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Mechanical Properties Evaluation for Heat Treated Aluminium Alloy 6061

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ABSTRACT

Aluminum is a widely known alloy for its unique properties, such as low density, high strength-to-weight ratio, excellent formability, and good thermal and electrical conductivity, aluminium alloys are widely used in a variety of applications like in aerospace, automotive, construction, and Consumer electronics etc. Heat treatment is a widely accepted method for altering the microstructure of metals and alloys without changing the product form, thereby improving mechanical properties. The main objective of this study is to evaluate different mechanical properties of aluminium alloy 6061 subjected to heat treatment process. In this study two heat process adopted annealing and age hardening. Two different parameters studied in age hardening first heating specimen to 5300C for 6 hours, followed by water quenching in room temperature for 72 hours, then reheating at 1500C for 2 hours. second heating specimen to 5300C for 6 hours, followed by water quenching in room temperature for 72 hours, then reheating at 2000C for 2 hours. The results age hardening has better hardness compared to non-heat treated alloy and annealed alloy, in age hardening at 2000C has highest hardness number, which reveals that hardness increases with increasing temperature for quenched heat treatment process. The mechanical properties of age hardening are superior to those of annealing. Energy absorption was low for age hardening at 2000C. The tensile test results ultimate tensile strength is predominating in alloy subjected to age hardening compared to non-heat treatment.

Introduction

Aluminum, with the symbol Al and atomic number 13, is a moderate metallic with a faint silver color. Aluminum is the most common metal and one of the three most abundant elements in the earth's crust, along with oxygen and silicon. It accounts for 8% of the earth's solid shell. Aluminum alloys with a structure containing copper, zinc, magnesium, manganese, and silicon are easily formed. Because of their high strength-to-weight ratio, aluminium alloys are important in the aerospace, transportation, and construction industries. Aluminum is one of the materials that remains a popular choice among researchers, technicians, and innovators. The microstructure and properties of aluminium alloys are frequently altered through the use of heat treatment Maisonnette et al. (2011b). The alloy composition, the heat treatment process variables, and the desired properties all affect how heat treatment specifically affects aluminium alloy. Through the introduction of dislocations, precipitates, or solid solutions into the microstructure, heat treatment can strengthen the aluminium alloy. Heat treatment techniques can make aluminium alloys more ductile by removing brittle phases or introducing deformation mechanisms that increase plasticity. By altering the surface oxide layer, lowering the impurity concentration, or causing the formation of protective precipitates, heat treatment can also increase the corrosion resistance of aluminium alloys Fellicia et al. (2019). Aluminum alloys are used in a wide range of industries, including aerospace, automotive, construction, electronics, etc., where different types of loading conditions are present. As a result, aluminium is subject to a variety of failure modes, including cracking, deformation, wear and tear, and corrosion, all of which have a significant impact on its performance and service life. High stress and quasi-static of AA6061 T6 was studied by (Li et al.,2006). The goal of this study is to better understand the mechanical and physical characteristics of aluminium alloys so that they can be modified to overcome their flaws and perform better.

Aluminium alloy 6061 contains silicon and magnesium as its main alloying components. Excellent mechanical and welding capabilities is one of the best common aluminium alloys for general purpose use. Al 6061 has a high strength-to-weight ratio, making it perfect for uses where weight is important, like in aerospace and automotive applications. Additionally, it is easily formed into a variety of shapes and sizes.

Table 1. Designation system and characteristics of wrought aluminum alloys

Series No.	Primary alloying Element	Relative Corrosion Resistance	Relative Strength	Heat Treatment
1XXX	None	Excellent	Fair	Non-heat treatable
2XXX	Copper	Fair	Excellent	Heat treatable
3XXX	Manganese	Good	Fair	Non-heat treatable
4XXX	Silicon	-	-	Non-heat treatable
5XXX	Magnesium	Good	Good	Non-heat treatable
6XXX	Magnesium & Silicon	Good	Good	Heat treatable
7XXX	Zinc	Fair	Excellent	Heat treatable

Heat Treatment

Heat treatment is a process where a material such as metal alloy is heated and cooled in order to alter their mechanical and physical properties. Heat treatment techniques come in a variety of forms such as annealing, tempering, quenching and ageing. In order to achieve the desired properties, each process involves heating the material to a specific temperature and cooling it at a controlled rate. The process of annealing allows a material to soften and become more ductile by heating it to a high temperature and then slowly cooling it.

Quenching is the process of rapidly cooling a material in a liquid, such as water or oil, in order to increase its hardness. Aging is the process of heating a material to a lower temperature for an extended period of time, allowing it to become stronger and more resistant to fatigue.

Age hardening is a heat treatment technique used to increase the strength and hardness of certain metal alloys, because it involves the precipitation of small particles within the material, this process is also known as precipitation hardening. Typically, the age hardening process consists of three steps: solution treatment, quenching and ageing. The material is heated to high temperature in first step then cooled rapidly in water or oil and aged for some time and reheat it lower temperature for specific period of time.

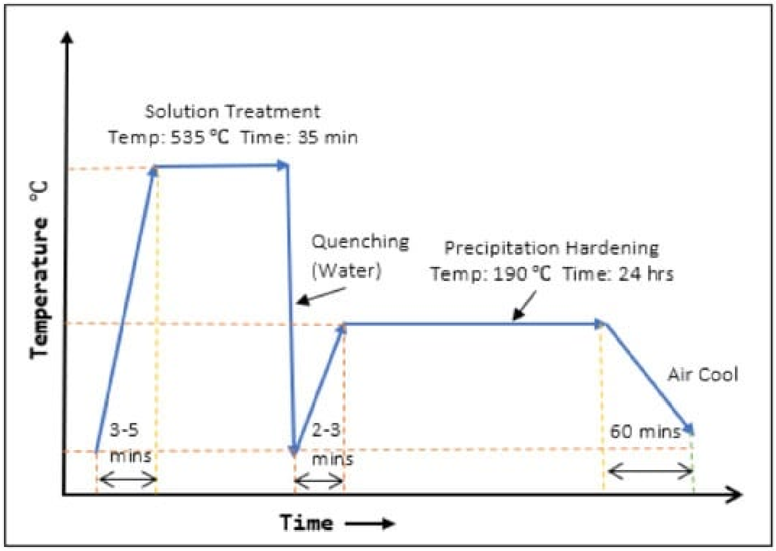


Figure 1. Schematic representation of heat treatment [(Riaz et al., 2020)]

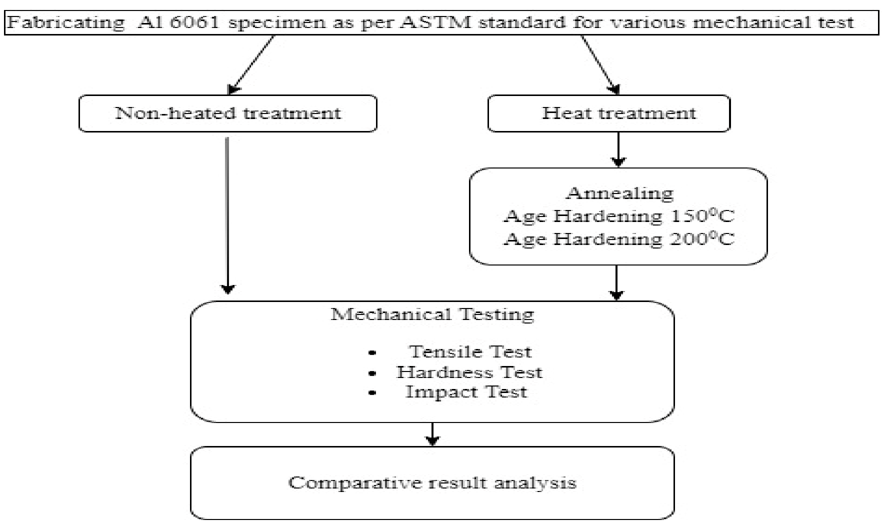


Figure 2. Flow chart for sequence of operation

Materials and Methods

Al 6061 has selected in this project, because it has excellent mechanical properties and excellent machinability and weld ability. This is one of the best common aluminium alloys for general purpose use. table below 1 shows chemical composition of aluminium alloy 6061.

Table 2. Chemical composition of aluminum alloys in wt.% (Amit et al.,2017, p.167-179)

Material	Mg	Mn	Fe	Si	Cu	Zn	Ti	Cr	Others	Al
Al alloy	1.12	1.12	0.97	0.96	0.31	0.26	0.14	0.04	<0.05	remaining

Specimen Development

Drawing

Drawing test specimens as per ASTM standard using CAD program as showing in figure 3.

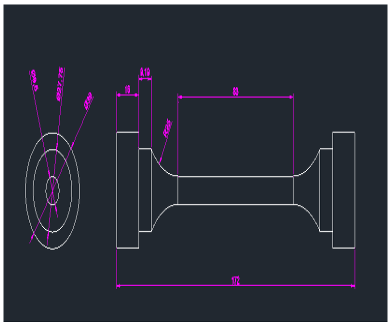
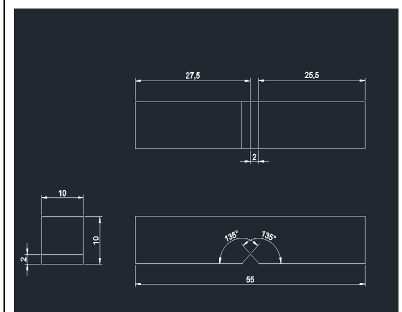
Tensile test Specimen		Impact test specimen
		

Figure 3. Shows 2D and 3D drawing for tensile test specimen.

Fabrication

In figure 4 is shown aluminum alloy 6061 as rod shape with dimension 40mm dimeter into 1meter length. In project fabrication, required 3Nos of aluminum rods to fabrication 7Nos of tensile test specimen and 7Nos of impact test specimens.



Figure 4. Show Aluminum 6061alloy bar and its machined specimens

Table 3. Experimental Plan

Heat treatment methods					
Type of Experimental Test	**Non-Heat treatment**	**Annealing**	**Age -Hardening 150^{0}C**	**Age -Hardening 200^{0}C**	**Total of Specimens**
Tensile Test	2	3	3	3	11
Impact Test	2	3	3	3	11

Hardness Test 5 points test	2	2	2	2	08

The total number of specimens for tensile test is 8 Nos. It divided into 4 group dependents to heat treatment method as mentioned in table 3, the heat process carried out as shown in figure 6.

Experimental Procedure

Heat Treatment Process

In this project, we going to select to two most important heat treatment process annealing and Age-hardening process. in table 3 explained the procedure to conduct heat treatment by using Nabertherm furnace as shown in figure 5.

Figure 5. Nabertherm Furnace

Figure 6. Placing of specimen in furnace

Table 4. Heat treatment procedure

Method of heat treatment	Procedures
AA6061-T0(annealing Method	The aluminum alloy 6061 samples heat treated using Annealing T0 method which is heat treated at 400^0C for 5hours and then keep cool slowly inside furnace.
AA6061-T6(Age -Hardening $150C^0$	The aluminum alloy 6061 samples heat treated using Age -hardening 150^0C method which is heat treated at 530^0C for 6 hours and quenching in fresh water for 72 hours and then reheating at 150^0C for 2 hours finally normalizing in room temperature degree
AA6061-T6(Age -Hardening $200C^0$	The aluminum alloy 6061 samples heat treated using Age -hardening 150^0C method which is heat treated at 530^0C for 6 hours and quenching in fresh water for 72 hours and then reheating at 150^0C for 2 hours finally normalizing in room temperature degree

Mechanical Properties Evaluation

To evaluate mechanical properties such as tensile strength, yield strength, toughness, and hardness, the following experiment procedure was adopted and all tests were carried out at the Middle East College.

Tensile test	**Brinell hardness test**	**Charpy impact test**
		
Tensile tests were performed on the SM1000 Universal Testing Machine for yield strength, ultimate tensile strength, and percentage of elongation of the developed specimen, as shown in above figure.	The Brinell hardness test, used to determine the hardness of developed specimens.	The Charpy impact test was carried out using an impact test setup that included a striking arm and a specimen holder with a calibrated dial gauge. The amount of energy absorbed by the specimens is determined by the test.

Figure 7. Different mechanical test equipment

Result and Discussion

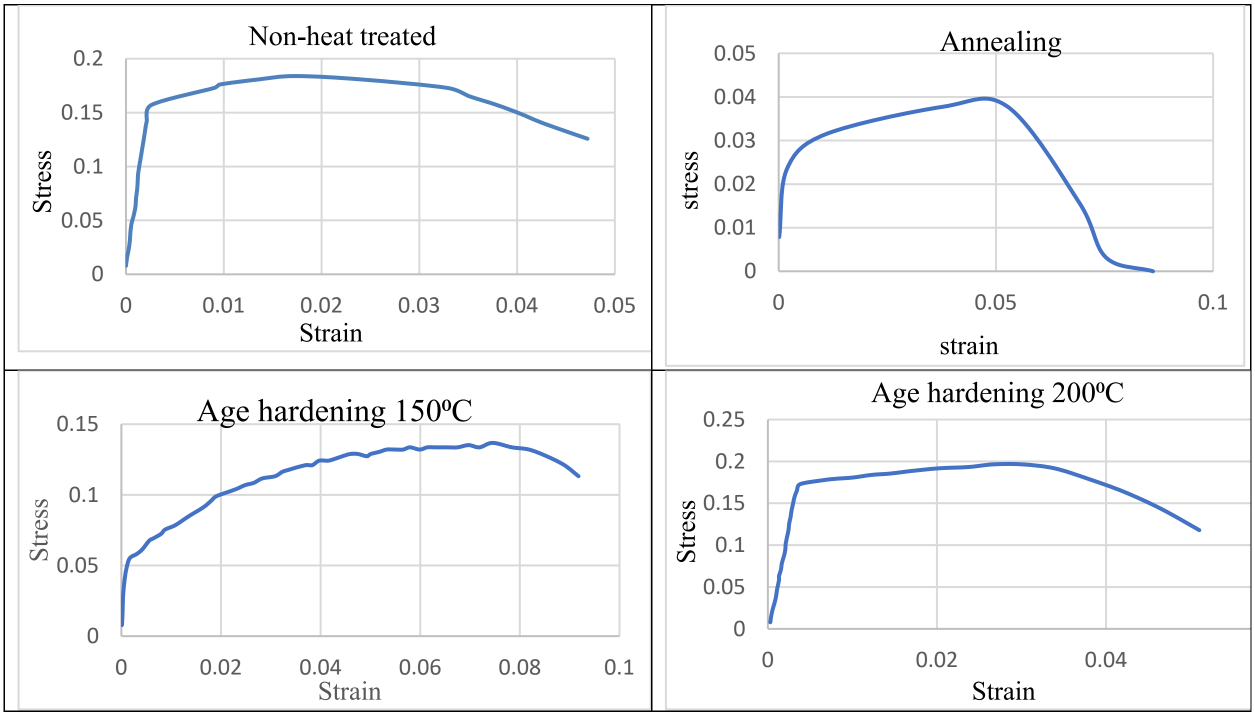
Tensile Test

Tensile tests were performed for developed specimen before and after heat treatment, and the results for various processes are shown in the figure below.

Yield strength of 0.023kN/mm^2 was found at a load of 1.5 kN for annealed specimen tested using universal testing machine. The ultimate tensile strength was 0.037 kN/mm^2 at maximum load of 2.4kN with total elongation at fracture was 15.16 mm. Yield strength of 0.055kN/mm^2 was found at a load of 3.5 kN for age hardening at 150^{0}C treated specimen tested using universal testing machine. The ultimate tensile strength was 0.136 kN/mm^2 at maximum load of 8.7 kN with total elongation at fracture was 17 mm. Yield strength of 0.17kN/mm^2 was found at a load of 11 kN for age hardening at 200^{0}C treated specimen tested using universal testing machine. The ultimate tensile strength was 0.196 kN/mm^2 at maximum load of 12.5 kN with total elongation at fracture was 8.1 mm.

Non heat treated	Annealing	Age hardening at 150^{0}C	Age hardening at 200^{0}C

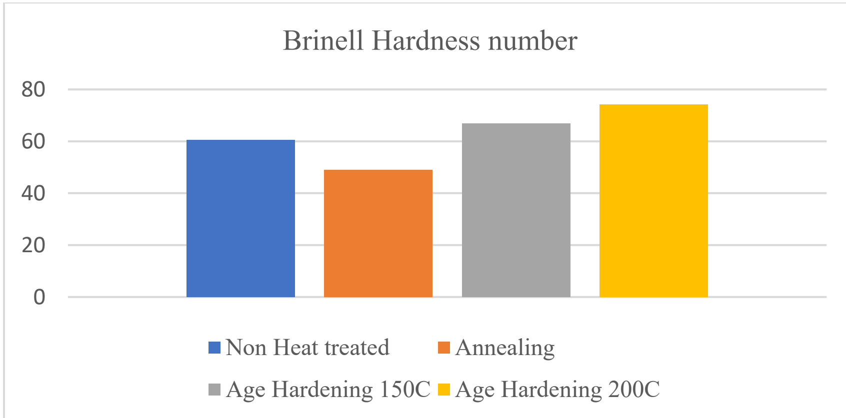
Figure 8. Fractured tensile tested specimen



Graph. 1. Stress strain diagram for all developed specimen

When heat treated specimen were compared to non-heated aluminium alloy, following conclusion were drawn. The yield strength reduced by 84% and 63.3% in annealed and age hardened at 150^{0}C but the yield strength value was observed to increase by 11.7% in age hardened at 200^{0}C. this may be due to that the ductility of the specimen is increased due to the heating and slow cooling process and 2000C will precipitate the elements, increasing the hardness of the material. Similar observation was found for an ultimate tensile strength were UTS was reduced by 79%, 26% and increased by 6.2% this is due to fact that age harden material has increased its hardness to precipitation of alloying elements. and elongation was increased by 83.5%, 105% and reduced by1.9% for annealed, age hardening at 1500C and 2000C respectively.

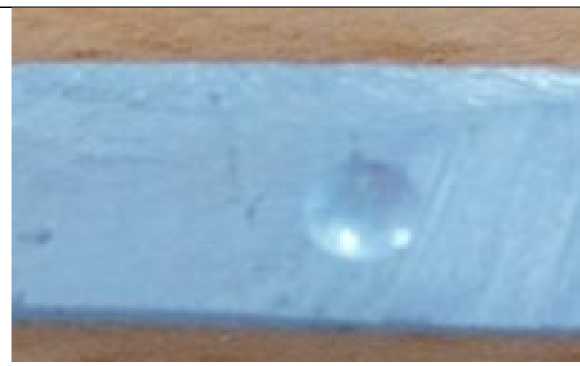
Brinell Hardness Test Result



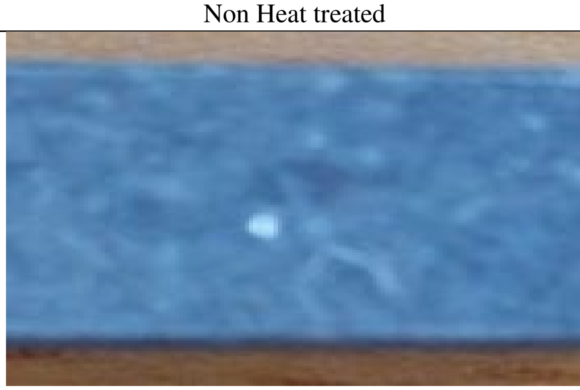
Graph. 2. Brinell hardness number for all developed specimen

Hardness is resistant to scratch, the heat treatment process reduces the hardness and increases the ductility. The hardness value for non-heat treatment specimen was found 60.5HB, 48.9 HB for annealing heat treatment specimen, 66.85 HB for age hardening 150ºC heat treatment and 74.35 HB for age hardening 200ºC heat treatment, which mean the high hardness and strength with low ductile materials.

Non Heat treated



Annealing heat treatment specimen



Age Hardening 150ºC

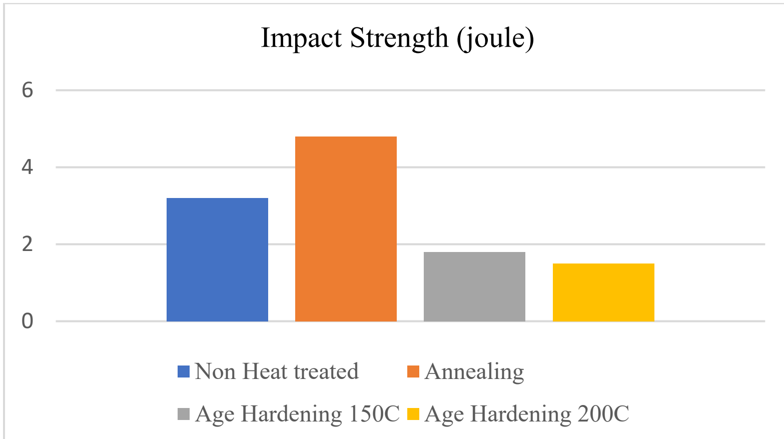
Age Hardening 200ºC

Figure 9. Brinell hardness tested specimen

The maximum hardness value found for hardening 200ºC heat treatment which is 18.35% more compared non-heat treated material, the least hardness value found for annealed specimen were hardness value was reduced by 19.1%, which shows clear indication that a annealed specimen is more ductile as observed in previous section were the elongation was maximum for annealed specimen.

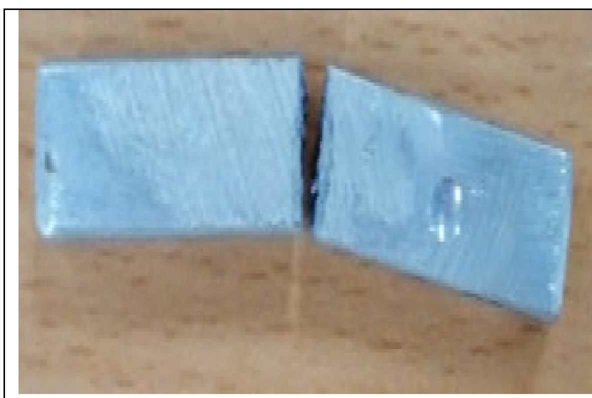
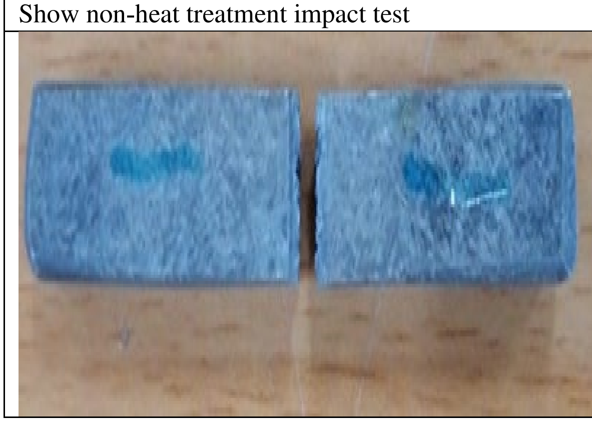
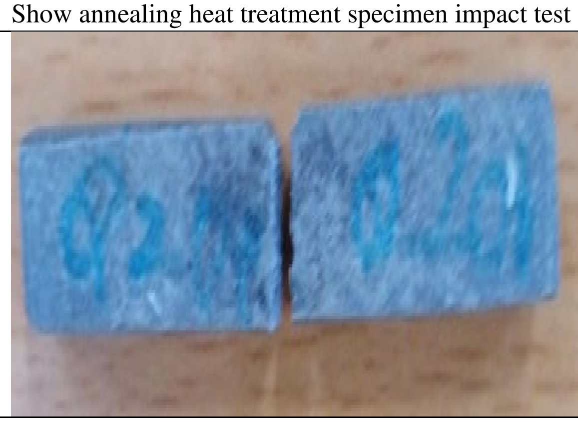
Impact Testing

Impact test was carried out to measure the impact strength (toughness) of material, the test was conducted for all developed sets of specimen.



Graph 3. Impact strength for all developed specimen

Graph 3 shows impact strength for al developed specimens, as observed from below figure the maximum energy absorption ability was found for annealed specimen whose hardness value was minimum discussed in previous section.

 Show non-heat treatment impact test	 Show annealing heat treatment specimen impact test
	

Shows age hardening 150⁰C specimen impact test	Show age hardening 200⁰C specimen impact test

Figure 10. Charpy impact tested specimen

Conclusions

According to the study's findings, which are summed up in the points below, heat treatment significantly affects how aluminium alloy 6061's mechanical properties change.

- A tensile test showed that the material's strength decreased with heat treatment process but it can be improved by proper age hardening process.
- In the Charpy impact test, aluminium alloy 6061's heat treatment effects of annealing and age hardening result in a decrease in toughness strength when compared to results from tests conducted without heat treatment.
- Brinell hardness number was reduced with annealing heat treatment process but improved for age hardening at 150^0C, and 200^0C due to fact that heat treatment will breaks atomic bonds among the atoms which will increase the free movement of atoms

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