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Influence of Non-Natural Ageing Temperature on the Microstructural Characteristics and Mechanical Properties of Cast Aluminum 6063 Alloy

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Abstract

This research considered the effect of non-natural aging on the microstructural characteristics and mechanical properties of as-cast aluminum 6063 alloys. The samples were developed through a sand casting process and machined into tensile and impact test samples before carrying out solution heat treatment at 550˚C (0.83 T_m) on two parts of the samples while retaining one part as the control. The two parts were further divided into sets denoted A and B and were aged at 180˚C (0.27 T_m) and 160˚C (0.24 T_m), respectively, for 12 hours. The results showed that sample A has the optimal yield strength and ultimate tensile strength of 192 and 206 MPa, respectively. Likewise, the sample gave the highest impact strength value of about 9.63 J/mm^2. The observed results were supported by the optical micrograph, which revealed that the sample has evenly dispersed precipitates in its microstructure. This is deemed responsible for the observed increase in strength of the sample.

Keywords

Aluminum Alloy, Non-Natural Ageing, Mechanical Properties, Microstructural Features

1. Introduction

The recent world needs the application of light structural materials in other to improve fuel economy, energy consumption, and gas emissions in industries.

Properties such as specific strength, specific stiffness, good formability, and good corrosion resistance make aluminum alloy an ideal material for manufacturing components for automotive and aerospace applications and have increased the use of aluminum and its alloys globally. Components of internal combustion engines such as cylinder heads, cylinder blocks, crankshafts, and pistons are the main automotive components where aluminum cast alloys are used. Hence, in order to achieve the desired properties, which do not depend only on the casting condition and solidification rate but are also significantly influenced by their chemical composition and heat treatment, investigation of these processing routes has been a continuous practice [1] [2].

Aluminum alloys are increasingly serving as a better replacement for steel in many industrial applications due to their lightweight. Aluminum alloys possess excellent mechanical, thermal, and electrical properties utilized in diverse applications in the automobile and aerospace industries. The functionality of Aluminum is highly dependent upon its microstructure. Although Aluminum is isotropic, the differing compositions dictate the exhibited properties [3]. The AA6xxx series of Aluminum are the most extensively extruded, especially for chassis construction, architectural applications, bicycle frames, transportation equipment, bridge railings, and welded structures. Of the AA6xxx series, the most utilized is the 6063 Al because of the extrudability, surface finish, corrosion resistance, and weldability [4].

Pure aluminum does not have the ideal casting and mechanical characteristics. Therefore, aluminum is combined with silicon and magnesium to improve these qualities, resulting in a 6063 aluminum alloy. Due to the creation of the intermetallic complex Mg_2Si, adding these alloying elements enhances the aluminum's reactivity to heat treatment. This greatly increases the alloy's strength while improving casting and corrosion resistance. A common name for this alloy is Al-Mg-Si, and because of its outstanding extrudability, superior finishing quality, and strength, it is recognized as an architectural and ornamental alloy [5].

Due to their light weight, strength, and workability, the 6xxx series of aluminum alloys are essential to modern vehicles and have experienced a sharp increase in their use in cars, high-speed rail, and airplanes. These Al-Mg-Si alloys' noteworthy mechanical qualities are mainly attributable to solid-state precipitation during elevated-temperature artificial aging or cyclic deformation, which results in a high density of precipitates. Al-Mg-Si alloy micro alloying is an efficient method to modify the microstructure and characteristics of the precipitates, in addition to aging and cyclic deformation treatments [6].

Homogenizing and changing the plate-like AlFeSi phase into a more rounded AlFeSi phase required adding a small quantity of manganese. This transition enhanced the material's ductility. Interestingly, manganese also increased the alloy's quench sensitivity, even at a slow cooling rate of $50^\circ C \cdot min^{-1}$. Also, manganese addition can expedite the transition from the less favorable AlFeSi phase to the more advantageous AlFeSi phase. The wide use of 6063 Al has contributed to the availability of tons of scrap materials, which requires optimal recycling. However, recycling 6063 Al is challenging because the ferrous content is not easily removed, even with the current levels of technology, thereby degrading the quality of the recycled materials [7]. The current technique is to dilute the recycled waste aluminum with purer Al to reduce the ferrous content, especially during casting [8].

The pioneering casting technique is sand casting, and although there have been many sophisticated casting techniques, sand casting is still being utilized because of its relatively low cost of production [9].

It is vital to design the fluid flow pattern in sand casting to reduce the probability of defects such as shrinkage, porosity, blow holes, pinholes, and other casting defects. It is also important to design a good gating system to avoid turbulence, which might result in oxide film formation, dross, sand inclusion, and air entrapment. With accurate gate section design, air entrapment is minimized, a uniform thermal gradient is achieved, and mold erosion is prevented [10] [11]. In 6063 Al, the alloying elements are less soluble in the solid phase than in the liquid phase, which inherently causes the segregation of the alloying elements. Therefore, the segregation of the alloying elements is minimized by heating the metal at elevated temperatures close to the solidus temperature and kept constant to homogenize the structure (aging) [12] [13]. The main alloying elements in 6063 Al are Mg-Si, responsible for improved strengths and further increased by precipitation hardening. It is also important to note that the right proportion of alloying elements is important to attain optimal aging conditions. The general requirement for optimal aging is the formation of finely dispersed coherent precipitates. This research investigates the microstructure and mechanical properties of 6063 Al aged at different temperatures.

2. Materials and Methods

The 6063 Al used in this research was obtained from a metal extrusion company in Nigeria; the chemical composition of the alloy is given **Table 1**.

The material for the research was cast using a sand mould. The mould composition is silica sand built with a non-pressurized in-gate system. The intricacies of the mould were designed using a wooden pattern with a good surface finish. The non-pressurized gating system was designed in the ratio 1:2:2 as shown in **Figure 1**. The ratio means the cross-sectional area of the down sprue, runner bar, and ingates are one, two, and two units, respectively. This design had one in-gate to minimize turbulence and increase the casting yield.

The Al6063 was charged into a crucible and placed into the furnace for melting

Table 1. Chemical Composition of Al6063.

Elements	Al	Mg	Si	Fe	Mn	Cu	Cr	Ti	Ca	Sr
Composition	98.6631	0.4321	0.3625	0.0469	0.1516	0.0036	0.0026	0.0062	0.011	0.0156

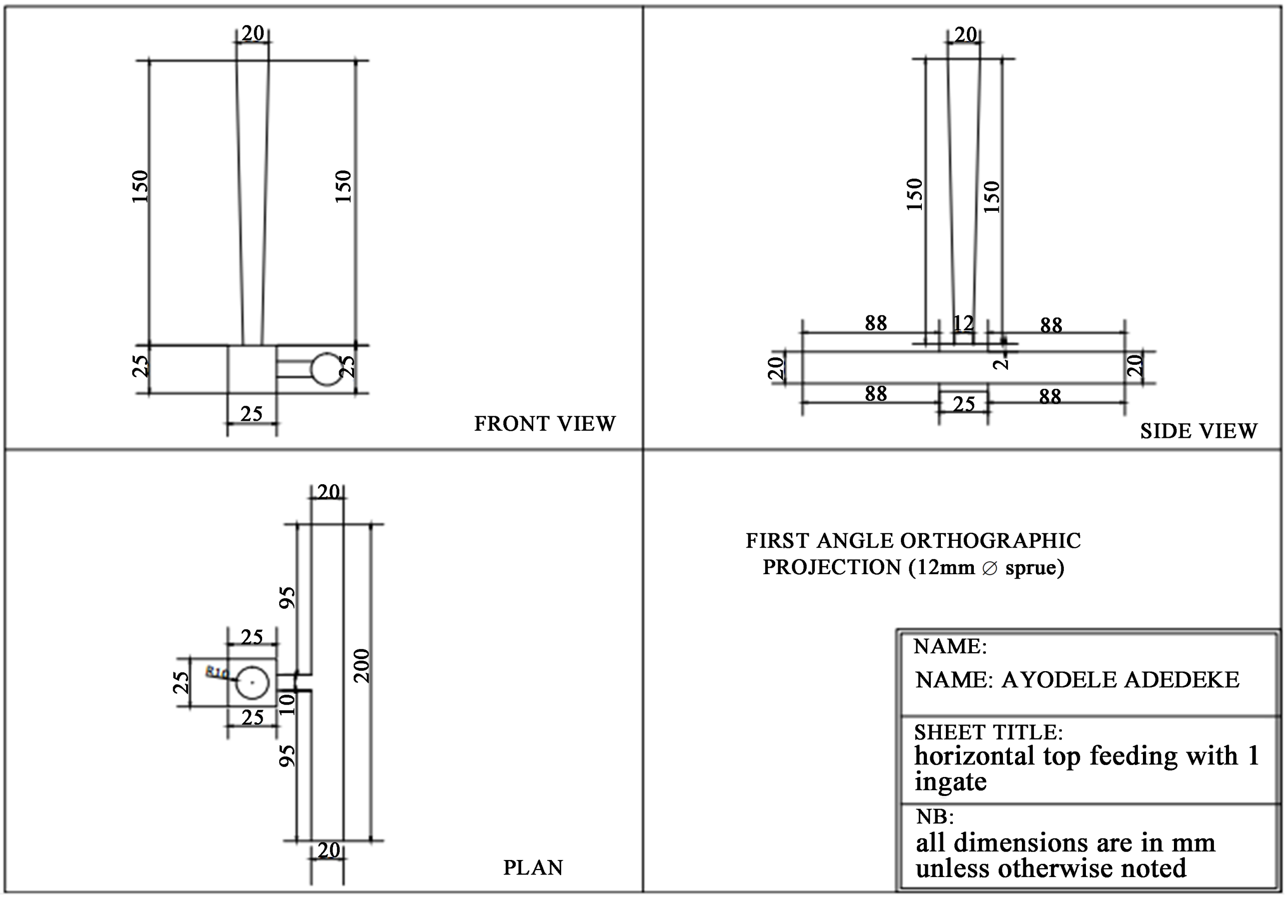

Figure 1. Non-pressurized horizontal gating system with single in-gate.

before being poured into the mould cavity. The pouring rate was controlled to avoid casting defects, and the mould was allowed to cool before being removed from the mould. Fifteen samples were produced overall as the as-cast sample for each condition. Three samples each were labeled A, B, and C. All the samples were solution-treated at 550˚C (0.83 T_m), after which the samples were quenched to room temperature. Sample C was utilized as the control sample, while samples A and B were aged at 180˚C (0.27 T_m) and 160˚C (0.24 T_m) for 12 hours, respectively. Three tensile samples representative of each condition were machined. The tensile experiment was performed using a Houns-field tensile testing machine. The load-displacement curves from the samples were used in generating engineering stress-strain curves and true stress-strain curves for the samples. The remaining 6 samples were used for the impact tests.

Also, the samples were prepared for metallographic examination by polishing the samples with progressive grits of emery paper ranging from 220, which is the roughest, to 1200, which was the finest grinding step in this research. The samples were further polished using alumina suspension on a polishing cloth to obtain a mirror-like surface finish for cross-examination. The sample's surface was further etched using a mixture of dilute HF, $NH_3(OH)_4$, and H_2O to show morphological features in the samples.

3. Results and Discussion

The tensile results are shown in Figure 2 & Figure 3. The engineering stress-strain curve provides insight into the deformation mechanism in the alloy, while the true stress-strain curves provide an accurate volumetric view of the stress-strain relationship because it factors in the volumetric change as the material deforms plastically. Since it is easier to obtain the yield strength and ultimate tensile strength from the engineering stress-strain curves, therefore the values from the engineering stress-strain curves are used in this research. Figure 2 shows the stress-strain curves of samples A, B, and C. The results showed yield strength (YS) of 192 MPa and ultimate tensile strength (UTS) of 206 MPa at 8% strain for sample A. Similarly, samples B and C yielded 178 MPa and 136 MPa, respectively, while their UTS were 190 MPa and 148 MPa, respectively. The elongation in Samples A and B was similar, while sample C was slightly higher than for the

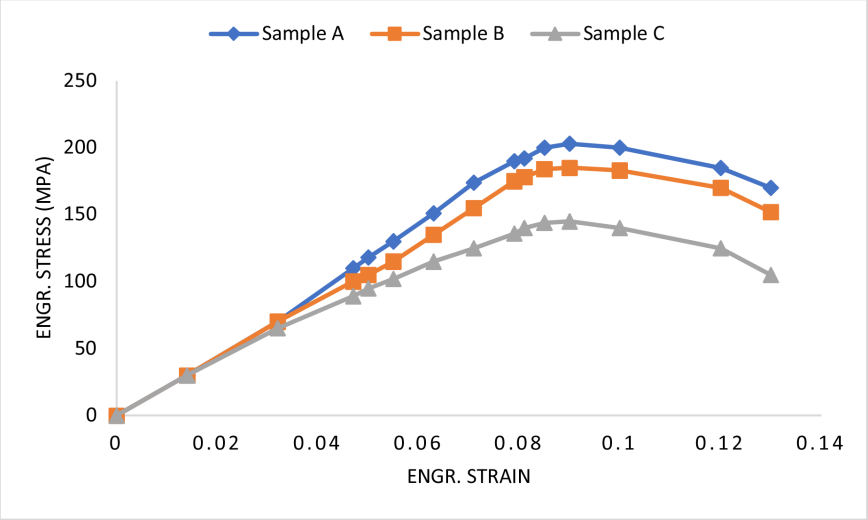

Figure 2. Engineering stress-strain curve for samples A, B, and C.

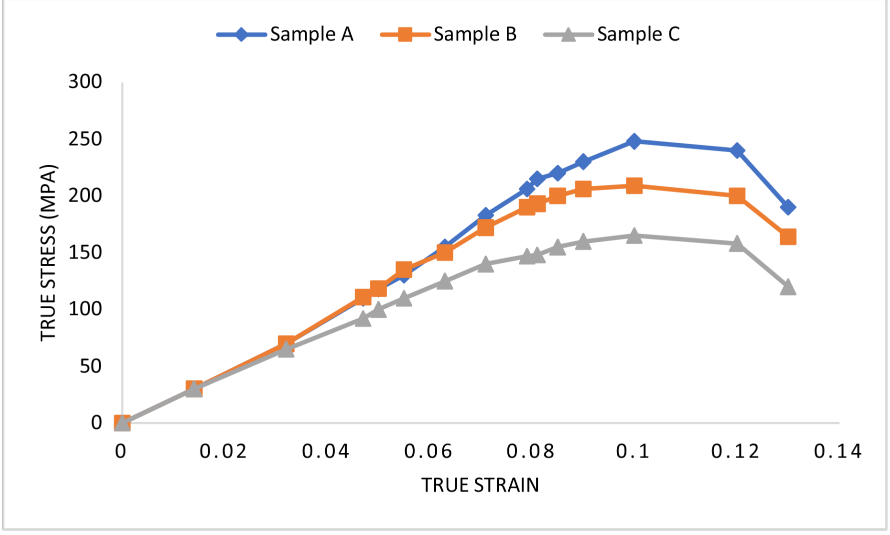

Figure 3. True stress-strain curve for samples A, B, and C.

other samples. The difference in the YS and UTS of samples A and B shows that Sample A has higher strength and toughness than Sample B. This implies that more coherent precipitates are formed at slightly elevated temperatures, which aid bonding within the sample [14]. Samples A and B showed a 41.1% and 30.8% increase in YS, respectively, while the increase in UTS was 39.2% and 28.4%, respectively.

The impact strength results shown in **Figure 4** revealed that Sample A has the highest impact strength of about 9.63 J/mm^2, while Sample B and C have impact values of 9.08 J/mm^2 and 4.98 J/mm^2, respectively. This result agrees with the tensile experiment showing that the optimal aging condition for this research was achieved at 180˚C (0.27 Tm) for 12 hours. This shows that samples A and B with 93.4% and 82.3% have enhanced impact strength, respectively, compared to the control sample C.

The optical micrographs for each sample are shown in **Figure 5**. Sample A revealed that the precipitates were finely dispersed in the 6063 Al, implying a coherent precipitate formation. This showed that the precipitates are well diffused in the structure, serving as effective dislocation barriers for dislocation movement. This dispersal is attributed to be responsible for the higher tensile and impact strengths observed in the sample. In Sample B, the precipitates were less dispersed as some clusters of precipitates are seen within the grains, which are not serving as effective barriers to dislocation motion in the sample. Also, low-temperature aging can cause under-aging where the precipitates are not fully dispersed in the structure which can cause reduction strengths, as observed in Sample B. In Sample C, the precipitates are along the grain boundaries, showing that the precipitates were not dispersed in the structure, which is responsible for the low tensile and impact strengths recorded in the sample [14].

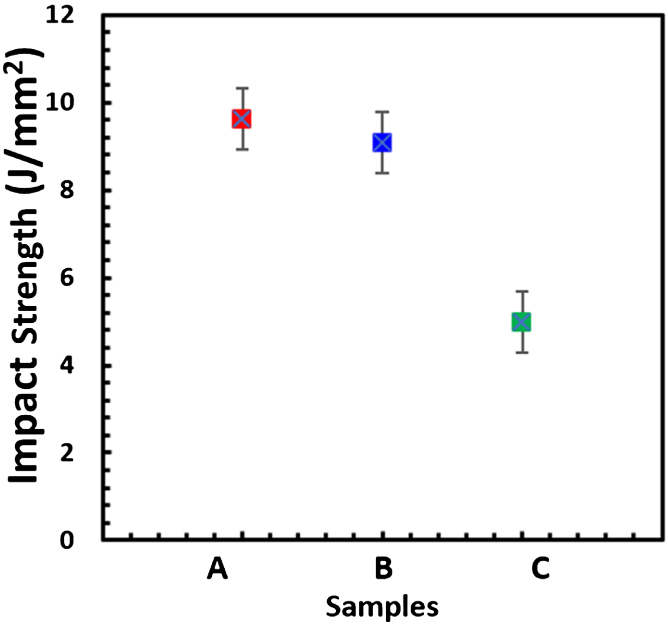

Figure 4. Impact strength for samples A, B, and C.

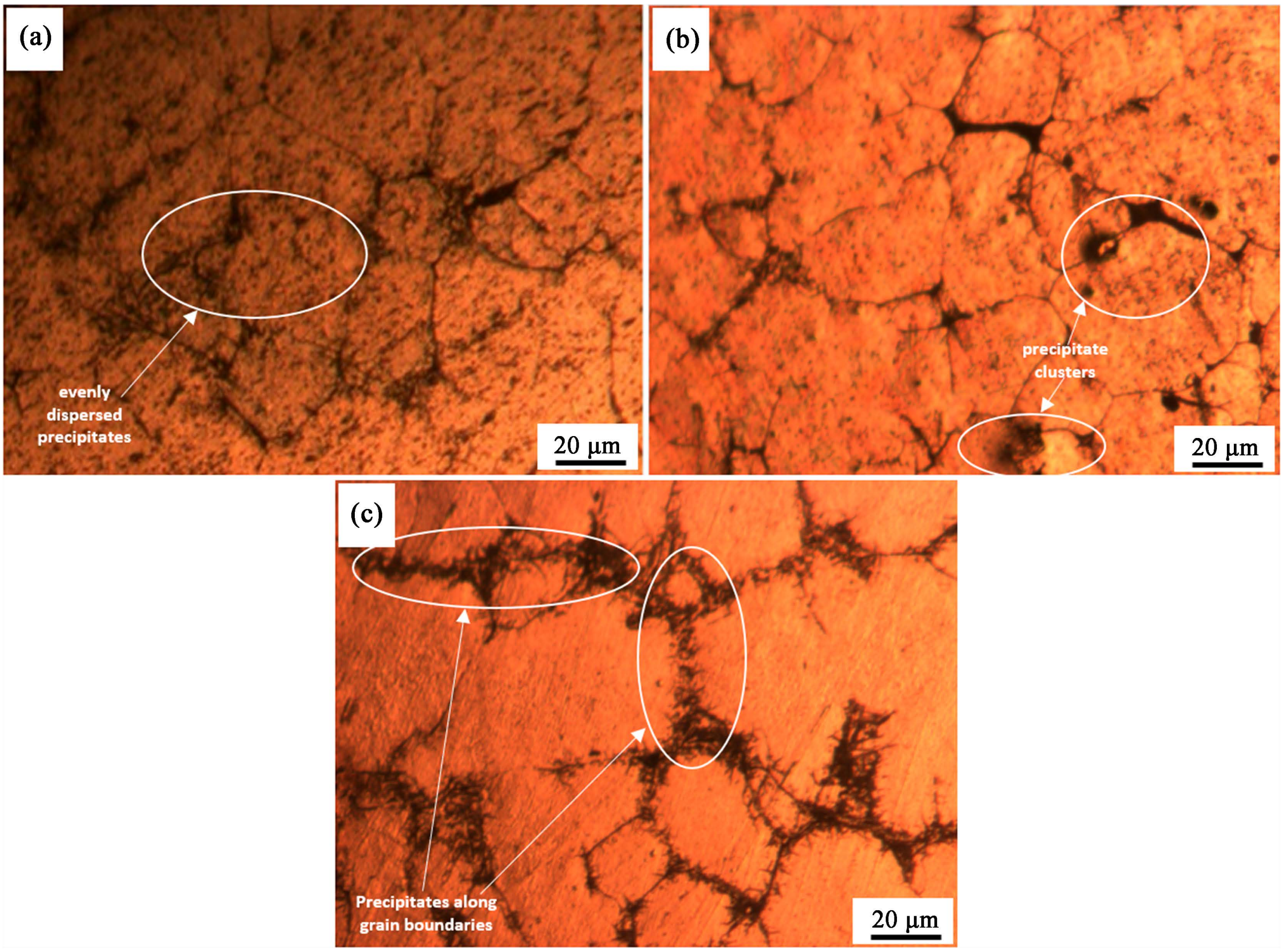

Figure 5. Optical micrographs for Samples A, B, and C.

4. Conclusion

This research investigates the impact of non-natural ageing of the microstructure and mechanical properties of aged 6063 Al alloy. It was discovered from the resulted that high temperature aging at 180˚C gave optimum values with the best mechanical properties for sample A. The optical micrographs of the sample showed that the alloying element's dispersal in the structure depends on aging conditions. Sample A showed evenly dispersed particles within the structure, implying that high amounts of coherent precipitates can be achieved at sufficiently elevated temperatures and aging time. The optimal aging conditions for this research were found in sample A which improved the tensile strength of the alloy by 40% and impact strength by 80%.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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