California State University, Long Beach

Department of Mechanical and Aerospace Engineering

Fall 2022

Lab Report
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Experiment Number: 3
Date Performed: 09 / 28 / 2022

Title: Precipitation Hardening of Aluminum Alloys

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

Instructor: Dr. Shamim Mirza

1. OBJECTIVE

The objective of the experiment is to be able to use the aging and de-aging processes in order to observe the effects they have on the hardness of Al 6061.

2. PROCEDURE and LIST OF APPARATUS

Figure 1: Raw Al 6061 Sample

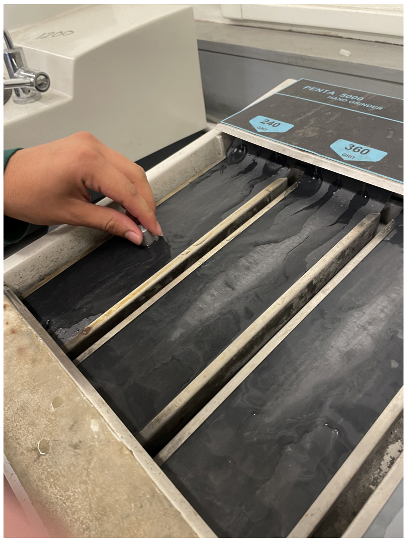


Figure 2: Pace Technologies Penta 5000 5-Station Hand Grinder

The first step of the experiment is to polish both sides of the Al 6061 sample to a mirror finish using the Pace Technologies Polisher. Using the Tru-Blue Rockwell Hardness Tester, the Rockwell F Scale hardness values are taken three times.

The next step is to put the sample into the Paragon oven for one hour at a temperature of 529 °C. The sample is then immediately quenched in water and both of its sides are polished again using the Pace Technologies Polisher. The Rockwell F Scale hardness values are taken three times using the Tru-Blue Rockwell Hardness Tester.

The sample is then aged by putting it into the Paragon oven for 10 minutes at a temperature of 280 °C. The sample is immediately quenched in water after taking it out of the furnace and both sides of the sample are polished using the Pace Technologies Polisher. The sample is placed on the Tru-Blue Rockwell Hardness Tester and its Rockwell F hardness values are taken three times. This entire aging process, including the polishing and hardness testing, is repeated at the same temperature using time intervals of 20 minutes and 30 minutes. This process is also done at 250 °C using a different Al 6061 sample.

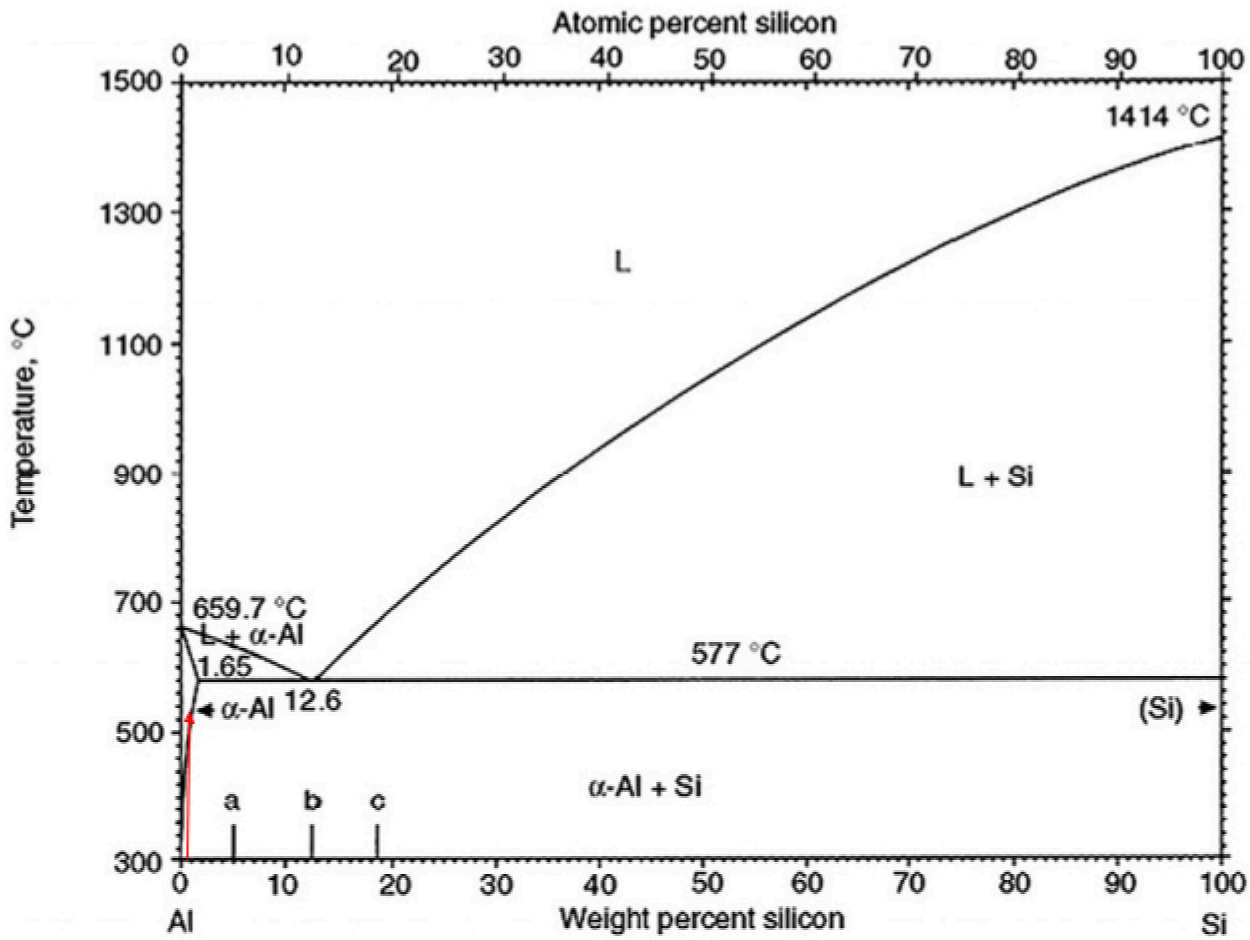


Figure 3: Al-Si Phase Diagram

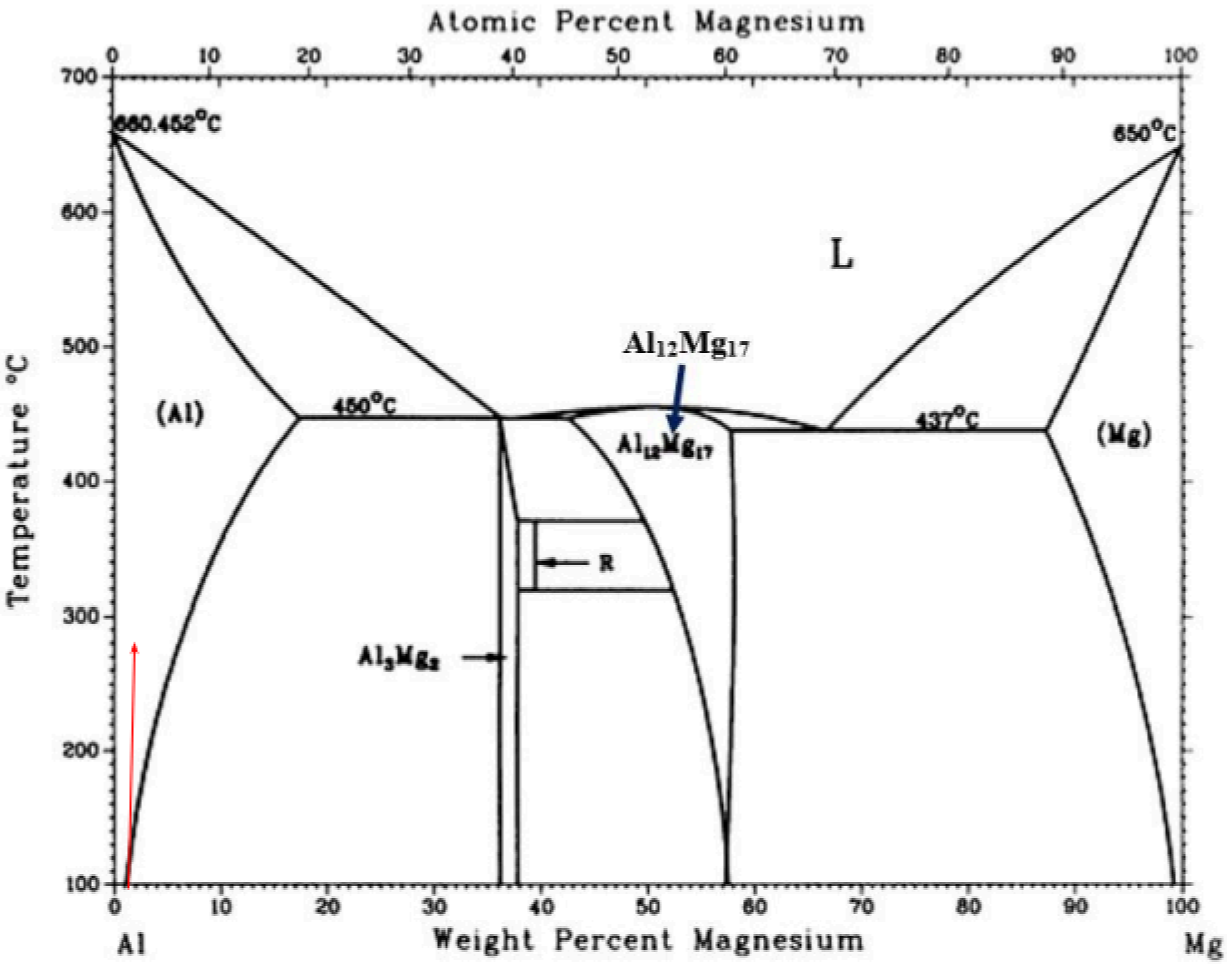


Figure 4: Al-Mg Phase Diagram

How the temperatures of 529C, 280C and 250C were picked are based on how the aluminum changes into the alpha state with that specific alloying material or not. Al 6061 has two major alloying materials: magnesium 1% and silicon 0.6%. To treat most of the sample by pushing it into α-Al, the sample needs to be taken to 529C with 0.6% silicon as seen in the Al-Si phase diagram in figure 3.
At 280C and 250C only a portion of the sample would transition in α-Al as that is the point the Al-Mg slips into α-Al zone with 1% Mg in figure 4.
Those two temperatures thus reflect how heat treatment affects the sample via separating the affected alloyed materials.

Samples are left in the freezer when the experiment takes more than one day to complete in order to prevent it from aging. The natural aging procedure is different to the artificial aging procedure done in the experiment since the supersaturated sample is left at room temperature rather than heated to a high temperature during the natural aging process.

Figure 5: United Tru-Blue II Rockwell Hardness Testing System

Figure 6: Paragon HT14 Oven

3. DATA & RESULTS

Hardness (HRA)
77.12
75.13
79.89

Table 1. Class data for hardness testing of raw sample

HTQ $529^{\circ}C$**, 1 hr**

	1st Result	2nd Result	3rd Result	Average HRA
Group 1	69.69	73.50	72.94	72.04
Group 2	67.47	70.80	72.97	70.41
Group 3	75.96	77.53	76.84	76.78
Group 4	73.56	73.00	74.04	73.53

Table 2. Class data for hardness testing of quenching heat treatment

$250^{\circ}C$

Time (min)	Group #	1st Result	2nd Result	3rd Result	Average HRA
10 min	Group 3	75.13	75.19	79.23	76.52
	Group 2	73.33	72.21	74.92	73.49
20 min	Group 3	64.18	71.85	69.86	68.63
	Group 2	75.60	73.79	74.26	74.55
30 min	Group 3	88.86	89.39	89.36	89.20
	Group 2	88.40	89.59	88.53	88.84

Table 3. Class data for hardness testing for aging at 250 ℃

$280^{\circ}C$

Time (min)	Group #	1st Result	2nd Result	3rd Result	Average HRA
10 min	Group 1	77.69	80.01	78.13	78.61
	Group 4	80.70	80.94	81.49	81.04
20 min	Group 1	79.54	79.19	81.15	79.96
	Group 4	78.50	79.35	80.07	79.31
30 min	Group 1	74.91	75.23	76.06	75.40
	Group 4	70.03	72.54	71.92	71.50

Table 4. Class data for hardness testing for aging at 280 ℃

4. SAMPLE CALCULATIONS

N/A

5. DISCUSSION

The high temperatures used in artificial aging are meant to speed up the aging process and cause the Al 6061 material to harden quicker as opposed to natural aging which happens at room temperature and takes longer. In theory, the higher the temperature, within a certain range, and the longer the material is artificially aged, the harder the material.

Our lab results justify the theoretical decrease and increase in hardness of the material through the aging process. The raw aluminum alloy sample tested for an average hardness of 77.38, and solution treatment of heating at 529 ℃ for an hour then quenching resulted in a decrease across all samples to an average hardness of 73.17. This is due to the fact that extreme heating causes dissolution in the material and high saturation can thus be obtained by quenching. The material was held in the furnace for an hour in order to nearly completely transform it to a single phase. Reheating the metal to either 250 ℃ or 280 ℃ causes the atoms in the material to form an ordered array, yet keeps the material in the two-phase region. This in turn increases the strength of the material, as seen in our data. For 10 minutes, there was an increase to an average of 75.01 and 79.90 for 250 ℃ and 280 ℃ respectively. For 20 minutes at both temperatures, each pair of groups got contradicting results. One group got a decrease in hardness, and the other an increase. However they again agree with each other at the 30 minute mark. For 250 ℃ at 30 minutes there was an average increase in hardness, and for 280 ℃ at the same time was an average decrease in hardness.

The sample at 250 showed peak hardness at 30 minutes, and the sample at 280 showed it at somewhere between 10 and 20 minutes on average. This peak is when the precipitate starts to form in terms of finely dispersed particles. If the material is left for too long, then the secondary phase will start to coalesce into larger particles, in turn decreasing the material's strength. This is known as over aging, and is exactly what we saw in the sample at 280 ℃. The hardness of the material first increased after 10 minutes, then decreased after some point between 10 and 20 minutes. Heating at 250 ℃ resulted in greater hardness at the end of the 30 minutes, then at any point of the 280 ℃ sample. Therefore, aging samples at lower temperatures for longer yields better results then high temperatures for a short time.

Natural aging is when a supersaturated solid solution exists at room temperature. This can take many hours, therefore artificial aging is a more viable process. Our raw sample, being naturally aged, had an average hardness of 77.38, yet this hardness was achieved by only 10 minutes of artificial hardening at 250 ℃. Only having 3 time stamps resulted in some confusion as to where exactly the peak hardness occurs at each temperature. Group 3 has a decrease in hardness at 20 minutes, yet an increase in hardness at 30 minutes. This should not happen since a decrease in hardness would mean that the material was over aged already, so even more time would decrease it even moreso. Therefore this must have been a mistake during the experiment, a result of accidentally leaving the material too long or the wrong temperature furnace.

6. ANSWER TO INSTRUCTOR'S QUESTIONS

1. Plot curves of hardness vs. aging time for aging temperature used in the experiment. (6 points)

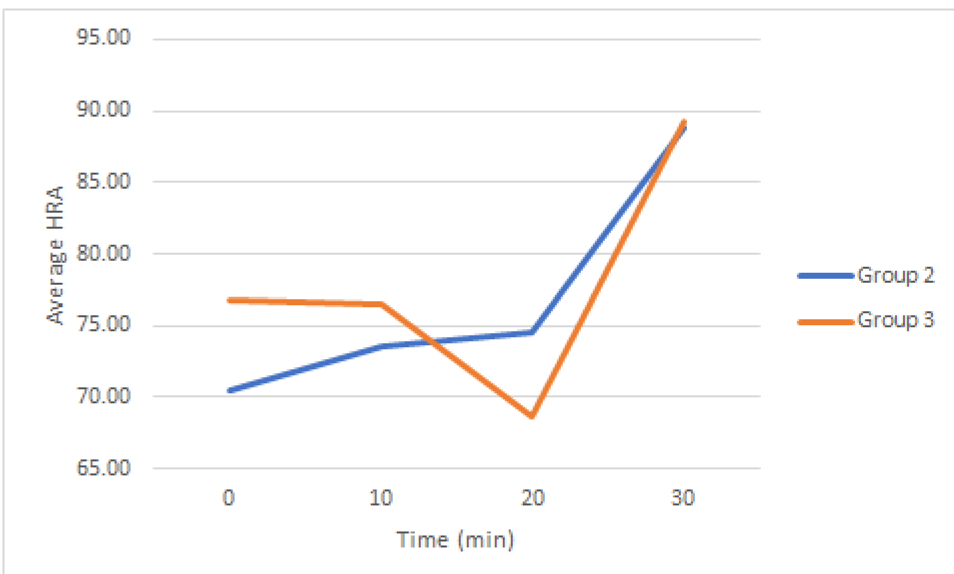


Figure 5: 250C aging for specimens

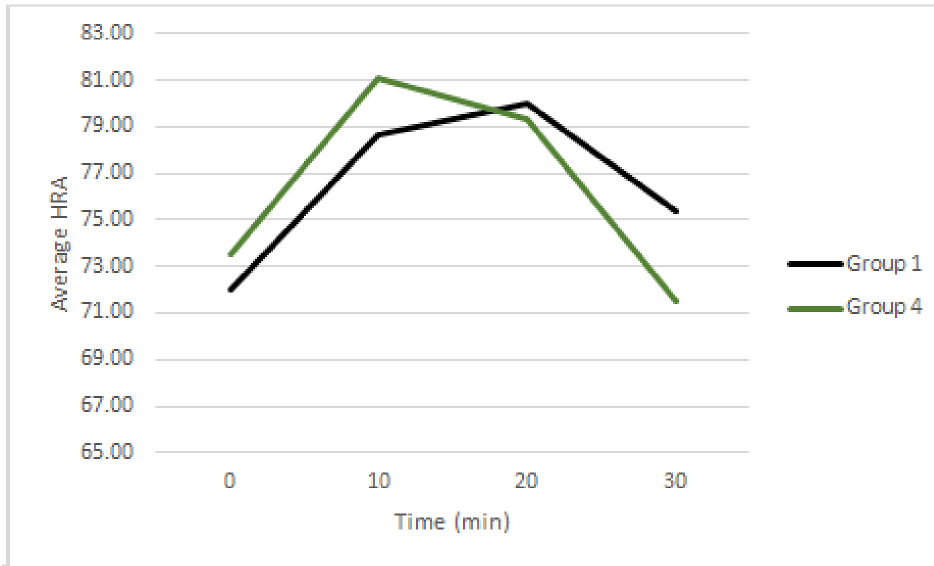


Figure 6: 280C aging for specimens

2. How does the aging time affect the hardness of the specimen? (6 points)

Aging time continuously increases the hardness of the specimen up to a certain point depending on the temperature. When the peak aging time is reached, the hardness suddenly begins to drop as the specimen becomes overaged. With $250^{\circ}C$, the overaging temperature was never reached. This was most likely due to a lack of time for the material to heat up.

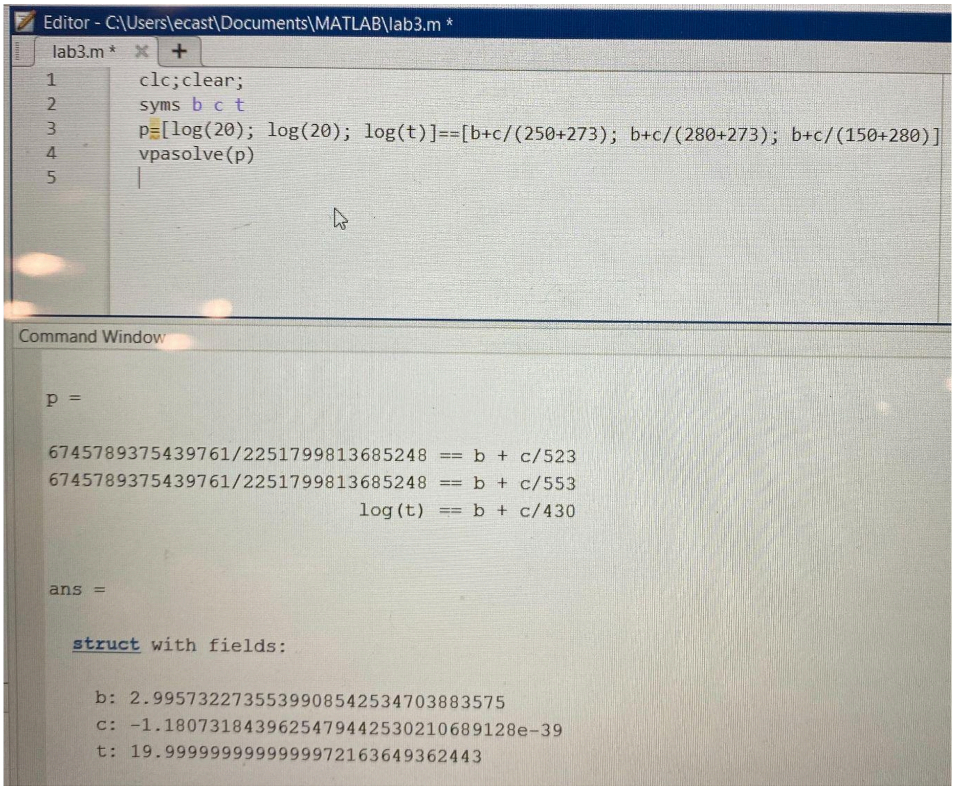
3. How does the aging temperature affect the hardness of the specimen? (4 points)

The hotter the temperature, the harder the specimen becomes. A hotter temperature speeds up the aging and thus makes overaging come much sooner. With $280^{\circ}C$, the overaging process actually occurred. In comparison with $250^{\circ}C$, the $280^{\circ}C$ was hot enough to overage the material in the 30 minutes portion of the experiment.

4. Determine the peak aging times for specimens aged at the temperature used in the experiment.

It can be determined that the samples at 250C reach their peak aging time after 30 minutes of heating. The sample heated at 280C reached their peak aging time between 10 minutes and 20 minutes.

5. Use the Arrhenius equation ($\ln t = b + c/T$) to predict the peak aging time if the specimen is aged at 150C. Show all your calculations. Do not use seconds as a unit of time! (5 points)



t=20min

6. Sketch and describe the change in the microstructure during solution treatment and aging. (15 points)

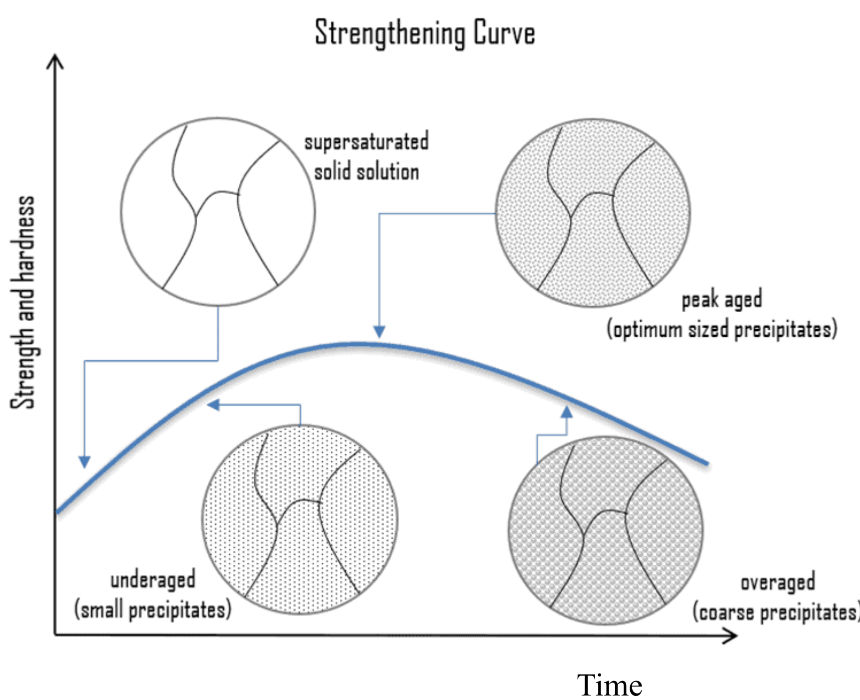


Figure 7: Strengthening Curve

From this diagram it can be seen that the Al 6061 heated at 250C reached a peak aging time and had medium sized particles. However, the samples heated at 280C became overaged and the particles were too large which decreased the sample hardness.

7. RECOMMENDATIONS AND CONCLUSIONS

In this experiment, we learned about the effect of aging on a material. Aging a material will continuously harden the material until a certain amount of heat intake. Given enough heat, the material will overage and lose hardness. In order to improve the experiment, students should focus more on polishing correctly. If the material is polished incorrectly, hardness readings will not be accurate. Other recommendations would be correct placement of the material when measuring hardness. Placing the material in a good location will prevent a misread from measuring the corner of the material or being too close to a previous point.

8. REFERENCES AND ACKNOWLEDGEMENT

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