Optimizing Aging Time: Mechanical Behaviour and Microstructure Evolution of A6061 Aluminium Alloy

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ABSTRACT

The mechanical behaviour of A6061 Aluminium alloy, which is well known for its strength, corrosion resistance, and light properties, is investigated herein for various aging times (1, 2, 3, 4, and 5 hours) at 220°C. The study aims to establish the optimum aging time that maximizes the mechanical performance of the alloy by systematically studying microstructure changes and tensile properties (Ultimate Tensile Strength, Yield Strength, and %elongation). Microstructural observation revealed slight refinement in grain size. Strength was found to be increasing and decreasing with increasing aging time showing optimum range (UTS: 241 MPa, YS: 163 MPa, % elongation :11.7) at 3rd hour. The increasing and decreasing trend in the strength values is attributed to initiation of Mg_2Si and finally the formation of equilibrium phase. The purpose of the research is to understand how aging influences precipitate development, which has a direct influence on the material's ductility, strength, and hardness. In addition, the study yields a comprehensive appreciation of the aged alloy's suitability for various engineering applications, including structural, automotive, and aerospace components.

Keywords: Aluminium, Microstructure, Ultimate Tensile Strength, Yield strength, % Elongation

1 Introduction

Due to its excellent strength-to-weight ratio, corrosion resistance, and low weight, A6061 Aluminium alloy is greatly appreciated in technical fields. It is widely employed in industries where performance and reliability are critical, such as structural engineering, automobile, and aerospace. Age hardening, a process that enhances the mechanical properties of the alloy through controlled heat treatment, is what provides it with its high versatility. This alloy is pivotal in the manufacturing of lightweight yet durable structural components, including bridge frameworks and high-rise building reinforcements. In the automotive industry, A6061 is extensively used for crafting engine mounts, chassis, and body panels, enabling better fuel efficiency through weight reduction. Its remarkable performance under extreme conditions makes it the material of choice for aerospace applications such as fuselage components, wings, and support structures. Additionally, it is favoured in marine environments for producing corrosion-resistant ship structures and underwater equipment. The alloy's adaptability is also evident in consumer electronics, where its strength and lightweight properties contribute to the production of robust device casings. Finally, its machinability and aesthetic finish allow for its use in sports equipment like bicycle frames and outdoor gear, balancing performance with visual appeal.

Tommy et al. [1] has discussed the influence of variations in Aging conditions on ferrosilicon-silicon carbide reinforced Aluminium Metal Matrix Composite. In an attempt to make insight into the Aging properties of Al-Si materials, the research explores the influence of Aging temperature, reinforcement volume fractions percentage and Aging duration on the mechanical characteristics of the composite such as strength, hardness, impact toughness, and stress-strain behaviour. Guzman et al. [2] focuses on the aging time and temperature effects and investigates 6061 Aluminium alloy's mechanical properties as it ages. The ultimate tensile strength of 293.7 MPa was achieved under the optimum aging

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conditions, determined to be 170 °C for 18 hours. The formation of β (Mg2Si) precipitates contributes to the mechanical properties as detected by microstructure analysis. The research accentuates the significant role of heat treatment conditions to enhance the tensile strength of the alloy. Gharib et al. [3] investigates the mechanical properties of A6061 Aluminium alloy with time exhibited significant improvements subsequent to artificial aging heat treatment and Equal Channel Angular Rolling (ECAR). Through optimization of aging time and temperature, the research demonstrated a 150% enhancement in strength and 50% in formability. The boundaries of reduced formability typically experienced with ECAR were overcome by artificial aging, which enhanced strength as well as ductility. The optimal aging conditions for desired mechanical attributes were determined through an artificial neural network. Wang et al. [4] studied the mechanical properties of the Aluminium alloy AA6061 under different aging treatments, specifically focusing on the influence of pre-aging and artificial aging on microstructures and crystallographic textures. It clarifies how different treatments influence mechanical strength, tensile strength, ductility, and work-hardening behaviour. Jeevansuriya et al. [5] discusses the duplex Aging on Aluminium 7075 alloy (Al-Zn-Mg-Cu) ascribed to the age hardening strengthening mechanism and determined the specimen's surface topography and mechanical properties. The results revealed that yield strength and tensile strength of the material increased by approximately 25% in the two-hour aging process at 160 °C respectively. Li et al. [6] looks closely at how the mechanical properties of four approximately similar gradient Li content binary Al–Li alloys (0.91–3.98 wt.%) vary with aging. The alloys were aged at 175 °C for x hours (x = 0–120 hours). With increasing Li content, the peak aging times of the four alloys were 6 hours, 12 hours, 48 hours, and 48 hours, respectively. Baruwa et al. [7] observed that castability and strength, Aluminium-silicon (Al-Si) alloys—particularly those belonging to the 4xxx series—are used greatly in the automotive industry. Although grain-refining elements such as Zr, Ti, Sc, and Ce are added in trace amounts, other elements such as Mg, Zn, Cu, Ni, Sn, and Pb are added to strengthen their solid solutions. Impurities like Fe, Pb, and Mn can also improve alloy properties. From samples aged for different durations, Kseer [8] investigates the mechanical properties of Aluminium alloy 6061 under aging. Mechanical properties were found to have been enhanced overall after heat treatment at 200°C for two hours, with the best results achieved. Microstructural changes, particularly the onset and development of Mg_2Si, enhanced some major qualities like ultimate tensile stress, yield stress, ductility, and microhardness significantly and improved the alloy's mechanical properties. By applying low temperature thermomechanical treatment (LTMT), a combination of conventional age hardening and strain hardening, Sadanand et al. [9] investigates the mechanical properties of AA6061 under aging. Study shows that increasing the level of deformation reduces the aging time of the alloy but enhances its strength and hardness. The research also considers the impact of pre-deformation, different deformation, and aging cycles on the mechanical properties of the alloy, highlighting the potential for enhanced performance with improved treatment processes. Şahbaz, M [10] has studied about the aluminium alloy AA6082 after annealing and at various cooling rates and during artificial aging. From the research it was found that increased cooling rates produced finer grains and improved mechanical properties such as hardness, yield strength, and compression strength. Artificially aged samples possessed the most excellent mechanical characteristics, highlighting the significant role that heat treatment and cooling play on the functionality of the alloy. Muttahar et al. [11] found in the work that the dispersed, spherical and needle-like morphology of the precipitate exhibited variations in phase constituents and morphological microconstituents due to variations in aging of Al-Si-Cu alloys. He observed that this phase can influence the mechanical properties of the alloy. Kreyca et al. [12] found that yield strength changes due to the artificial Aging times (4 and 8 hours) at 170°C for Al A6061 alloy. From the research, it was observed that the yield strength increases with increased aging time, particularly at lower temperatures, but the alloy softens at high temperatures as precipitates dissolve quickly.

This research investigates the mechanical behaviour of the Aluminium alloy A6061 at 220°C for various aging times between 1 and 5 hours. The research tries to identify the optimal aging time to maximize performance by investigating tensile properties, including ultimate tensile strength (UTS), yield strength (YS), and elongation, as well as microstructural changes. It has been observed that the strength values are influenced by aging, the formation of precipitates, and the refinement of grain, all of which impacts the ductility, durability, and hardness of the alloy. These findings promote our understanding of how aging enhances the properties of a material for a variety of applications. This data ensures that A6061 alloy can be further processed to meet the stringent needs of high-strength construction materials, lightweight automobile parts, and aerospace components. Overall, the research provides valuable information on enhancing the mechanical properties of the alloy for innovative engineering applications.

2 Experimental Procedure

Alloy A6061 was heated in a muffle furnace at 670ºC using graphite crucible. It was then cast in pre heated metal mould and cast samples were produced in rod shape. Cut samples underwent solutionization at 530ºC for 6 hrs followed by Aging for 1, 2, 3, 4 and 5 hrs. aged samples were examined for microstructure and tensile strength (UTS, YS, % Elongation) according to ASTM standard E8.

3 Results and Discussion

Microstructure

The microstructural images of alloys aged at 1, 2, 3, 4, and 5 hours are shown in Figures 1–5. It has been observed that the grains become finer with aging. The microstructures consist of a homogeneous distribution of Mg_2Si precipitates. Through the inhibition of dislocation motion, these precipitates contribute to the strengthening of the alloy. In addition, heat treatment inhibits grain coarsening, which is required to maintain the structural integrity of the alloy and is found to be in accord with the published analysis of Guzman et al. [3]. In preventing coarse precipitates that would impair the mechanical properties of the alloy, optimal aging creates fine, homogeneously distributed precipitates that fortify the alloy [12].

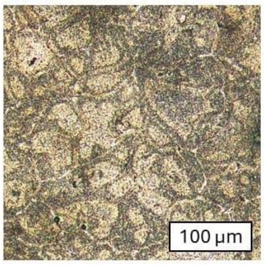

Fig.1: *1Hr Aged.*

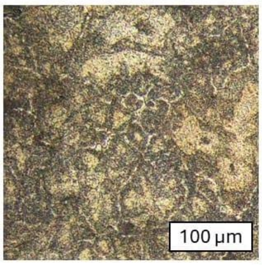

Fig.2: *2Hr Aged.*

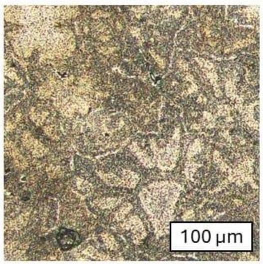

Fig.3: *3Hr Aged.*

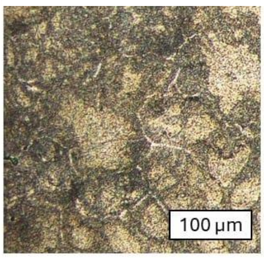

Fig.4: *4Hr Aged.*

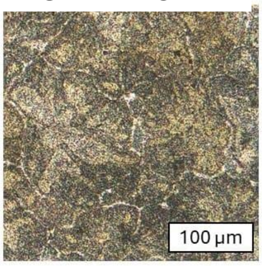

Fig.5: *5Hr Aged.*

Tensile strength

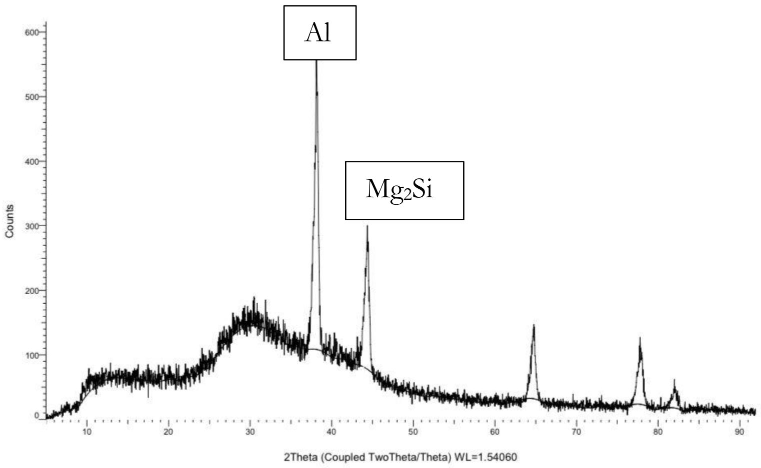

Fig.6: *XRD of 3hr aged alloy*

Fig 6 shows XRD of 3rd hr aged alloy. It is clear from the plot that Mg_2Si is forming in the alloy Figures 7-9 are comparative plots of tensile strength (UTS, YS, and %elongation) versus aging time. The reason behind the upward slope on the UTS and YS plots is the initiation of Mg_2Si. When three hours of aging are present, the UTS and YS plots become decreasing in nature, because of the beginning of the equilibrium phase of Mg_2Si. The percentages of elongation in Fig. 9 vary slightly. By reducing precipitate size and distribution, aging treatment variation significantly enhances tensile strength. Though strength loss results from over aging, optimal aging maximizes the trade-off between ductility and tensile strength [12]. Tensile strength is found to increase by initial aging temperature increase due to optimal heat treatment conditions as reported by Guzman et al. [3]. This is also true for the current study.

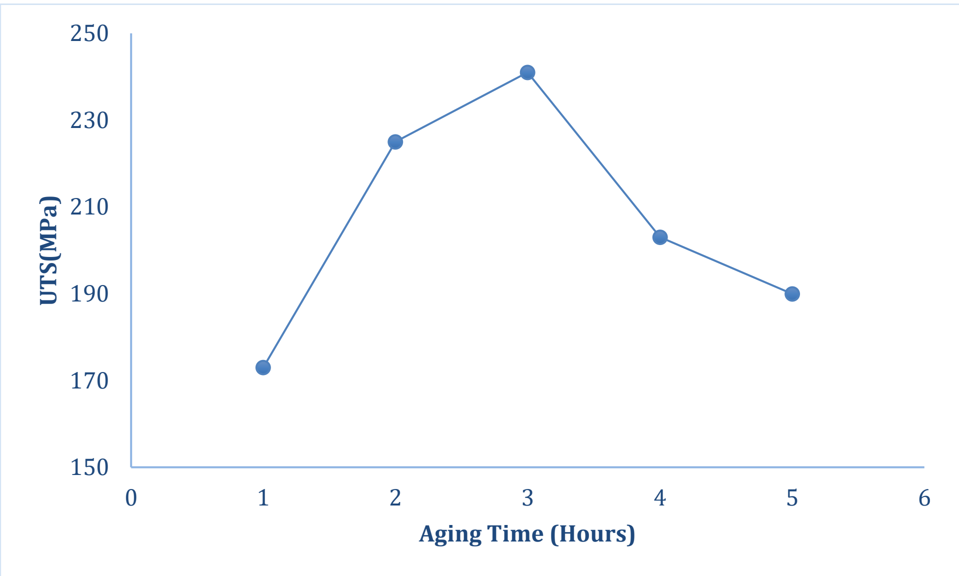

Fig.7: *UTS v/s Aging time*

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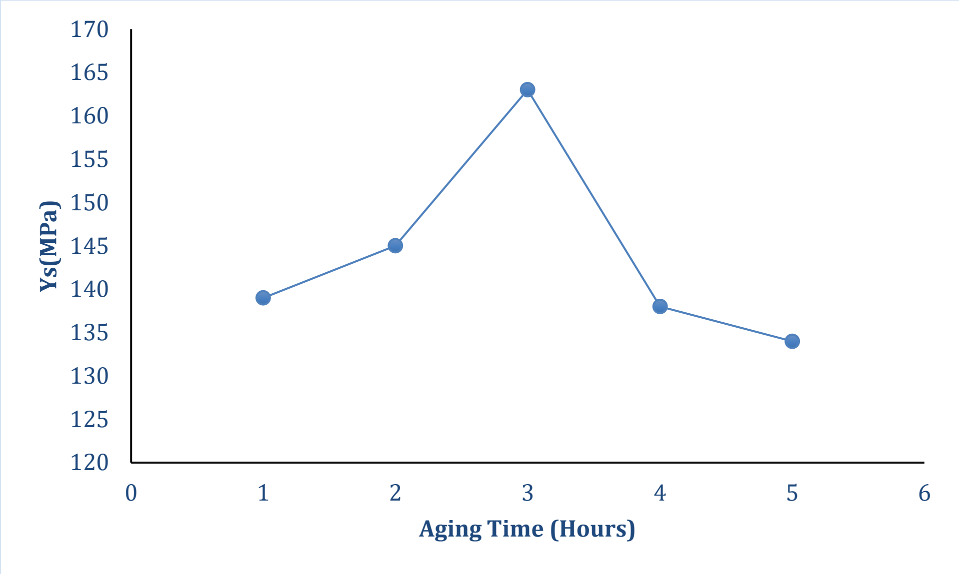

Fig.8: *Yield strength v/s Aging time*

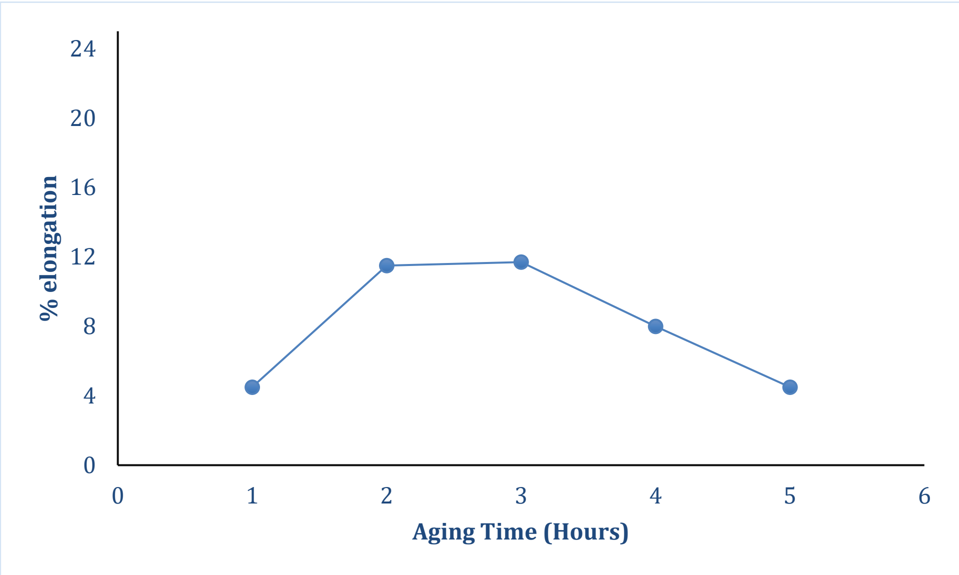

Fig.9: *% elongation v/s Aging time*

4 Conclusions

The mechanical properties and microstructure of A6061 Aluminium alloy are drastically affected by aging at 220°C, as per the research. The 3-hour aging duration is determined to be the most effective among the tested periods, providing the best combination of ultimate tensile strength (241 MPa), yield strength (163 MPa), and elongation (11.7%). A slight refinement in grain size happens during aging, as per microstructural studies, and this improvement is vital in order to raise the strength and ductility of the alloy. The growth of Mg_2Si precipitates and their final transformation into the equilibrium phase accounts for the initial increase in strength followed by a fall afterwards.

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