinell Hardness:
https://www.azom.com/article.aspx?ArticleID=6115

AISI 1045 Carbon Steel Brinell Hardness:
https://www.azom.com/article.aspx?ArticleID=6130

Conversion to HRA Chart:
https://tubingcentral.com/wp-content/uploads/2017/12/Hardness-Conversion-Chart.pdf

Steve Fang took the picture of the board of data