Quest Journals
Journal of Research in Mechanical Engineering
Volume 8 ~ Issue 10 (2022) pp: 01-09
ISSN(Online):2321-8185
www.questjournals.org

Research Paper

Simulation of Heat Treatment Procedure for Aluminium Alloy Using Matlab Programming

Uhuami Abdulwahab[1] M. B Ndaliman[2], O. A Olugboji[2], & K. C. Bala[2]
[1]*Industrial Training Fund, Industrial Skills Training Centre, Lokoja, Kogi State, Nigeria*
[2]*Department of Mechanical Engineering, Federal University of Technology*
Minna. Niger State, Nigeria

ABSTRACT: *Temperature of aluminum alloy is simulated using MATLAB programming language for annealing, soaking to have uniformity of microstructure and quenching treatment processes. Workpiece selected for the study was aluminum alloy 6061-O, T1, T4 and T6 of different shapes: plate, cylindrical, rectangular, cubic and spherical aluminum alloy. The simulation identified the following properties: geometry (size), thermal conductivity, density, load pattern or shape which determine possibility of good heat treatment. Temperature of treated specimen were analyzed using Finite Difference Method. At annealing temperature of 409.5 ^oC, fracture resistance of 670.5MPa and ultimate tensile strength value 298 MPa were achieved with 4% of ductility. Holding this temperature of 409.5 ^oC was necessary for achieving uniform microstructure at about 600 seconds which later quenched in water for 799 seconds to room temperature of 28 ^oC. Therefore the aluminum has equivalent length (thickness) treated of 25mm in plate section. The workpiece in the study increases in strength with increase in temperature for annealing therefore increases in thermal conductivity of the specimen was experienced. However, heat treatment in plate section of aluminum (6061-O) was faster in comparing to rectangular and cylindrical surfaces. Heat transfer coefficient was 1384W/m^{2}K in plate and 692 W/m^{2}K in cylindrical specimen of Biot number 0.2. The heat treatment processing was completed after 2256 seconds and aluminum 6061-O is more easily heat treatable to aluminum 6061- (T1, T4, T6) under the same condition.*
KEYWORDS: *Heat Treatment, Annealing, Quenching, Biot Number*

R*eceived 13 Oct., 2022;* ***R****evised 26 Oct., 2022;* ***A****ccepted 28 Oct., 2022 © The author(s) 2022.*
P*ublished with open access at* ***www.questjurnals.org***

I. INTRODUCTION

Planning and scheduling are decision-making processes that are used on a regular basis in most manufacturing and service industries [1]. These forms of decision-making play an important role in procurement and production, in transportation and distribution, and in information processing and communication [2].

In heat treatment planning process, decision making method which tends to improves Aluminum Alloy samples of various geometry functionability is very necessary [3]. Heat treating is an industrial metalworking processes used to alter the physical, and sometimes chemical, properties of material [4]. The most common application is metallurgical process [5]. Heat treatments are also used in the manufacture of many other materials, such as glass [6]. Heat treatment involves heating of material to extreme temperatures, to achieve a desired result such as hardening or softening of the material [7]. Heat treatment techniques in general include annealing, case hardening, precipitation strengthening, tempering and quenching. It is noteworthy that the term heat treatment applies only to processes where the heating and cooling are done for the specific purpose of altering properties of materials intentionally [8]. Heating and cooling often occur incidentally during other manufacturing processes such as hot forming or welding. Heat treatment is often associated with increasing the strength of material but, it can also be used to alter certain manufacturability objectives such as to improve machining, formability, restoring ductility after a cold working operation [9].

Heat treatment has contributed immensely to manufacturing industries by improving the quality and the mechanical properties of materials which are to be manufactured [10].

Therefore, the objective of this paper is to design an interface using MATLAB software that will be used to analyse and predict the annealing temperature, soaking temperature quenching temperature and to also investigate the rate of heat transfer in the workpiece using Biot number.

II. HEAT TREATMENT

Heat treatment of a metal or alloy is a technological procedure which involves controlled heating and cooling operations, conducted for the purpose of changing the alloy microstructure to achieve required properties [11]. There are two common processes of heat treatment and they include hardening and annealing [12].

(i) Alloying Elements in Aluminum

The alloying elements commonly used in heat treatment of aluminum alloys include copper, silicon, magnesium, manganese and occasionally, zinc, nickel, titanium and chromium [13]. The overall effect of alloy additions is to raise the tensile strength, yield strength and hardiness with corresponding reduction of percentage elongation. Alloying elements are added extensively to aluminum castings to improve casting qualities as well as mechanical properties [14]. In general, the 6000 series of heat treatable aluminum alloys are applied in a wide range of products, largely as extruded shapes, the principal applications of the 2000 and 7000 series alloys are in the aircraft and aerospace industries [14]. Modest inroads are being made by titanium alloys, beryllium and composite materials, but aluminum is still the principal structural material in both aircraft and missiles. Even in the new giant transport and passenger planes, as well as the supersonic Concorde, designers working with materials engineers have chosen aluminum as the major structural material [15].

(ii) Annealing Heat Treatment

Annealing is a heat treatment procedure involving heating the alloy and holding it at a certain temperature (annealing temperature), followed by controlled cooling. Annealing results in relief of internal stresses, softening, chemical homogenizing and transformation of the grain structure into more stable state [16]. According to [17], annealing is typically carried out to relieve stresses, increase softness, ductility, and toughness, to produce a specific microstructure and/or negate the effects of cold work. In annealing the material is exposed to an elevated temperature for a time and then slowly cooled.

III. MATERIALS AND METHOD

In this section, the main idea of the system coordinates relies on resolving these quantities onto horizontal and vertical components as in the Diagram 1, we obtain the position of the center of mass of the two rods, where (x_1, y_1) are the position of the inner bob and (x_2, y_2) is the position of the outer bob. To simply our numerical analysis, let us firstly discuss especially case when $m_1 = m_2 = m$ and$L_1 = L_2 = l$. That is, we consider two identical rods with ($I = \frac{1}{12}ml^2$). Assume that masses of rods can be neglected but their moment of inertia should be included to better reflect the physical system they represent.

(iii) Materials

The materials used in carrying out the experimental analysis include: Heat treatment of a metal or alloy is a technological procedure which involves controlled heating and cooling operations, conducted for the purpose of changing the alloy microstructure to achieve required properties [18]. There are two common processes of heat treatment and they include hardening and annealing.

(iv) Alloying Elements in Aluminum

The alloying elements commonly used in heat treatment of aluminum alloys include copper, silicon, magnesium, manganese and occasionally, zinc, nickel, titanium and chromium. The overall effect of alloy additions is to raise the tensile strength, yield strength and hardiness with corresponding reduction of percentage elongation. Alloying elements are added extensively to aluminum castings to improve casting qualities as well as mechanical properties. In general, the 6000 series of heat treatable aluminum alloys are applied in a wide range of products, largely as extruded shapes, the principal applications of the 2000 and 7000 series alloys are in the aircraft and aerospace industries. Modest inroads are being made by titanium alloys, beryllium and composite materials, but aluminum is still the principal structural material in both aircraft and missiles. Even in the new giant transport and passenger planes, as well as the supersonic Concorde, designers working with materials engineers have chosen aluminum as the major structural material [18].

(v) Annealing Heat Treatment

Annealing is a heat treatment procedure involving heating the alloy and holding it at a certain temperature (annealing temperature), followed by controlled cooling. Annealing results in relief of internal stresses, softening, chemical homogenizing and transformation of the grain structure into more stable state [19]. According to [20], annealing is typically carried out to relieve stresses, increase softness, ductility, and toughness, to produce a specific microstructure and/or negate the effects of cold work. In annealing the material is exposed to an elevated temperature for a time and then slowly cooled [20].

(vi) Methods

Heat is transferred in the process by three separate modes, conduction, convection and radiation or a combination of these three modes.

(vii) Conduction

Conduction is a flow of heat in response to a temperature gradient within an object or between objects that are in physical contact. It occurs in a stationary heat process medium. It is most likely to be of concern in solids, although conduction may exist to some extent in gases and liquids. Conduction is governed by Fourier's law, which states that 'the rate of flow of heat through a simple homogeneous solid is directly proportional to the area of the section at right angles to the direction of heat flow, and to change of temperature with respect to the length of the path of the heat flow [21].

(viii) Classification of Workpiece Shape

The Biot (Bi) number means the ratio of outside heat transfer coefficient to the conductive heat transfer coefficient inside the workpiece [22]. It is always used to assess the temperature uniformity of the workpiece.

$$Bi = \frac{ht_{eff}}{\lambda} \quad \begin{cases} < 0.1 \ lumped \\ otherwise \ massive \end{cases} \tag{1}$$

$$h = h_{conduction} + h_{convection} + h_{radiation} \tag{2}$$

$$\text{Plate, } t_{eff} = V/A \tag{3}$$

$$\text{Cylinder or bar with rectangular section, } t_{eff} = 2V/A \tag{4}$$

$$\text{Spherical object, } t_{eff} = 3V/A \tag{5}$$

$$\text{Cubic object, } t_{eff} = 3V/A \tag{6}$$

where: h is Heat transfer coefficient or heat flux in W/m^{2}K, t_{eff} Is equivalent thickness of the workpiece in m, V is workpiece volume in m^3 and A is workpiece surface area in m^2.

(ix) Convection

Convection can be defined as a method of transferring heat by the actual movement of heated molecules, usually by a freestanding unit such as a furnace [23]. This analysis is adopted for quenching process. The convection heat transfer is governed by Newton's law of cooling and given by [23]:

(x) Radiation

According to [24], radiation is a process by which energy, in the form of electromagnetic radiation, is emitted by a heated surface in all directions and travels directly to its point of absorption at the speed of light; thermal radiation does not require an intervening medium to carry it.

(xi) Temperature Distribution of Workpiece

Material/workpiece temperature depends on material properties, thermal conductivity, radiation heat transfer, and convection heat transfer during heat treatment [25]. In this process the workpiece is subjected to heat transfer media of convection and radiation. Therefore temperature in this region is distributed and thus calculated using Finite Difference Method as follows:

Let energy (E_H) required in Joules for heat treatment process equals:

$$E_H = E_{conv} + E_{rad} \tag{7}$$

$$E_{conv} = hA(T_{av} - T_{mat}) \tag{8}$$

$$E_{rad} = \varepsilon\sigma A(T_{heater} - T_{mat}) \tag{9}$$

The heat stored in the workpiece are based on forward and backward Taylor series expansions of $f(t)$ about $time\ (t)$ such as [26] as shown in equation (10), (11) and Figure 1:

$$f(t+h) = f(t) + hf'(t) + \frac{h^2}{2!}f''(t) + \frac{h^3}{3!}f'''(\theta) \tag{10}$$

$$f(t-h) = f(t) - hf'(t) + \frac{h^2}{2!}f''(t) - \frac{h^3}{3!}f'''(\theta) \tag{11}$$

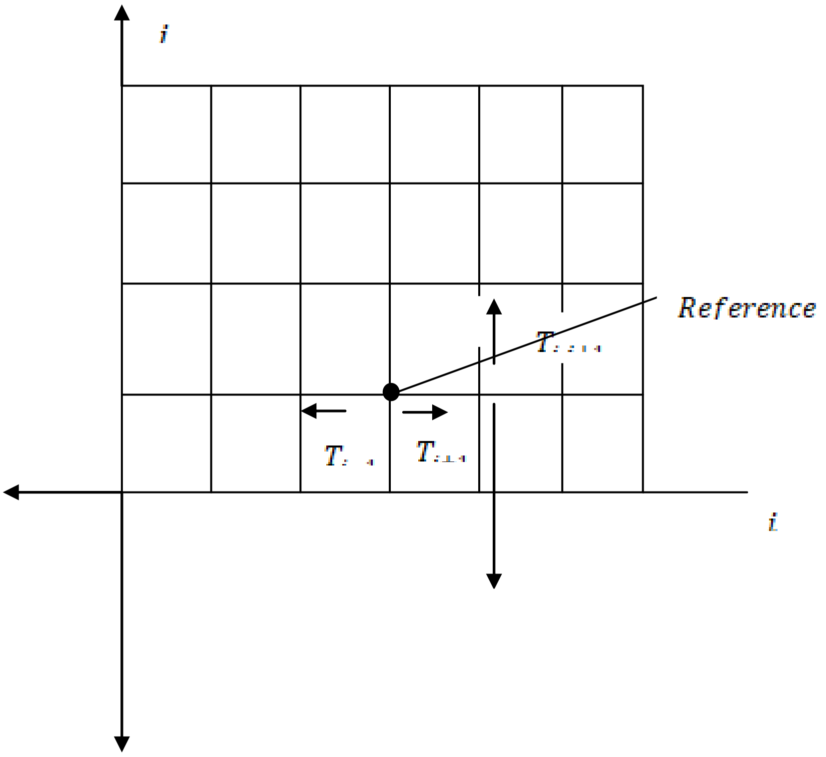

Figure 1: Finite Difference for Temperature Nodal Point

By relating resolving the torque (T) in i and j direction with respect to Figure 1, then we have the following directions from reference point $\left(T_{i,j}\right)$ in either square mesh or rectangular mesh as [27]:

$$T_{i,j+1} = T_{i,j} + hf'\left(T_j\right)_{i,j} + \frac{h^2}{2!}f''\left(T_j\right)_{i,j} + \frac{h^3}{3!}f'''\left(T_j\right)_{i,j} \tag{12}$$

$$T_{i,j-1} = T_{i,j} - hf'\left(T_j\right)_{i,j} + \frac{h^2}{2!}f''\left(T_j\right)_{i,j} - \frac{h^3}{3!}f'''\left(T_j\right)_{i,j} \tag{13}$$

$$T_{i,j+1} + T_{i,j-1} = 2\,T_{i,j} + h^2 f''\left(T_j\right)_{i,j} \tag{14}$$

Considering Laplace equation given by:

$$\nabla^2\theta = 0$$

$$\Rightarrow\ f''(T_i)_{i,j} + f''\left(T_j\right)_{i,j} = 0$$

By substituting equations (12 to 14) into Laplace equation above we have:

$$\frac{T_{i+1,j} + T_{i-1,j} - 2\,T_{i,j}}{h^2} + \frac{T_{i,j+1} + T_{i,j-1} - 2\,T_{i,j}}{h^2} = 0$$

For a square mesh $h = h,$ and a rectangular mesh $h \neq h,$ thus:

$$T_{i,j} = \frac{T_{i+1,j} + T_{i-1,j} + T_{i,j+1} + T_{i,j-1}}{4} \tag{15}$$

Equation (15) improves with over -relaxation formula with weighting factor $\lambda, 1 < \lambda < 2$

$$\left(T_{i,j}\right)_{overrelation\ \ for\ n\ time} = \lambda\left(T_{i,j}\right)_n + (1-\lambda)\left(T_{i,j}\right)_{n-1} \tag{16}$$

The finite difference gives good numerical approximation [28].
This predicted temperature in equation (16) is melting temperature of the workpiece. The one-third of workpiece (pure metal) melting temperature (T_m) or one-seventh metal alloy melting temperature are annealing temperature at this point the temperature is held for reasonable time and the procedure is called soaking. Thus we have:

$$T_{i,j\ annealing\ pure} = \frac{1}{3}\left(T_{i,j}\right)_{overrelation\ \ for\ n\ time} \tag{17a}$$

$$T_{i,j\ annealing\ alloy} = \frac{1}{7}\left(T_{i,j}\right)_{overrelation\ \ for\ n\ time} \tag{17b}$$

$$T_{i,j\ recrystallisation\ pure} = 0.3\left(T_{i,j}\right)_{overrelation\ \ for\ n\ time} \tag{18a}$$

$$T_{i,j\ recrystallisation\ alloy} = 0.7\left(T_{i,j}\right)_{overrelation\ \ for\ n\ time} \tag{18b}$$

IV. RESULTS AND DISCUSSION

This section presents the results and discussions of the findings. The details of the heat treatment CAD GUI in the study are presented in Figure and Figure 3.

The user workpiece selection is done by inputting physical geometry (area or volume) and thermal conductivity of the workpiece. The Biot number decides if the material is in powder (lumped) or crystal (mass) form and eleven materials are required for the analysis. The calculate button display the heat transfer coefficient of the workpiece located at the upper right corner of the GUI which displays the transfer coefficient. The equivalent lengths of treated workpiece were also known parameter. Button press of Temperature Finite Difference displays GUI of temperature prediction by activating the button of temperature finite difference resulted in displaying the GUI of temperature prediction.

The heat transfer coefficient of GUI for workpiece specification Figure 2 is automatically transferred to Figure 3. These parameters are required for temperature prediction.

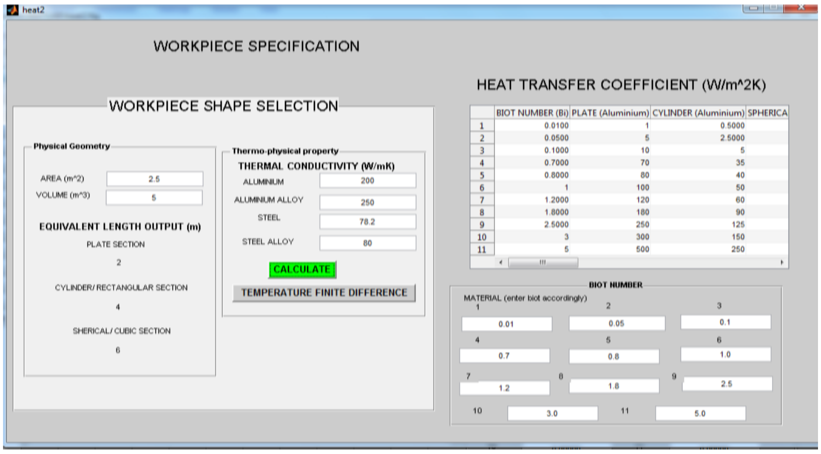

Figure 3: GUI for Heat treatment Temperature

Illustrated in Figure 4.3 is the Finite difference method for heat treatment; in the GUI boundary condition are required for thermal properties of the workpiece and furnace. Incremental function, and the iteration required number are entered.

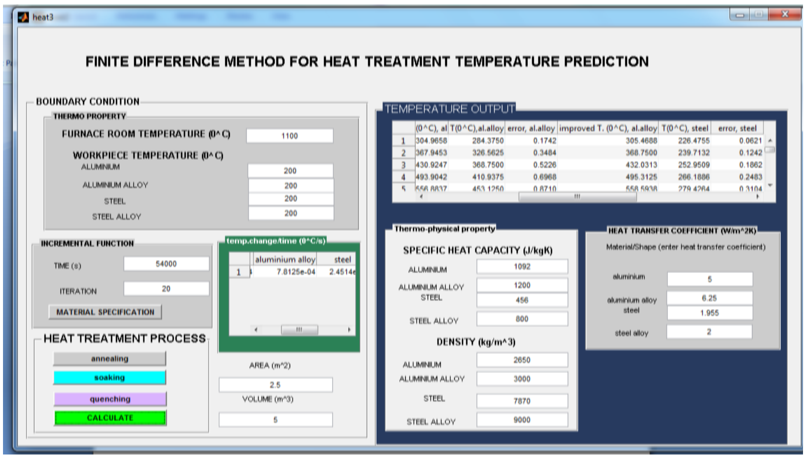

Figure 4.3: GUI for Heat treatment Temperature

The CAD could runs for four different materials (workpiece) simultaneously. The simulation procedure were centered on the following aluminum alloys 6061-O annealed, 6061-T1 Cooled from hot working and naturally aged, 6061-T4 Solution heat treated and naturally aged and 6061-T6 Solution heat treated and artificial aged.

The required boundary condition for this study in which heat treatment simulation results were obtained is shown in Table 1. The melting temperature of the alloy was 685 ^{O}C while the heat treatment temperature was obtained at time interval of 120 seconds per iteration.

Table 1: Boundary Condition

Parameters	Quantity
Area of the workpiece	0.01m^2 (10,000 mm^2)
Volume of the workpiece	0.00025m^3 (250,000 mm^3)
Initial Furnace temperature	50 ^{O}C
Room temperature of the alloy	32 ^{O}C
Melting Temperature of AA 6061	658 ^{O}C
Time interval	2 minute (120 seconds)
workpiece shapes	Plate, cylinder and spherical
Thermal conductivity of AA 6061 (O, T1, T4, T6)	173, 163,158 and 152 (W/mK) respectively

(a). Heat Transfer Coefficient (HTC)

The results obtained in the analysis, in which equivalent treated lengths (thickness) were; plate section was 0.025m, cylinder/rectangular bar section was 0.05m; spherical and cubical was 0.075m. The heat transfer coefficients of Aluminum 6061-O, T1, T4, T6 and plate section are shown in Tables 2, 3, 4, 5 and 6 respectively.

$$Bi = \frac{ht_{eff}}{\lambda} \quad \begin{cases} < 0.1 \text{ lumped} \\ \text{otherwise massive} \end{cases} = \frac{\text{HTC outside work piece}}{\text{HTC inside work piece}}$$

Table 2: HTC of Aluminum 6061-O

Biot	Plate (W/m^2K)	Cylindrical (W/m^2K)	Cubic (W/m^2K)
0.2	13048	653	434.7
0.3	2076	1038	692
0.4	2766	1384	922.7
0.5	3460	1730	1153
0.6	3912	1956	1304
0.7	4844	2422	1615
0.8	5536	2766	1845
9	6228	3114	2076
1.0	6920	3460	2307
1.1	7612	3806	2537
1.2	7824	3912	2391

The heat transfer coefficient (HTC) results for Aluminum 6061- (T1, T4) are tabulated in Tables 4.3 and 4.4 respectively for aluminum plate, cylindrical and cubic sections.

Table 3: HTC of Aluminum 6061-T1

Biot	Plate (W/m^2K)	Cylindrical (W/m^2K)	Cubic (W/m^2K)
0.2	1384	692	461.3
0.3	2076	1038	692
0.4	2766	1384	922.7
0.5	3460	1730	1153
0.6	4152	2076	1384
0.7	4844	2422	1615
0.8	5536	2766	1845
9	6228	3114	2076
1.0	6920	3460	2307
1.1	7612	3806	2537
1.2	8304	4152	2768

Table 4: HTC of Aluminum 6061-T4

Biot	Plate (W/m^2K)	Cylindrical (W/m^2K)	Cubic (W/m^2K)
0.2	1264	632	421.3
0.3	1896	948	632
0.4	2528	1264	842.7
0.5	3160	1580	1053
0.6	3792	1896	1264
0.7	4424	2212	1475
0.8	5056	2528	1685
9	5688	2844	1896
1.0	6320	3160	2107
1.1	6952	3476	2317
1.2	1264	632	421.3

The summarized HTC result obtained in Table 4 is plotted in Figure 4 where the HTC is in W/m^2K of different plate section is plotted along y-axis while along x-axis is the equivalent Biot number of the heat treatment simulation.

Considering melting temperature of aluminum 6061 alloy at 658 ^{o}C; one-third of the melting temperature is required for annealing treatment. The dimensionless number called Biot number was used to quantify the rate of heat transfer in the alloy. Thus, Biot number of 0.2 was selected for the analysis. Therefore, heat transfer coefficient (HTC) for Aluminum (6061-O, T1, T4, T6) with 1384, 1304, 1264 and 1216 W/m^{2}K were selected for annealing treatment and tempering

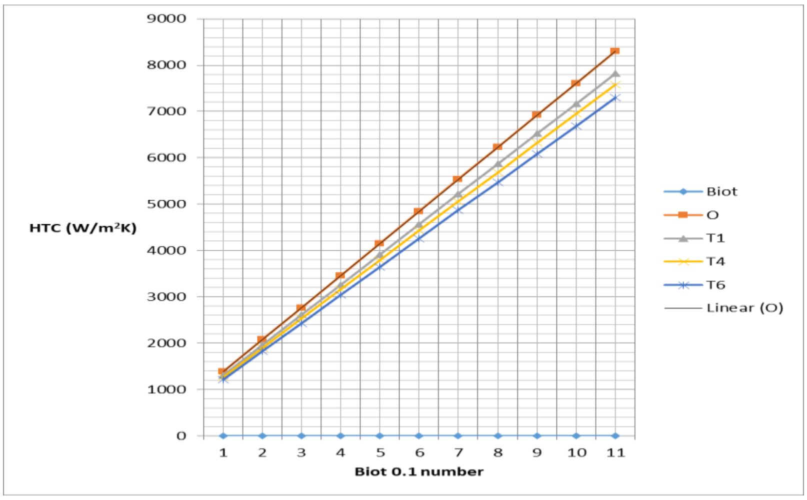

Figure 4: HTC of Aluminum 6061 Plate Section for various investigation on Basic tempers

The total temperature history for annealing, soaking and quenching heat treatment process for aluminum 6061-O alloying plate is plotted in Figure 5. Aluminum alloy was employed for the analysis which was classified by Biot number. The initial temperature of the specimen was set at 32 ^{o}C as input for the simulation. Geometry of the specimen was 0.01m^2 and 0.00025m^3 for area and volume respectively. Furnace initial temperature was set at 50 ^{o}C, total heat treatment time was 2256 seconds. The treated AAW 6061 (O, T1, T4 and T6) specimens were plate, cylinder and spherical workpiece.

The rate of heat transfer was obtained in the specimen with equivalent treated thickness of 25mm in plate, 50mm in cylinder/rectangular bar and 75mm in spherical object. The rate of heat transfer across aluminum specimen 6061 (O, T1, T4 and T6) was shown in Table 4.2. Heat transfer coefficient (HTC) rate across the workpiece were: 1384, 692, and 461.3 W/m^{2}K, in plate, cylinder and spherical specimen respectively for Biot number of 0.2. Selecting of Biot number of 0.2 shows that AAW-6061-O has highest of HTC with 1384 W/m^{2}K and lowest in AAW-6061-O with 1216 W/m^{2}K of HTC in same plate section.

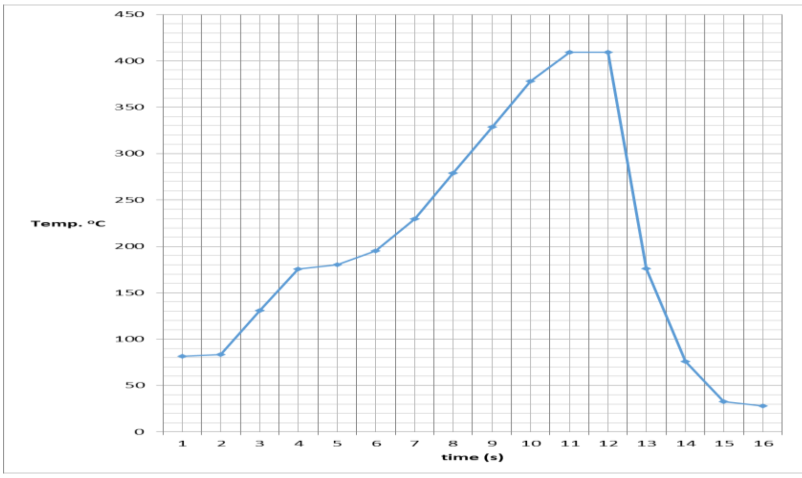

Figure 5: Complete Temperature history of Heat Treatment Process

V. CONCLUSION

Annealing consists of heating a metal to a specific temperature and then cooling at a rate that will produce a refined microstructure. Annealing is most often used to soften a metal for cold working, or to improve machinability, or to enhance properties like electrical conductivity. In both pure metals and many alloys that cannot be heat treated, annealing is used to remove the hardness caused by cold working. The metal is heated to a temperature where recrystallization can occur, thereby repairing the defects caused by plastic deformation. In this work, the metals, the rate of cooling will usually have little effect. Most non-ferrous alloys like aluminum alloys 6061 that are heat-treatable are annealed to relieve the hardness of cold working. These may be slowly cooled to allow full precipitation of the constituents and produce a refined microstructure.

REFERENCES

[1]. Alberg H., Material Modelling for Simulation of Heat Treatment", A *Master's Thesis submitted to the Department of Applied Physics and Mechanical Engineering, Division of Computer Aided Design, Lulea University of Technology,* 2003, pp. 9.

[2]. ASM, *Metals Handbook: Properties, selection for Iron and Aluminium alloy,* Ninth Edition American Society for Metals Handbook Committee, Metals Park, Ohio, 1990, pp.3- 56.

[3]. U. A. Saleh, J. M. Akmal, and W. A. W. Jamaludin, Performance of the Htbris Photovoltaic-Thermoelectric Generator System under Malaysian Weather Conditions, 2021. Proceedings of the 5th IEEE International Conference on Energy Conversion (CENCON) 2021. IEEE.

[4]. Bejan, A., and Kraus, A.D., *Heat Transfer Handbook*, Third Edition, John Wiley & Sons, Inc., Hoboken, 2003..

[5]. U. A. Saleh, M. A. Johar, S. A. B. Jumaat, M. N. Rejab, and W. A. Wan Jamaluddin, "Evaluation of a PV-TEG Hybrid System Configuration for an Improved Energy Output: A Review," Int. J. Renew. Energy Dev., vol. 10(2): 2021, p. 385–400,

[6]. Bylund, D., Cruz, R., Kalach, S., & Tsoi, M., Air Quenching of Aluminium: The Effect of Quench Orientation and Air Velocity, B.Sc Project, Worcester Polytechnic Institute, 2008, p.2

[7]. Burnett, J.A. and Pedovan, J. Residual stress field in heat treated case-hardened cylinders", *Journal of Thermal Stresses*, Vol. 2: 1979, p. 251-263.

[8]. Boitout, F., Damian D., Gooroochurn, Y., Mourgue, P., and Porzner H., Simulation of Heat Treatment, ESI Group, Paris, France. http://www.esi-group.com , visited and retrieved on Oct. 1st, 2011.

[9]. Callister.Jr, W.D., *Fundamentals of Material Science and Engineering*, Fifth Edition, John Wiley and Sons Inc., York, 2001.

[10]. U. A. Saleh, J. M. Akmal, and W. A. W. Jamaludin, "Photovoltaic-Thermoelectric Generator Monitoring System using Arduino Based Data Acquisition system Technique, "Proceedings of the 3rd IEEE International Conference on Artificial Intelligence in Engineering and Technology (IICAIET2021) 2021, IEEE.

[11]. David, S.T., Ogle, R.S., Robert, D.M., and Grant, E.S., Practices and Equipment for Heat Treating Aluminium Alloys, Articles on Nonferrous Alloys, 1970, p.239-243.

[12]. Donzella, G., Granzotto, S., Amici, G., Ghidini, A. and Bertelli, R., Microstructure and Residual Stress Analysis of a Rim Chilled Solid Wheel for Rail Transportation System, *Conference Paper on Computer Methods and Experimental Measurements for Surface Treatment Effects II*, 1995, p.293-300.

[13]. Fontecchio, M., Quench Probe and Quench Factor Analysis of Aluminum Alloys in Distilled Water, *M.Sc Thesis in Materials Science and Engineering*, Worcester Polytechnic Institute, 2002, p.4-15.

[14]. Funatani, K., and Totten, G.E., Present Accomplishments and Future Challenges of Quenching Technology, *Proceedings of the 6th International Federation of Heat treatment and Surface Engineering Congress, IFHTSE, Kyongju, Korea*, 1997, p. 20-27.

[15]. U. A. Saleh, J. M. Akmal, and W. A. W. Jamaludin, "The real-time Monitoring of TEG using the LabVIEW Technique for Green Energy Generation, "Proceedings of 2021 I-RIA2921 Innovative Research, Invention and Application Exhibition (I-RIA2021) 2021.

[16]. Hibbit, L-E and Marcal, P.V. A numerical thermo-mechanical model for the welding and subsequent loading of a fabricated structure", *Journal of Computers and Structures*, 1973, p. 1145-1174.

[17]. Jeffery, A., *Advanced Engineering Mathematics,* Second Edition, Harcourt Academic Press, Massachusetts, USA, 2002, p. 56-80.

[18]. Josefson, B.L., Residual stresses and their redistribution during annealing of a girth- utt welded thin walled pipe, *Journal of Pressure Vessel Technology*, Vol.104: 1982: p. 245-250.

[19]. Ju, D.Y., Sahashi, M.M., Omori, T. and Inoue, T., Residual Stresses and Distortion of a Ring in Quenching-Tempering Process Based on Metallo-Termo-Mechanics, in *Procedure Second international Conference on Quenching and the Control of Distortion*, Cleveland/Ohio, USA, 1996, p. 249-257.

[20]. Saleh, U. A., S. A. B. Jumaat, M. A. Johar and W. A. Wan Jamaluddin, Analysis of the Performance of Thermoelectric Generators for Ambient Energy Generation through ANSYS Software. Proceedings of the 11th Annual International Conference on Industrial Engineering and Operations Management Singapore, 2021, IEOM.

[21]. KeithCompany.com, Aluminium Solution Heat Treatment, Technical Data, www.KeithCompany.com, 2012.

[22]. Kopeliovich, D., *Basic Principles of Heat Treatment*, www.substech.com, visited and retrieved on 2011.

[23]. M. N. Rejab, M. A. Johar, W. A. Wan Jamaludin and U. A. Saleh, Rooftop and Attic Area Thermal Energy from Solar Radiation as Renewable Energy in Malaysia, "Proceedings of the 9th International Conference on Smart Grid and Clean Energy Technologies (ICSGCE 2021) October 15-17, 2021, p. 109–114, ICSGCE

[24]. Saleh, U. A., F.I Onuigbo, Suleiman Abdulrahman and A. E. Ayodeji., Construction of a Direct Solar Dryer for Perishable Farm Products. International Journal of Scientific Research Engineering and Technology. ISSN: 2278-0882, 6 (2), 2017.

[25]. Phongsophitanan U., Polboon M. and Chumchery N., Study Conditions of Aluminum Billets for Relationship between Precipitated Phases and Homogenizing Temperature with Different Cooling Methods, JOM., 7(2): 2011, p. 121-125.

[26]. Mlkvik, M., Olšiak, R., Smolar, M., Comparison of the Viscous Liquids Spraying by the OIGand the Oil Configurations of an Effervescent Atomizer at Low Inlet Pressures, Journal ofMechanical Engineering – Strojnícky časopis 66 (1): 2016, p. 53 – 64.

[27]. Vishwanath, M., Lakshaman, A.N., Ramesh G.K., Numerical Simulation of Heat Transfer Behavior of Dissimilar AA5052-AA6061 Plates in Friction Stir Welding: An Experimental Validation, Journal of Mechanical Engineering Strojnícky časopis 69 (1), 2019, p. 131 – 142

[28]. Saleh, U. A., Haruna,Y. S, Gwaram U. A and Abu, U. A., Evaluation of Solar Energy Potentials for Optimized Electricity Generation at Anyigba, North Central Nigeria. Global Scientific Journals. ISSN: 2220-9186, 6(2): 2018.