Study on Material Integrity of Aluminium 7075 after Heat Treatment Process for Medical Tools

by

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Mechanical Engineering with Honours

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

____
Dr. Azlan Ahmad

UNIVERSITI TEKNOLOGI PETRONAS
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January 2020

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHAMMAD NORAZMEER BIN MOHD NOOR

ABSTRACT

Several researchers have conducted studies on the recycling of aluminium waste to reduce carbon footprint and the aim of this study is to conduct heat treatment process on aluminium 7075 waste and determine whether it is a suitable material replacement for medical tools usually made up of stainless steel. Based on its quality, considered to be the strongest aluminium alloy, aluminium 7075 is selected. Heat treatment parameters is decided to be at 110°C, 130°C and 150°C, each having three heating duration of 1, 3 and 5 hours. Density test using gas pycnometer device and Vickers Microhardness test is done after the heat treatment process to see the best results among the set heat treatment parameters compared to the untreated sample. The results of the tests shown that sample heat treated at 130°C at 1-hour duration has the most preferable density and hardness value, which is at 2.7984 g/cm^3 and 180.35 HV. Comparison of the test results with the known specification of stainless steel concluded that the heat treated aluminium 7075 at 130°C for 1 hour have higher hardness value that steel with a much lower density. The result of the comparison shows that heat treated aluminium 7075 is a viable substitute in making medical tools.

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CHAPTER 1

1.0 INTRODUCTION

1.1 Background

Technological advancement has affected the various industries such as in the manufacturing sector which opens the way for the increase in demands of natural resources, especially metal for fabrication of vehicle, equipment etc. One of the materials commonly used in the industry is aluminium, as the material's alloy has very good mechanical properties, low density and a high elastic framework and strength that is very useful in the manufacture of aircraft and car frames and metal equipment [1]. The wide use of aluminium is the industry will make it possible to increase the demand for aluminium in the near future.

The argument is backed by [2], where it is estimated that the demand for aluminium will increase by a factor between 2.6 and 3.5, more than the expected demand for steel ranging between 1.8 and 3.5. In the car manufacturing industry, fuel consumption can be reduced by about 5 to 7% by using aluminium instead of steel for every 10% reduction in weight that supports increased use of the material [3]. However, rising demand would pose a serious problem which contributes to the decline in our quality of the environment.

Overall raw material production contributes 25% of global carbon dioxide (CO_2) emissions and aluminium production accounts for 3% of the total emission [2]. Based on the statistics, finding a solution to which the effect on the environment is a reasonable thought, and one of the solutions is to recycle the industry-produced aluminium waste. Recycling aluminium waste provides a significant effect in the effort to preserve the environment [4].

It could also be cost-effective to use waste aluminium. Aluminium could be cheaper than stainless steel which is more costly with rising grade depending on the usage. Nonetheless, aluminium processing itself is costly as the process absorbs very current value for the electrolytic reduction process, where the power consumption may account for up to 40% of the total production cost [3].

Different efforts have been made in the recycling of aluminium, and the conventional method is to melt the aluminium scraps and cast them as billets, while another approach is to use pre-compaction and hot aluminium chip extrusion to create about the same mechanical properties as the conventional method [2]. Through the numerous recycling campaigns, the recycled commodity is hoped to be able to serve as a replacement material for some of the costly metals used in the industry today without losing the properties of the substituted material such as the use of titanium in medical appliances.

In the medical sector, titanium has been commonly used in the manufacture of the equipment since the 1970s primarily due to its high strength and strong corrosion resistance by alloying it with other elements such as aluminium and vanadium. [5]. This research will therefore observe the possibility of aluminium waste alloy as a replacement material for medical equipment manufacturing without affecting the material's initial mechanical properties. The statement of the problems will be defined in the next part for a clearer view of the research purposes.

1.2 Problem Statement

The pollution contributed by material production of aluminium is recorded as high as 3% from the global CO_2 emission which reduces the quality of the environment. Due to the statistic, various efforts have been done to recycle the aluminium chips that is produced during material fabrication and re-use the recycled product to reduce the effect on environment.

Furthermore, the usage of titanium alloys or stainless steel for appliances in the medical fields also is very costly but provides good properties that is suitable for its application. Through the usage alternative materials that has properties at par with the currently used materials with cheaper price, cost of appliances could be reduced.

Aluminium billets that consists of scrap aluminium chips has the possibility of decrease in mechanical properties due to the consolidation of metal chips. Selection of suitable recycled aluminium alloy and manufacturing process would improve the quality and guarantee the desired mechanical properties. The suggested alloy to be studies is Aluminium 7075 because of its excellent mechanical properties.

Currently, usage of titanium alloy that contains vanadium has corrosion issues where vanadium ion is released into the bloodstream and cause health concerns for patients. Studies had been done to find potential material substitute that has mechanical properties at par with the currently used titanium alloy and solve the problem. Testing on aluminium 7075 will be one of the step taken towards that objective.

The following section will describe the objectives of this research and outline the scope of study for a better understanding of research goals and the area where the research is focused on.

1.3 Objective and Scope of Study

The objectives and scopes of study is proposed in the following part to ensure the project is conducted with a set target, and at the same time does not exceed the defined boundary of the research to produce the desired output.

Based on the initial study, the objectives of the project are listed below:

i. To prepare Aluminium 7075 under different temperature and time duration.
ii. To study the effect of heat treatment towards material integrity of Aluminium 7075.
iii. To compare heat treated Aluminium 7075 through microhardness test and density test.

The scope of study for this project is as listed below:

i. To determine the method and parameters of heat treatment process to be conducted on the Aluminium 7075.
ii. To conduct the heat treatment process on the aluminium alloy.
iii. To cut the aluminium alloy sample and conduct material integrity testing for each of the samples and study the results.
iv. To compare the results of the testing between samples that produce the maximum and minimum values, and untreated sample.

The initial project research theory on the heat treatment process, and related testing is documented in the next part of the report for a deeper understanding on the decision-making process and project execution.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Aluminium Alloys

Aluminium is one of the metals that is highly available throughout the earth. Aluminium accounts for roughly 8% of the Earth's stable surface weight [3], [6]. The special characteristic of aluminium that is the reason why it is very sought for is its high strength compared to its lightweight properties, durability, etc, by alloying with other elements or composites such as Fe, Cu, etc in Aluminium 7075 [3], [7]. Aluminium 7075 with the addition of high Zinc content as an alloying element also shows especially high strength and many aging methods have been used for the said material [8]. Thus, with the predicted demand of aluminium to be increasing in the future, it is a valid choice to select aluminium alloy as potential substitute material for medical appliances.

There are 2 major classification of aluminium alloys, which are cast and wrought aluminium alloy. Focusing on the wrought alloy, based on the Aluminium Association system, the wrought aluminium alloys is further classified using a four-digit system starting from 1xxx to 9xxx series. Out of all the series, the 7xxx series that has Zinc as the primary alloying element is the strongest aluminium alloy and is suitable for high strength application [9]. However, its drawback is that, taking aluminium 7075 as example, the fatigue strength is lower compared to steel where in high fatigue conditions, fatigue endurance of aluminium 7075 are at 5 million cycles with maximum stress resistance of 140-160 MPa [1].

TABLE 2.1 Wrought Aluminium Alloy Designation System

Alloy Series	Principal Alloying Element
1xxx	Aluminum (99.000% minimum)
2xxx	Copper
3xxx	Manganese
4xxx	Silicon
5xxx	Magnesium
6xxx	Magnesium and silicon
7xxx	Zinc
8xxx	Other elements

The statement concluded that applications that involves high fatigue conditions, aluminium 7075 is not a viable substitute material without conducting mechanical properties enhancement process beforehand such as using severe plastic deformation for material grain refinement [10]. Taking the issue into consideration, basic medical appliances are normally not operated in such harsh condition. Improving the mechanical properties of aluminium 7075 could also be considered to achieve better performance thus, the alloy is suitable to be selected as a material for medical appliances.

The next part will involve in the theory of heat treatment process that will be conducted in this research, which in theory is capable of improving material mechanical properties.

2.2 Heat Treatment

Heat treatment process is a treatment for metal that has said to be able to improve their properties. Through the process, the microstructures are affected in the terms of precipitates behaviour, grain size and the changes in mechanical as well as corrosion resistance [8]. A study done by [11], found that after heat treatment is done on welded zone of material Aluminium 6065, the hardness of the joint increased by almost 50 MPa as the aging treatment causes the structure of the metal to be more uniform throughout the solid. According to the study, the mechanical performance of Aluminium 7075 can also be improved by heat treatment process as illustrated in [11, Fig. 1].

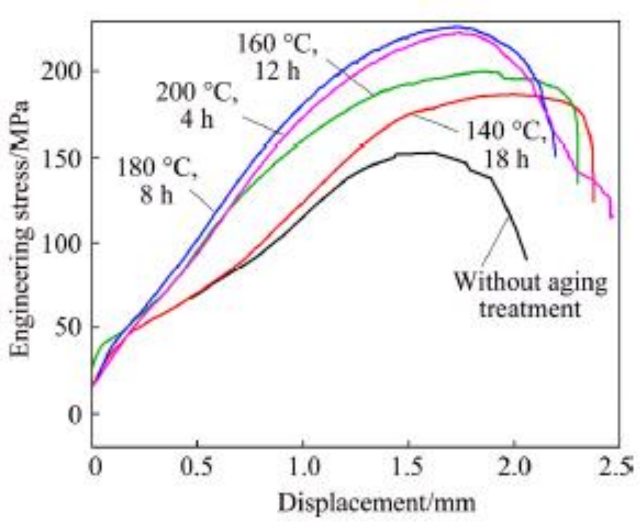

FIGURE 2.1 Uniaxial Tensile Stress-Displacement Curves

Increase in mechanical performance also includes the increase in hardness values of a material when heat treatment is conducted. According to [12], Ni-P-TiN coatings was reported to have increase in microhardness and has the highest corrosion resistance after being heat treated at 500°C.

The surface of metal in heat treatment undergoes changes after the process. The heat treatment process hardens the outer part of a metal and encapsulate the soft part which will absorb impacts thus increases its strength. It is usually done at an elevated temperature and the time is varied. According to a study done by [13], as the heat treatment increases, the hardness measurement does not necessarily increase as well. The result shows that initially the hardness value increases for the heat-treated sample for 2 hours, but then decreases as the time increases, but still above the untreated sample [12, Fig. 2].

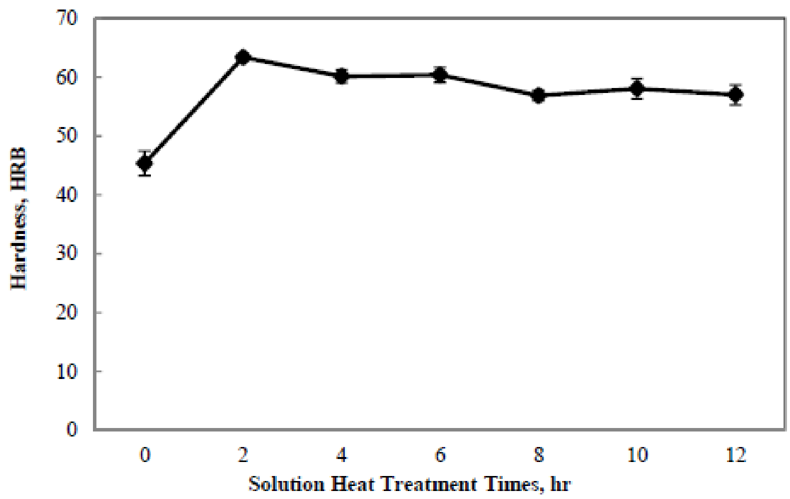

FIGURE 2.2 Hardness Variation of Heat Treatment at Temperature 520°C

The result is due to the fragmentation of Silicon particles at short heat treatment time, while longer heat treatment time reduces the vacancies between the particles and forming distortions, causing fewer precipitates and slowing down the increase in material strength. This statement is also in line with another study that produces the same hardness test patterns and discussed that higher holding times will cause the softening of the composites in the material [14].

To see the maximum hardness value that a material could achieve, heat treatment study on the material must be done with different sets of temperature values and the durations of each treatment process. Further added by [13], the heat treated aluminium alloy experiences increase in hardness value and then the value started to decrease because of overaging, where the hardness drops due to extensive aging that resulted in precipitation to be at the equilibrium phase. Thus, this study will also observe the result and compare the findings to see the correlation between the hardness value, density and heat treatment duration.

The project flow and methods will be explained in the next part of the report to have a focused view on the test that will be conducted as well as the timeline of the project starting from project initiation until completion.

CHAPTER 3

3.0 METHODOLOGY

3.1 Process Flow Chart

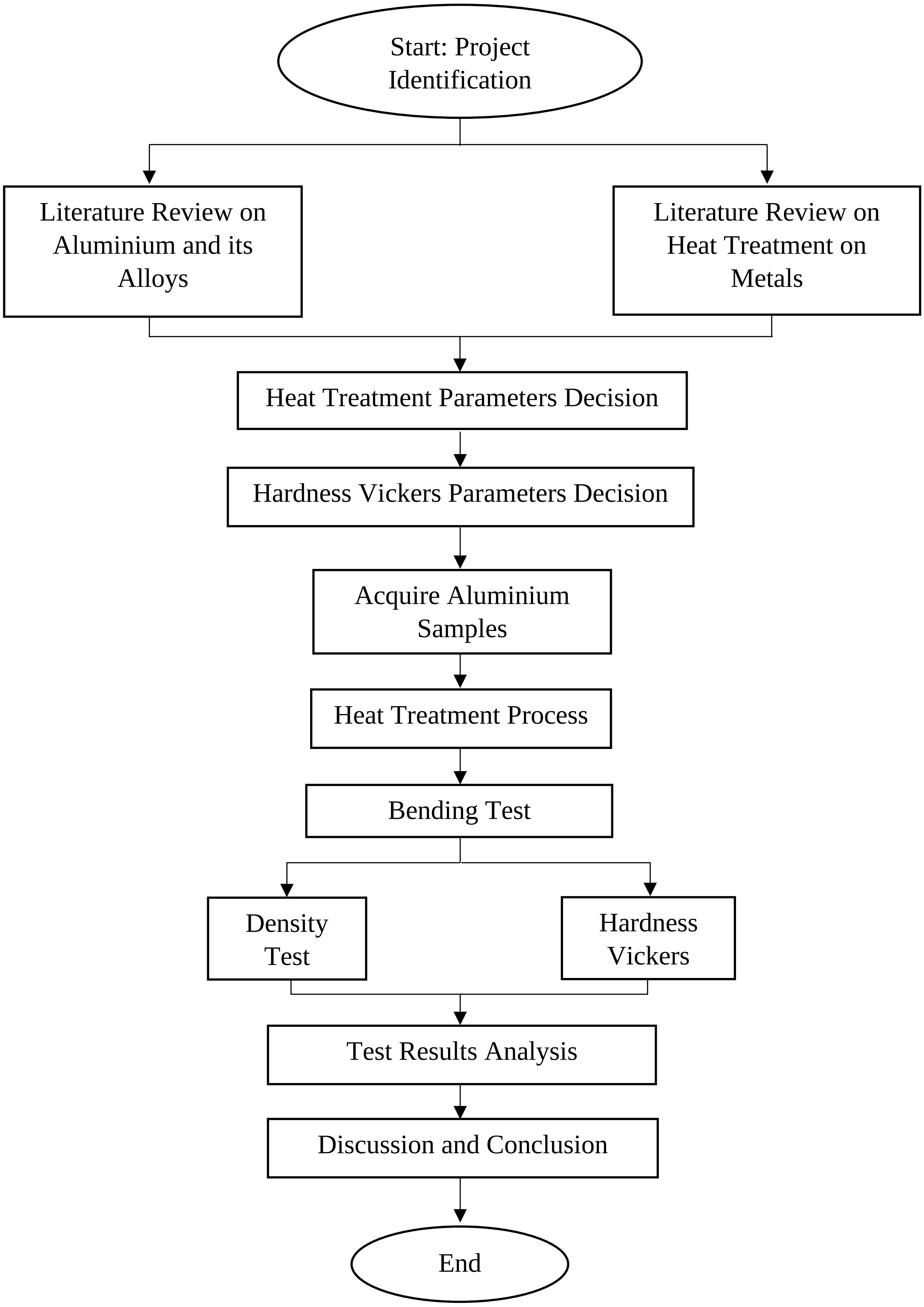

FIGURE 3.1 Project Flow

3.2 Design of Experiment

This part of the report is to show the preparation to proceed for material integrity testing before conducting the heat treatment process for smooth completion of testing.

3.2.1 Heat Treating Parameters

The heat treatment process requires the decision on two variables, which are the temperatures, and the aging time. Counting the variables into factor, the available equipment specification must be known, such as the maximum operating temperature of the equipment, which in this case, the oven. The oven available in the UTP Mechanical Department Block 17 has a maximum operating temperature of 150°C and the parameters of the heat treatment is as list in Table 2 below.

TABLE 3.1 Heat Treatment Parameters

Sample Name	Temperature (°C)	Aging Time (hours)
HT110-1	110	1
HT110-3	110	3
HT110-5	110	5
HT130-1	130	1
HT130-3	130	3
HT130-5	130	5
HT150-1	150	1
HT150-3	150	3
HT150-5	150	5

Maximum operating temperature of the oven is 150°C, thus the decided temperature values are 110°C, 130°C and 150°C, utilizing the maximum temperature value and 20°C difference in temperature. The aging time are 1, 3 and 5 hours for each of the temperature values. 9 samples will undergo heat treatment based on the decided parameters and 1 sample will left untreated for the comparison of result at the end of the project to see the difference in effects of heat treatment process.

3.3 Material Testing

The bending test will be conducted on the Aluminium 7075 plates after the heat treatment and the resultant product will be cut into several pieces for the several testing that shall be conducted. The 10 samples that has undergone bending test including the untreated sample will undergo Density Test and Microhardness Vickers test.

3.3.1 Density Test Method and Equipment

The first test that will be conducted is a density test to gain the density of the material by using a gas pycnometer machine. Density is obtained using the volume and mass to calculate density of a material. The tools and materials required for this test is a weighing scale, gas pycnometer and the samples. The purpose of this test is to see whether the heat treatment has an effect on the density of the material as theoretically, heat treating will change the structure of the material. Material packing or bulk density is important in material selection as it affects the performance of an equipment or machine [15].

$$Density\ \left(\frac{g}{cm^3}\right) = \frac{Mass\ (g)}{Volume\ (cm^3)} \qquad (1)$$

FIGURE 3.2 AccuPyc II 1340 V3.00

Sample is first weighed using a weighing scale to find the approximate mass of the sample and then placed into a cartridge and inserted into the gas pycnometer machine. Density of the sample is calculated using the mass and volume obtained using equation (1) and the density test is repeated 10 times. The density data is then averaged, and the resultant values are plotted into graphical form. The usage of gas pycnometer is decided based on a study that conducted density readings on plutonium aluminium alloy using both Archimedes method and gas pycnometer machine [16]. Based on the study, gas pycnometer produces improved accuracy of 0.002 compare to 0.02 by using Archimedes technique. Thus, the usage of gas pycnometer is justified.

3.3.2 Microhardness Vickers Test Method and Equipment

Heat treatment on metal will harden the outside part of the metal and one of the ways to measure the level of hardening is by Microhardness Vickers Test. The test involves creating a square pyramidal-shaped indentation on the surface of sample at a specific force value by a diamond indenter and the Vickers hardness value (HV) is calculated by measuring the width and length of the pyramidal-shaped indentation. The advantage of using Vickers hardness method is that the indentation produced is geometrically similar and is independent of the load force value unlike the indentation methods that use spherical indenters and is dependent on depth of indentation [17].

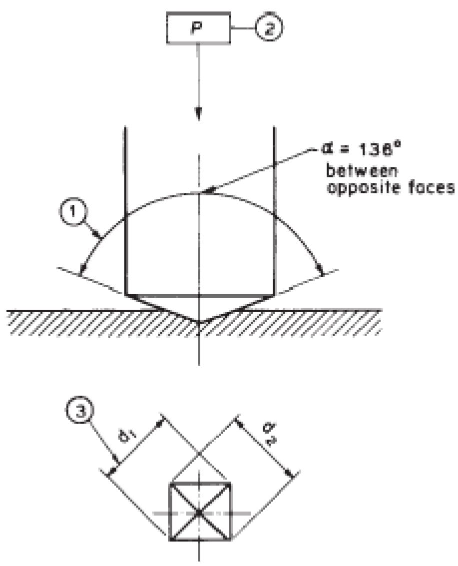

FIGURE 3.3 Vickers Hardness Test

$$HV = (2P\sin(\frac{\alpha}{2}))/(d^2) = \frac{1.8544P}{d^2} \qquad (2)$$

where:

P = force, kgf

d = mean diagonal of impression, mm

α = face angle of diamond = 136°

The Vickers hardness value is calculated using equation (2), where the varying values for the calculation is P, the indentation force and d, the mean diagonal impression [18]. However, value of m depends on the indentation itself and only indentation force is set beforehand. A suitable value for the indentation force is based on a study by [19] on 2219 aluminium, where the researcher set the force value at 300gf. In this project, considering aluminium alloy is the material which are similar to the study, the same indentation force is used.

The next part is the projection of project timeline for FPY I and FYP II as a guideline for the project to finish smoothly from project research, decision making, material acquisition, testing and the analysis and documentation of test results.

3.4 Gantt Chart and Milestones

Semester	**September - December 2019**														**January - May 2020**													
Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Phase 1																												
Understanding Project Requirements	X	X	X																									
Literature Review			X	X	X	X	X	X	X																			
Heat Treatment Parameters Decision										X																		
Testing and Equipment Decision										X	X	X																
Phase 2																												
Material Acquisition													X	X	X													
Test Equipment Booking																X	X	X	X									
Heat Treatment on Samples																				X	X							
Post-Heat Treatment Processing																						X						
Phase 3																												
Gas Pycnometer Density Test																							X					
Microhardness Vickers Test																								X				
Test Results Analysis and Documentation																								X	X	X	X	
Phase 4																												
Submission of Dissertation and Video Presentation																												X

Expected Progress

X Actual Progress

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 Sample Heat Treatment and Tests Preparation

The 9 samples for heat treatment and 1 untreated sample were acquired and at the same time, the equipment for heat treatment and material testing are booked such as the oven, gas pycnometer and Vickers microhardness testing machine. For the heat treatment process, each of the samples is placed on a tray and placed into the oven based on the set parameters. Temperature is allowed to first rise to the desired temperature, and then the sample is placed inside for the desired time duration.

FIGURE 4.1 Oven for Heat Treatment

After each heat treatment duration is completed, the sample is left outside and be quenched by air at room temperature for about 1 hour or until it is fully cooled. Based on the heat treatment technique for improving mechanical properties of aluminium alloy by appropriate heating and subsequent cooling explained by [13], quenching is an important part of the hardening process where supersaturated solid saturation is obtained. Through that process, material strength will increase.

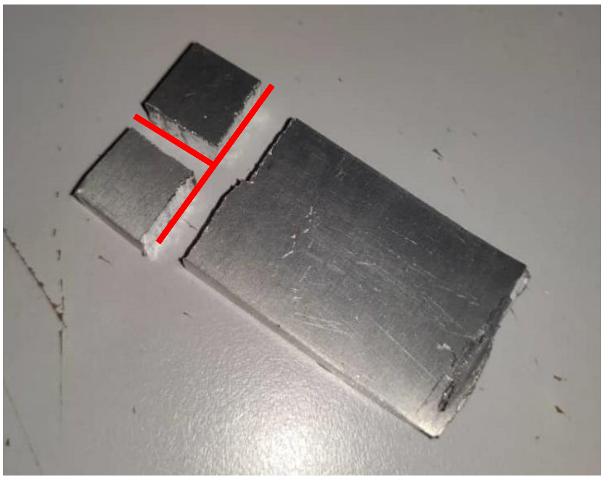

FIGURE 4.2 Sample Cutting for Testing

The 10 samples were then put to bending test and the end of the plates are cut into 2 small parts with the dimension of roughly 10mm x 10mm using a hand saw, each for the density test and microhardness test as shown in Figure 7 above.

4.2 Density Test Results

Each of the 10mm x 10 mm piece from 9 heat treated samples and 1 untreated sample were put into a gas pycnometer machine to accurately measure the density of the samples. The gas pycnometer uses Helium gas as the analysis gas and conducted at around 25°C temperature. The mass of a sample is weighed beforehand, and the volume is calculated by employing gas displacement method. The results of the density test conducted using the gas pycnometer device is as shown in Table 3 and Figure 8.

TABLE 4.1 Average Density Results

Sample	Average Density (g/cm^3)
HT110-1	2.8014
HT110-3	2.7970
HT110-5	2.7981
HT130-1	2.7984
HT130-3	2.7995
HT130-5	2.7990
HT150-1	2.7950
HT150-3	2.7999
HT150-5	2.7974
UNT	2.7977

Analysing the average density result for temperature 110°C, for time duration of 1 hour, the density increases significantly from the untreated value represented by the red line. However, the density value drops below the untreated level and started increasing slightly above the untreated level at the 5-hour mark. Taking only the density into factor, based on the results, at 1-hour duration the increase in density is only due to its volume since the mass is constant. It is possible that after cooling the volume of sample decreases and become more compact.

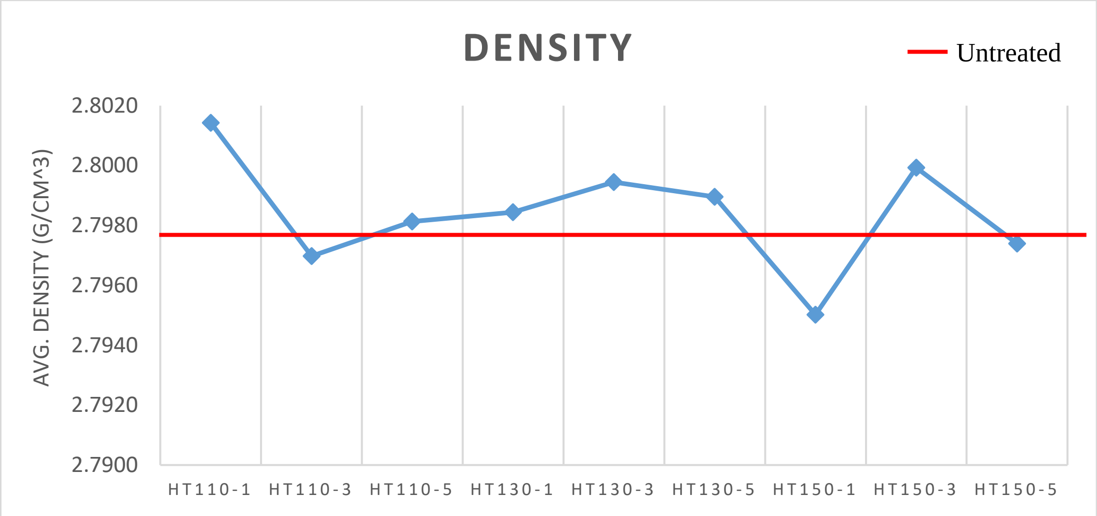

FIGURE 4.3 Graph of Density Test Results

At temperature 130°C, density of sample for the 1-hour duration increases above the untreated level and reaches its peak at the 3rd hour before showing the slight decrease in value. The increase and decrease trend are also similar to the samples subjected to heat treatment at temperature 150°C. However, for HT150-1 there is a sharp decrease in density below the untreated value but spiked significantly at the 3-hour mark before dropping again slightly below the red line at the 5th hour.

The overall summary for the trend in average density values for the heat-treated samples is the trend for temperatures 130°C and 150°C is similar, as the density is highest at the 3-hour duration. On the contrary to samples at temperature 110°C, the 3-hour sample is resulted in the lowest density value for the temperature point. However, the temperature that produces the most consistent results in having densities above the untreated sample is the samples at 130°C.

Measurement of the gas pycnometer is accurate to 0.0001 accuracy. Thus, if there is any flaw with the measurement, it would be the mass weighing part because the sample is weighed on a weighing scale manually. The trend gained from the density test results will be compared with the results from the microhardness test in the next part of the report.

4.3 Vickers Microhardness Test Results

The 2nd piece that are cut from the heat-treated samples are subjected to Vickers Microhardness Test. Based on [19], 300 gf is used as the indentation force for the test and since the material tested in this project is also aluminium alloy, the same indentation force should be suitable. Although the indentation depth does not play a role in Vickers microhardness, a comparison between indentation force of 300 gf and 200 gf is done to see the difference in indentation produced. In Figure 9 shows the indentation observed resulting from force of 200 gf and 300 gf.

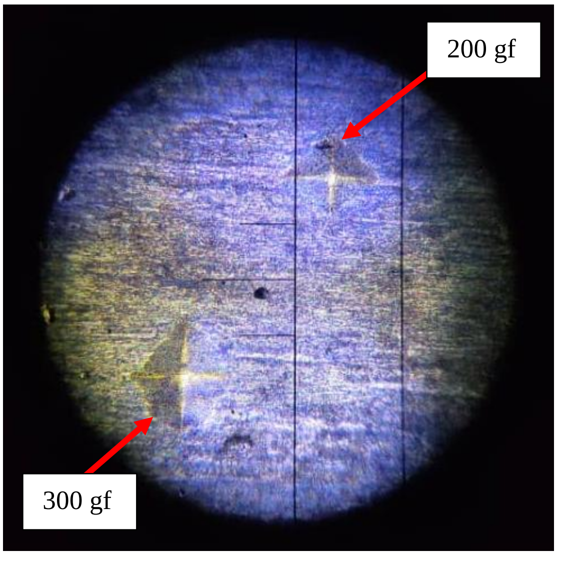

FIGURE 4.4 Indentation Resulting from 200 gf and 300 gf

Indentation formed from 200 gf is expectedly smaller compared to indentation using 300 gf. Considering that the length of diagonal of impression using the Vickers Microhardness equipment available is obtained manually, a bigger and clearer indentation is favourable for more accurate results. Thus, indentation for of 300 gf provides better observable indentation and is suitable to be used in the testing. 10 measurement were taken on the surface of the sample piece as shown in Figure 10 and the readings are averaged and presented in Table 4.

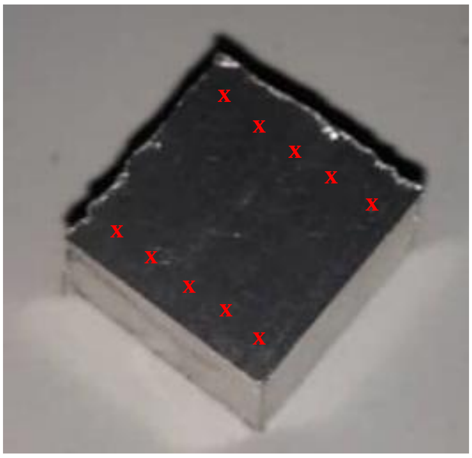

FIGURE 4.5 Measurement Points for Vickers Microhardness

TABLE 4.2 Average Vickers Microhardness Test Results

Sample	Average Vickers Hardness (HV)
HT110-1	161.58
HT110-3	166.68
HT110-5	175.51
HT130-1	180.35
HT130-3	169.68
HT130-5	175.91
HT150-1	158.54
HT150-3	155.41
HT150-5	175.92
UNT	168.87

The results obtained from the Vickers microhardness test shows that for temperature 110°C, hardness increase with increasing time of heating, while for temperatures 130°C and 150°C, for each of the 3-hour heating duration, the hardness drops in value similar to the trend displayed in the density test results where there are sudden increase and decrease in values as shown in Figure 11. Comparing between the trend of all the samples, all the 130°C samples are above the untreated line, thus favouring temperature point instead of the others. The result also shows that hardness value for HT130-1 has the highest average hardness among all the samples.

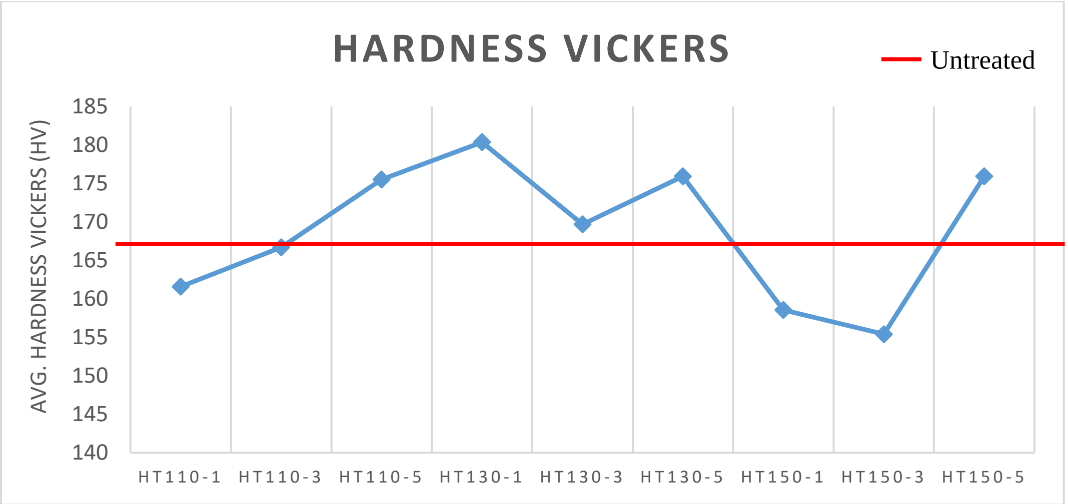

FIGURE 4.6 Graph of Vickers Microhardness Test Result

4.4 Maximum, Minimum, and Untreated Results Comparison

Based on the two test results, the maximum and minimum values are selected and compared to the untreated values. Figure 12 shows the comparison of the selected samples. The minimum value is determined to be HT150-1 where among the samples, it has the highest decrease in density and hardness compared to the untreated sample. On the other hand, the maximum value is HT130-1 because the density for all three time durations for samples of temperature 130°C is about the same values. Thus, the deciding factor is the hardness value which trumps all the hardness among the samples.

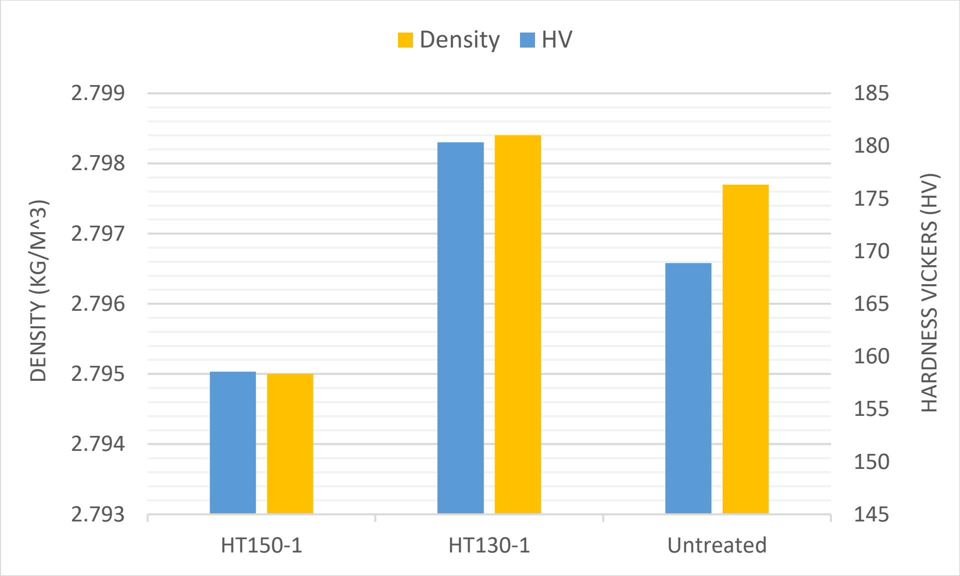

FIGURE 4.7 Graph of Maximum, Minimum and Untreated Results

HT150-1 resulted in having the lowest density among all the samples and also among the two lowest in hardness values that is because of insufficient heat treatment duration. However, according to the trend of the graph for both tests at 150°C, the highest density recorded is at 3 hour but produces the lowest hardness value, then the hardness increases but density decreases to the untreated value. Thus, a 5-hour duration are most probably still not sufficient and heat treatment at 150°C are not recommended because of the long duration of heat treatment.

On the contrary to that, sample HT130-1 returns the highest hardness value while producing an average increase in density, but higher than the density of the untreated sample. Based on the recorded results trend, if the sample is heated at 130°C for more than 1 hour, the density increases but hardness drops significantly. Thus, heat treatment at 130°C for 1 hour is the best temperature and time duration for the aluminium 7075 samples used in this study.

The results obtained has to be compared to the material that is used as medical tools and in this case the example is a surgical scalpel. A scalpel is usually using stainless steel as its material. Known density and hardness values of 316 stainless steel are at 8 g/cm^3 and 152 HV. As long as hardness is concerned, the hardness produced by sample HT130-1 is at an average of 180 HV and far exceeds the hardness of the stated stainless steel. However, the density of the sample is at around 2.8 g/cm^3 and is far less than the density of stainless steel. Based on the comparison of values, it is determined that heat treated aluminium 7075 at 130°C for 1-hour duration can indeed be a viable substitute material for medical tools because of higher hardness value and lightweight properties of the material compared to 316 stainless steel.

The next part of this report will conclude and summarizes this study and provide some recommendations that can be applied for future related studies.

CHAPTER 5

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The purpose of the study is to consider aluminium 7075 waste as a potential substitute for medical tools in material by optimizing forging parameters based on the results of material integrity testing. Heat treating waste aluminium 7075 plates at 110°C, 130°C and 150°C at different time durations produces a mixed trend of increasing and decreasing of hardness value and density.

At temperature 110°C, the density peaks at 1 hour but has lower hardness values compared to the untreated sample which indicates material softening after heat treatment. Increasing the time duration until 5 hour shows improvements but does not produce the highest hardness value and signifies that at 110°C, duration of heat treatment should be increased further. The same trend is shown for temperature 150°C where the results promotes higher heat treatment duration.

The best result is presented by sample HT130-1 which is heat treated at 130°C for 1 hour. The hardness recorded the highest value among all the samples despite the slight increase in density compared to the untreated sample. However, increasing the duration of the heat treatment may cause the precipitation in the material to be out of phase and cause the hardness of the material to drop. Nevertheless, by heat treating aluminium 7075 at 130°C for 1 hour produces a viable substitute for making medical tools that is usually manufactured using stainless steel.

To summarise, the objectives of this study is to conduct heat treatment and conduct material integrity testing on the samples were successfully carried out. The next part will discuss on the recommendations for future related studies.

5.2 Recommendations

This study focuses on the hardness and density values effects by heat treatment. The variation in temperature and heat treatment durations should be further improved by increasing the heating duration and temperature at a lower step size. The heat treatment should also be conducted at a lower or higher temperature range which are at less than 100°C or higher than 150°C.

Besides that, the Vickers microhardness test is highly dependent on the human eye competency and it varies from person to person. The equipment used for this study had reportedly using a low-quality lightbulb and causes the magnification image to be blurry. The samples are recommended to be polished so that there is better reflection of light on the surface and easier for the eye to determine the diagonal of impression and produce better and consistent results.

The density and hardness are also directly correlate with the microstructure of the material and optical micrographs should be used to study the formation of precipitation of the material. In addition to that, the percentage of elements in the material will vary the hardness and density of material and SEM-EDX test can be done to determine the phase and composition of the material.

Further study to increase the density of heat treatment aluminium 7075 can also be done by work hardening process. Increasing the density will strengthen the material and reducing the chances of material failure. Medical tools should comply with ISO13485 and the failure rate for a substitute material for medical tools should be very low because it involves human health concerns.

6.0 REFERENCES

[1] P. Tsai, T. Li, K. Hsu, J. Ke, J. Jang and J. Chu, “Coating thickness effect of metallic glass thin film on the fatigue-properties improvement of 7075 aluminium alloy,” *Thin Solid Films,* vol. 677, pp. 68-72, 2019.

[2] D. Baffari, A. P. Reynolds, A. Masnata, L. Fratini and G. Ingarao, “Friction stir extrusion to recycle aluminum alloys scraps: Energy efficiency characterization,” *Journal of Manufacturing Processes,* vol. 43, pp. 63-69, 2019.

[3] P. K. Krishnan, J. V. Christy, R. Arunachalam, A.-H. I. Mourad, R. Muraliraja, M. Al-Maharbi, V. Murali and M. M. Chandra, “Production of aluminum alloy-based metal matrix composites using scrap aluminum alloy and waste materials: Influence on microstructure and mechanical properties,” *Journal of Alloys and Compunds,* vol. 784, pp. 1047-1061, 2019.

[4] A. Tripathy, S. Mahalik, C. Sarangi, B. Tripathy, K. Sanjay and I. Bhattacharya, “A pyro-hydrometallurgical process for the recovery of alumina from waste aluminium dross,” *Minerals Engineering,* vol. 137, pp. 181-186, 2019.

[5] K. Wang, “The use of titanium for medical applications in the USA,” *Materials Science and Engineering,* vol. A213, pp. 134-137, 1996.

[6] J.-P. Goullé and L. Grangeot-Keros, “Aluminum and vaccines: Current state of knowledgeAluminium,” *Médecine et maladies infectieuses,* vol. Article in Press, pp. 1-6, 2019.

[7] J. Lakshmipathy and B. Kulendran, “Reciprocating wear behavior of 7075Al/SiC in comparison with 6061Al/Al2O3 composites,” *Int. Journal of Refractory Metals and Hard Materials,* vol. 46, pp. 137-144, 2014.

[8] M. A. Khan, Y. Wang, M. J. Anjum, G. Y. Abdul Malik, F. Nazeer, S. Khan, T. Ahmad and H. Zhang, “Effect of heat treatment on the precipitate behaviour, corrosion resistance and high temperature tensile properties of 7055 aluminum

alloy synthesis by novel spray deposited followed by hot extrusion," *Vacuum,* vol. 174, no. 109185, 2020.

[9] J. Davis, "Aluminum and Aluminum Alloys," in *Alloying: Understanding the Basics,* ASM International®, 2001, pp. 351-416.

[10] T. S. Ben Naser, and G. Krallics, "Mechanical Behavior of Multiple-forged Al 7075 Aluminum Alloy," *Acta Polytechnica Hungarica,* vol. 11, no. 7, pp. 103-117, 2014.

[11] J. Yi, G. Wang, S.-k. Li, Z.-w. Liu and Y.-l. Gong, "Effect of post-weld heat treatment on microstructure and mechanical properties of welded joints of 6061-T6 aluminum alloy," *Trans. Nonferrous Met. Soc. China,* vol. 29, pp. 2035-2046, 2019.

[12] M. S. Safavi and A. Rasooli, "Ni-P-TiO2 nanocomposite coatings with uniformly dispersed Ni3Ti intermetallics: Effects of current density and post heat treatment," *Surface & Coatings Technology,* vol. 372, pp. 252-259, 2019.

[13] R. Canyook, R. Utakrut, C. Wongnichakorn, K. Fakpan and S. Kongiang, "The effects of heat treatment on microstructure and mechanical properties of rheocasting ADC12 aluminum alloy," in *Materials Today,* Bangkok, 2018.

[14] S. Sharma, T. Nanda and O. Pandey, "Investigation of T4 and T6 heat treatment on the wear properties of sillimanite reinforced LM30 aluminium alloy composites," *Wear,* no. 426-427, pp. 27-36, 2019.

[15] M. H. Eisenbies, T. A. Volk, O. Therasme and K. Hallen, "Three bulk density measurement methods provide different results for commercial scale harvests of willow biomass chips," *Biomass and Bioenergy,* vol. 124, pp. 64-73, 2019.

[16] O. Ast*, M. Perez and S. Carlet, "PuAl alloys density measurements using gas pycnometer: First results," *Journal of Alloys and Compounds,* Vols. 444-445, pp. 226-229, 2007.

[17] M. Tiryakioðlu and J. Robinson, "On the representative strain in Vickers hardness testing of 7010 aluminium alloy," *Materials Science & Engineering A,* vol. 641, pp. 231-236, 2015.

[18] A. International, "Standard Test Method for Vickers Hardness of Metallic Materials," in *Annual Book of ASTM Standards,* West Conshohocken, PA, American Society for Testing and Materials, 2003, pp. E 92-82.

[19] Z. Li, M. Zhan, X. Fan, X. Wang and F. Ma, "Age hardening behaviors of spun 2219 aluminum alloy component," p. 11, 28 February 2020.