



Research Article

Influence of artificial aging on microstructure and mechanical properties of Aluminum 2219-T87 TIG welded joints

Atif SHAZAD^{1,*}, Maaz AKHTAR², Muhammad UZAIR¹

¹Department of Mechanical Engineering, NED University of Engineering and Technology, Karachi, 75270, Pakistan

²Department of Industrial Engineering, College of Engineering, Imam Mohammad Ibn Saud Islamic University (IMSIU), Riyadh, 11432, Saudi Arabia

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ABSTRACT

TIG welding technique was employed commonly for welding light weight materials such as aluminum at industrial level. In aerospace industry, Al 2219 material is utilized extensively in different temper grades. However, T87 temper grade is known for its superior strength compared to T6, although with reduced ductility and formability, making its behaviour under prolonged aging cycles particularly relevant for high-performance applications. This study specifically focussed on mechanical and microstructural performance of TIG-welded Al 2219-T87 joints before and after artificial aging using two extended aging durations. A filler wire with a diameter of 2.6mm, ER 2319, was used for welding 5mm thick plate. The welded joints were subjected to artificial aging at 190°C for durations of 18 hours and 24 hours to investigate the impact on joint properties. Microscopic examination was carried out on the weldments in both the as-welded condition and after the post-weld aging treatments to observe structural changes. After 18 hours of artificial aging, the weld zone and heat affected zone exhibited a fine and dense grain structure. Additionally, a large number of precipitates were observed after 24 hours of aging. The post-weld aged samples demonstrated significantly higher ultimate tensile strength and yield strength compared to the as-welded samples. Specifically, there was an enhancement of approximately 60% in ultimate tensile strength and 30% in yield strength when compared to the as-welded condition. The ductility, measured in terms of percent tensile elongation, of the welded joints also improved after 18 hours of aging. It was found that toughness increased by 40%, and there was a 90% increment in percent elongation after 18 hours of aging, attributed to the presence of fine, equiaxed grains and reasonable precipitation. Excessive precipitation and elongated grains were observed after 24 hours of aging.

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*Corresponding author.

*E-mail address: atifshahzad@cloud.neduet.edu.pk

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INTRODUCTION

Welding aluminium alloys is a promising joining practice commonly utilized in the aerospace industry. Al 2219 is a vital aluminium alloy that provides a high strength-to-weight ratio, good corrosion resistance, and absolute toughness. However, the high input heat energy involved in welding presents numerous challenges, such as reduction in joint strength, thermal deformations, and porosity [1, 2]. Thick plates often welded by using TIG welding but this technique leads to several distortions due to concentrated heat input at weld area, the strength and other mechanical properties get compromised because of these structural disorderness. The elevated heat input required for welding thicker sections exacerbates these thermal deformations [3, 4]. Several investigations have explored how different TIG welding procedures influence the mechanical and microstructural properties of Al 2219, aiming to mitigate such welding-induced defects. A comparison between Direct Current Electrode Negative Activated-TIG and Variable Polarity TIG was performed to evaluate joint properties. The results revealed that first welding technique exhibited low porosity and a narrow heat-affected zone [5, 6]. Similarly, the impact of the partially melted zone was evaluated after weld reinforcement on the welding joints of aluminium alloys. Partial melted zone's induced stress concentrations in welding reinforcements, ultimately reducing joint strength [7, 8]. The variation in grain size within the weld zone and heat affected zone, influenced by the number of TIG welding passes, significantly affects mechanical properties particularly microhardness and tensile strength [9, 10].

Typically, coarse grain boundaries observed in these regions tend to promote ductile fracture behavior, whereas finer grains enhance resistance to deformation by offering greater strength [11]. This microstructural inconsistency across the weld is often evident in micrographs of aluminium weld joints and is primarily attributed to variations in filler rod composition and fluctuations in heat input during the welding process [12]. Furthermore, the development of a continuous phase of weld material caused significant deteriorations in joint strength and specific techniques can be utilized to prevent these physical distortions like coatings etc. [13]. Negative effects observed due to over-aged zones adjacent to partial melted zones in aluminium welding joints. The mechanical properties of joints degraded due to over aged zone in the heat affected zone, Welding joints exhibited complex tensile behaviour due to the presence of partial melted zone's and over aged zone's [14].

The effects of reinforcement on the tensile behaviour of Al 2219 TIG welded joints were investigated by Wang et al. [15]. The results showed that the tensile strength of welding joints without reinforcement was 250 MPa, but it improved after reinforcement on both sides. Welding joints with welding toes in the weld zone exhibited greater elongation compared to joints with weld toes at the junction

of the weld zone and partial melted zone. The desired mechanical strength after welding is critical due to nature of heavy working loads and conventional welding processes degrades the structural integrity of the joint. Friction stir welding (FSW) is effective in strengthening joints because it creates a uniform weld zone with minimal heat-affected regions [16]. In one study, Hu et al. [17] explored the use of ultrasonic vibrations during FSW to further enhance the mechanical properties of the resulting joints. The results indicated that ultrasonic vibrations during welding led to improvements in tensile strength and fracture toughness [18].

The performance of FSW 2219 changes when the welding temperature is different which makes the tensile strength better. When the welding joints are cooled with water quickly, they become more brittle. The joints that are made underwater break at the edge of the weld zone and the heat affected zone [19]. Friction stir weld joints often have problems like tunnel defects and cavity formations which reduce the strength of the joint [20]. The intensity of these problems depends on how the welding is performed and how fast the tool rotates. Usually, bigger problems occur when the welding is slower, and the tool rotates faster which means there needs to be a balance between heat and material flow when welding [21-24].

To make the mechanical performance of welded joints better people often use heat treatments after welding. One way that works well is aging, which makes strength improved by creating and spreading out tiny particles. Even short heat treatments can make fatigue better by 20 to 25 percent [25, 26]. For Al 2219 TIG welded joints a special treatment that includes solution treatment, water quenching and aging at 175 degrees Celsius can make the joint strength better by 44 percent. Improve corrosion resistance. However, the heat-affected zone is still a little susceptible to corrosion. Shazad et al. [27]. Also found that artificial aging makes the ultimate tensile and yield strengths better and electron beam welding creates particles that are spread out evenly along grain boundaries. Heat treatments after welding are also very important for reducing stresses that come from temperature differences across the weld. If these stresses are not taken care of, they can degrade mechanical properties [28]. This degradation is mostly based on stress corrosion cracking, which is why heat treatment is necessary to keep the structure strong. Some studies on Variable Polarity TIG-welded Al 2219 showed that artificial aging makes the tensile and yield strengths better by 42 percent and 44 percent and also improves fatigue strength by 18 percent. Another study by Raza et al. [29] found that aging at 210 degrees celsius for four hours creates tensile strength and hardness because the tiny particles are spread out well.

A lot of research has been done on how Al 2219 behaves when welded and aged for a time and under different temper conditions. Not much is known about how the T87 temper grade behaves when aged for a long time. The T87 condition is stronger than T6. It is less flexible and less able

to be formed which makes it very important to know how it behaves over time for high-performance applications. This study looks at the microstructural performance of TIG-welded Al 2219-T87 joints that have been artificially aged for two different long periods of time. The Al 2219 performance is very important to understand. The welding temperature is very important for Al 2219. The Al 2219 joints are often used in applications. The performance of Al 2219 is very important for these applications.

The goal of this study is to learn more about Al 2219-T87. Al 2219-T87 is a very strong aluminium alloy. It is not very flexible. This makes it hard to use in some applications. The Al 2219-T87 needs to be studied. The study will look at how Al 2219-T87 behaves when it is aged for a time. This will help us understand how to use Al 2219-T87. The results of the study will be very important, for people who use Al 2219-T87.

MATERIALS AND METHODS

This study was conducted on a 5mm thick plate of Al 2219-T87 to investigate the effects of TIG welding. Specimens were prepared using a TIG welding technique with a welding speed of 200mm/min, which was chosen to ensure high-quality welding joints. The welding process utilized a Precision TIG AC type model equipment. In post weld heat treatment process artificial aging was performed only at 190 °C to assess improvements in the mechanical properties and microstructures of the welded joints. Two durations such as 18 hours and 24 hours were selected because significant data is available for durations less than 12 hours. Larger durations may identify the over aging duration for aluminum material at some specific aging temperature. To evaluate the ultimate tensile strength and yield strength, an H150KV Tensile testing machine was utilized. The samples were prepared according to the ASTM E8M-16a standard. To find out how much energy something can take the Charpy impact test was used. This test shows us how strong a material is when something hits it. The sampling were performed as per ASTM E23-18 standard. Hardness fluctuations were investigated using Vickers

Table 2. Tensile properties of Al 2219-T87

S. No	Characteristics	Value
1	Base metal	Al 2219-T87
2	Yield strength (YS)	390MPa
3	Tensile strength (UTS)	483MPa
4	Hardness (HV)	124
5	% Elongation	12%

tester for microhardness. Optical metallurgical microscope was employed to figure out the variations in microstructure due to artificial aging. The emission spectrometer used to identify the alloying contents in Al 2219 material, results are represented in Table 1. Table 2 indicates mechanical properties of base plate. The comparison between Al 2219 base material and the weld joints after artificial aging to check the impact of thermal cycle and duration time.

The aim of this study was to examine the impact of artificial aging on welded samples by comparing two different durations of aging. Following the TIG welding procedure, the samples underwent artificial aging by being placed in a furnace for either 18 hours or 24 hours. To ensure sufficient material penetration, a double pass welding technique was utilized. The TIG welding process involved the use of a 2.6mm diameter ER2319 filler wire.

RESULTS AND DISCUSSION

Microstructural Examination

This study investigated the variations in microstructure of TIG weld joints of Al 2219-T87 material after long durations of artificial aging. Figure 1 illustrate microstructure of Al 2219-T87 for comparison with the microstructures of this study. Microstructures in weld zone and heat affected zone of welded joints are shown in Figure 2 and Figure 3 respectively. Optical micrographs of weld zone after artificial aging in Figure 2 (b) and Figure 2 (c) represented fine grain boundaries compared to weld zone microstructure of welded joints without aging shown in Figure 2(a). Furthermore, after artificial aging, the grains in the weld zone exhibit a more equiaxed shape and are evenly distributed, whereas the grains in the weld zone without aging are irregularly spaced.

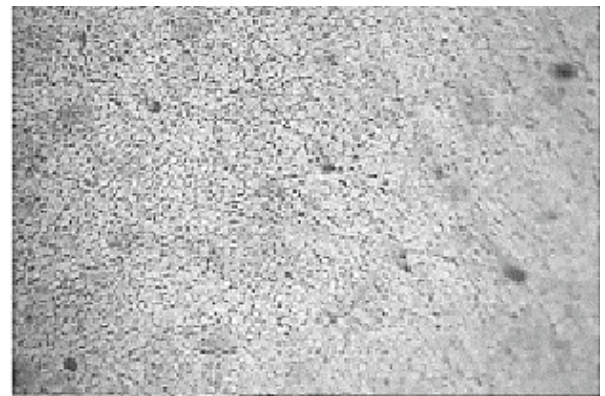
Additionally, a slight increase in grain elongation was observed in the non-aged samples weld zone. However, this difference was not significantly noticeable, suggesting that post-weld heat treatment does not have a significant effect on grain elongation in the weld zone. Figure 3 depicts the microstructures of heat affected zone in different conditions. A comparative analysis of heat affected zone microstructure is presented in Figure 3(a), Figure 3(b), and Figure 3(c), before and after artificial aging at two different time periods. Figure 3(c) demonstrates the

Table 1. Chemical composition by weight of Al 2219-T87

S.No	Element	Percentage
1	Mg	0.18
2	Si	0.23
3	Mn	0.28
4	Cu	6.2
5	Zn	0.11
6	Ti	0.073
7	Fe	0.31
8	Al	Remaining

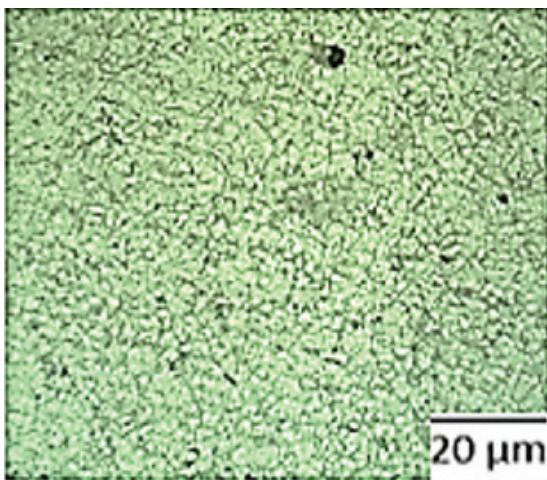


(a)

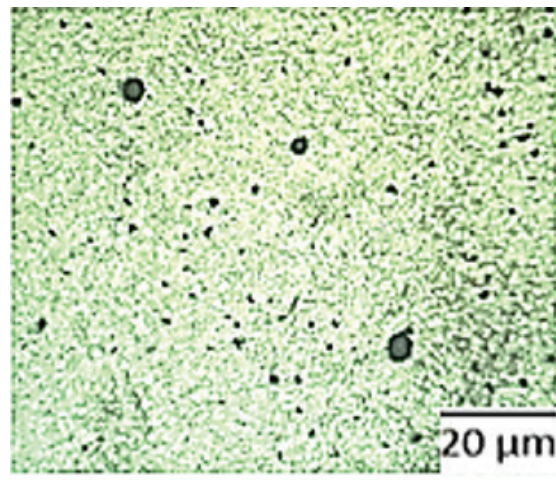


(b)

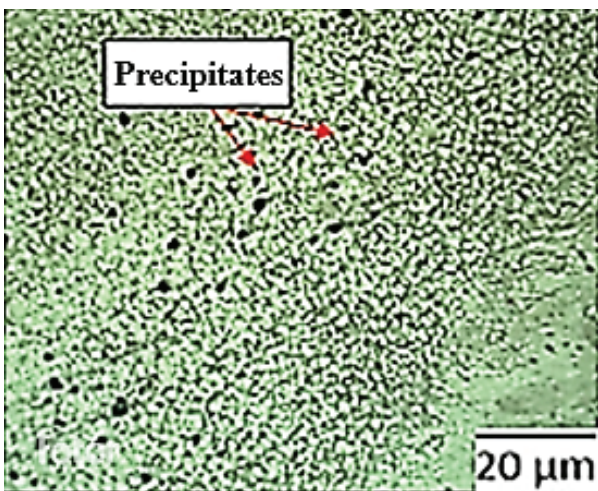
Figure 1. Microstructure of Al 2219-T87 (a) Heat affected zone after TIG (b) Base metal [30]. Adapted from: Venkatasubramanian G, Mideen AS, Jha AK. Microstructural characterisation and corrosion behaviour of top surface of TIG welded 2219-T87 aluminium alloy. *Int J Eng Sci Technol* 2013;5:624. Available at: https://www.researchgate.net/publication/264972445_



(a)



(b)



(c)

Figure 2. Microstructure of weld zone (WZ) of Al 2219- T87 (a) TIG welded sample without Aging (b) Sample after 18 hours aging (c) Sample after 24 hours aging.

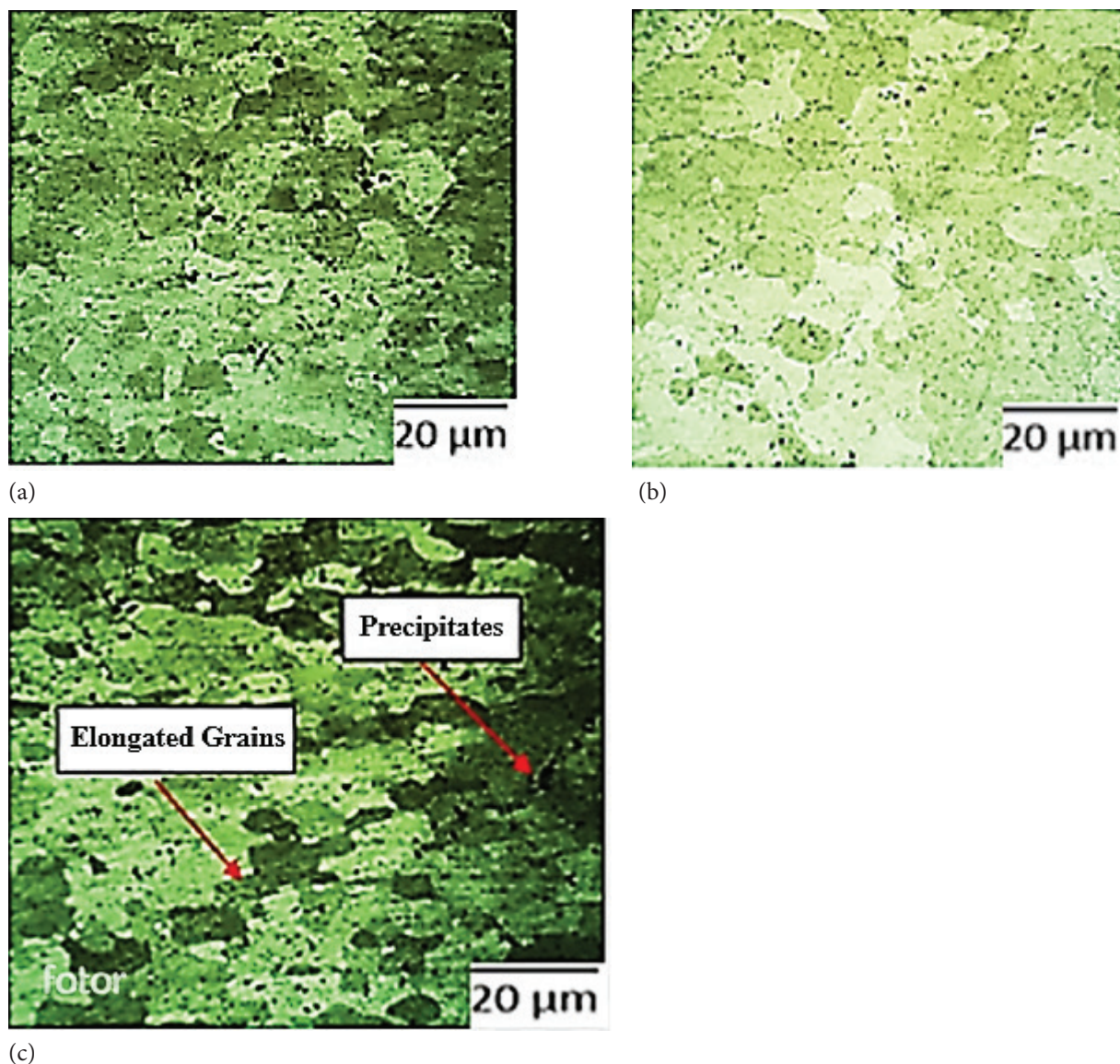


Figure 3. Microstructure of heat affected zone (HAZ) of Al 2219- T87 (a) TIG welded sample without Aging (b) Sample after 18 hours aging (c) Sample after 24 hours aging.

presence of distinct precipitates after a 24-hour aging, indicating their prominent formation. Conversely, Figure 2(b) illustrates a heat affected zone microstructure with dense and fine grains, which hinder dislocation movement and consequently enhance strength. Figure 1(a) showing similar microstructure in comparison with microstructure represented in Figure 3(a). The microstructure of artificially aged joints exhibits significant improvements, particularly in samples heated for 24 hours, where elongated grains are observed. This extended heating period induces internal stresses along grain boundaries due to excessive precipitation, resulting in sample hardening. However, the strength of the 24-hour heated samples is lower compared to the 18-hour heated samples.

In Figure 3(a), a disrupted grain structure is evident, which can be attributed to the high input heat during welding, in contrast to the more favourable grain structures observed in Figure 3(b) and Figure 3(c). The elongated grains are particularly noticeable in Figure 3(c). Size and orientation of grain boundaries are crucial for controlling of mechanical properties of weld joints. Referenced studies [6, 10] mentioned importance of grain size on overall performance of joint. Formation and distribution of precipitates across the weld joint also explained in literature as well, more precipitates offered more resistance to dislocation movements, hence resistance to deformation promote strength and degrade ductility.

Tensile Testing

Tensile testing was performed to investigate impact of artificial aging on strength of Al 2219 – T87 welding joints. Results represented in Figure 3 display the difference between joints yield strength before and after artificial aging of TIG welded joints. Welding input heat degraded strength upto 50% as shown in Figure 4, 150MPa YS was observed after TIG welding without artificial aging. However, artificial aging improved YS from 150MPa to 240MPa after artificial aging. Maximum

enhancement in YS was achieved after artificial aging for 18hours duration. Figure 5 displays a comparison of the UTS between welded joints before and after artificial aging. The results indicate that a ultimate tensile strength of 310MPa was achieved after an 18-hour artificial aging process. The increase in strength can be attributed to the presence of fine grains in the weld zone and the uniform distribution of precipitates within the material phase. No significant elongation of grains was observed during the 18-hour aging period.

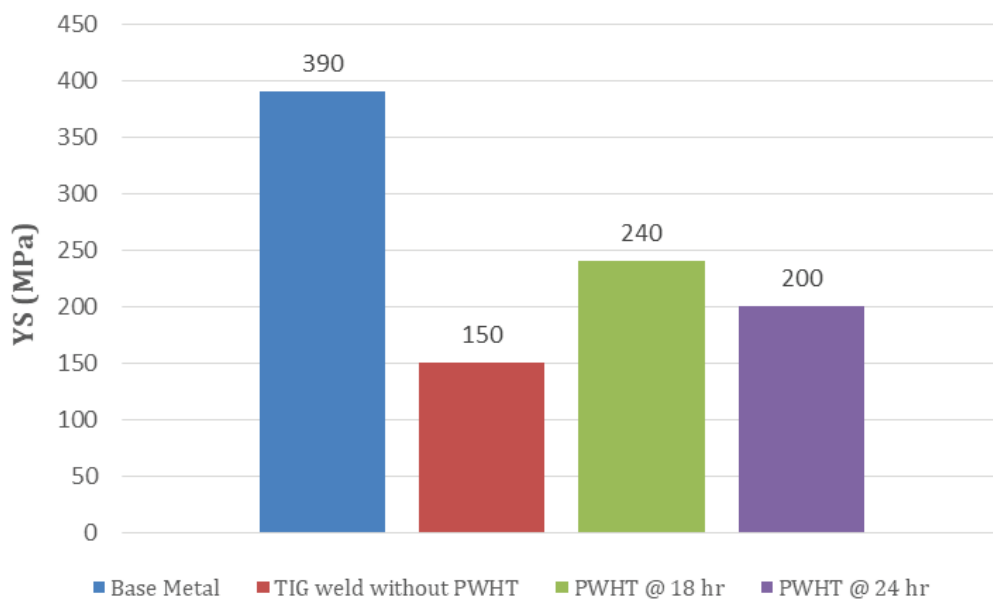


Figure 4. Comparison data of yield strength (YS).

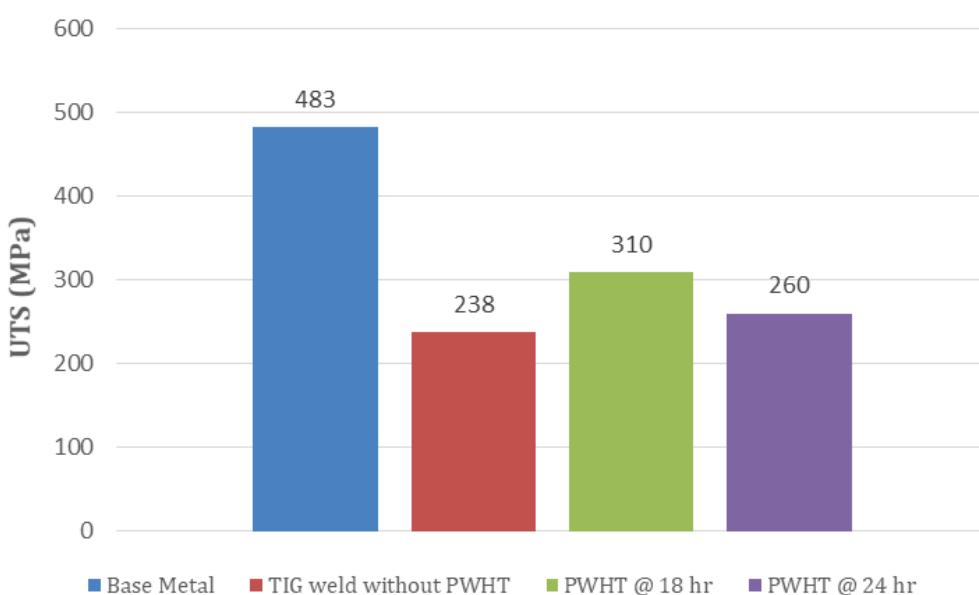


Figure 5. Comparison data of ultimate tensile strength (UTS).

However, when the artificial aging was extended to 24 hours, the microstructure exhibited both disrupted and elongated grains, leading to a reduction in ultimate tensile strength. The excessive formation of precipitates at the grain boundaries in both the weld zone and the heat affected zone of the 24-hour treated samples induced internal stresses. Consequently, the tensile strength of the 24-hour aged samples was lower compared to the 18-hour aged samples. Moreover, the increase in tensile strength observed after artificial aging can be compared with the findings of the reference study [29], which reported a maximum improvement of approximately 51 MPa. In contrast, this study achieved a tensile strength increment of 72 MPa. This enhanced improvement is attributed to the longer soaking duration employed in this study. Notably, the reference study used a shorter soaking duration of 4 hours at 210 °C around 20 °C higher than the temperature applied in this study for an extended soaking duration of 18 hours. The study investigated the impact of artificial aging on the ductility of welded joints. Figure 6 presents a comparison of the percentage elongation before and after artificial aging.

Significantly different results were observed between joints that underwent artificial aging and those that did not. Joints without artificial aging exhibited minimal percentage elongation, while those subjected to artificial aging, particularly for 18 hours, showed the highest percentage elongation. The improvement in ductility can be attributed to the formation of a uniform phase of precipitates and a reduction in defects at grain boundaries. The presence of fine grain boundaries and the distribution of precipitates along these boundaries contributed to

the reduction in defects. However, the samples aged for 24 hours displayed lower percentage elongation compared to the 18-hour samples. This decrease in ductility can be attributed to excessive precipitates at the grain boundaries, resulting in increased hardness due to prolonged aging duration.

Welding Efficiency

Welding efficiency of Al 2219-T87 joints was improved due to fine precipitates in weld zone. One reason of weld efficiency enhancement was greater dense ratio of precipitates in heat affected zone of 18 hours artificial aging. Joints strength was superior due to artificial aging compared to welding joints without artificial aging. Weld efficiency 64.2% after artificial aging for 18 hours was achieved as shown in Figure 7. Overall, 30.2% augmentation was achieved due to artificial aging for 18 hours. However, 9.5% increment in joint welding efficiency was attained due to artificial aging for 24 hours. Joints artificially aged for 24 hours exhibited low efficiency compared to 18 hours artificially aged joints due to precipitation hardening and elongated grains.

Micro-Hardness Testing

Hardness testing was conducted to assess the impact of artificial aging duration. Table 3 illustrates that the hardness of the welded joint increased after 24 hours of aging. The base metal hardness also improved for both durations, but a significant increase was observed after 24 hours of artificial aging. The primary cause of the hardness increment and ductility reduction is precipitation hardening. A detailed comparative study revealed that the hardness of coarse grains, the weld zone, and the

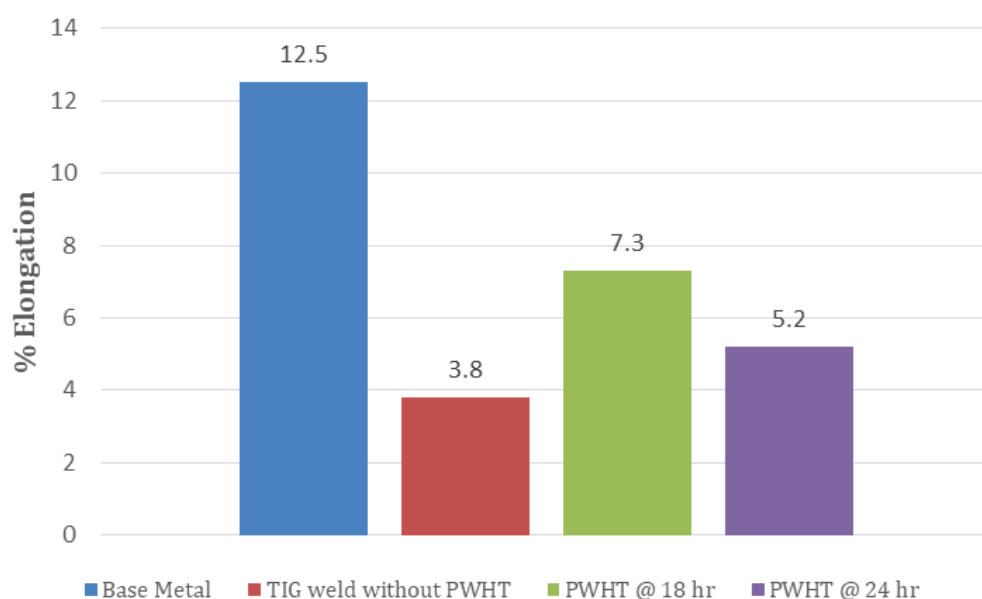


Figure 6. Comparison data of percent elongation.

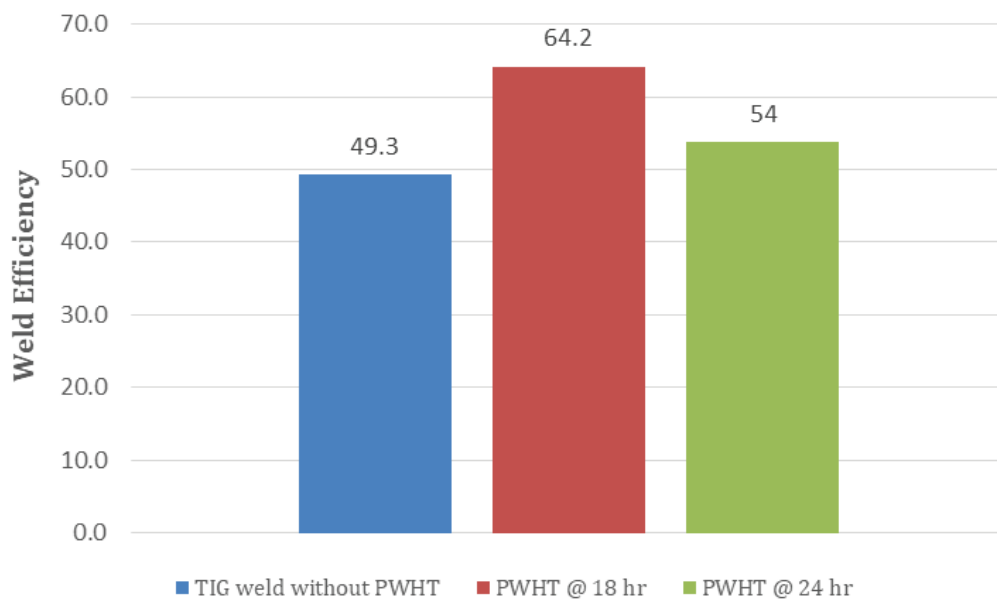


Figure 7. Welding efficiency.

Table 3. Evaluation of hardness (Vicker) due to artificial aging

S. No	Hardness region	18 hours	24 hours
1	Weld Zone	85-110	95-115
2	Coarse Grains	87-100	100-120
3	Fine Grains	74-86	82-85
4	Base Metal	110-128	112-135

base metal after 24 hours of aging was greater than that of the 18-hour aging weld samples. The degradation of mechanical properties and ductility due to extensive precipitation is evident from the hardness study. Therefore, 18 hours of artificial aging is the preferred choice for welded joints due to superior properties. Furthermore, a comparison with the findings of reference study [30] shows that a hardness of 81 HV was achieved using a short soaking duration at a higher temperature. In contrast, this study recorded increases of 25 HV and 40 HV in hardness for soaking durations of 18 hours and 24 hours, respectively. The significant hardness gain in the short-duration, high-temperature cycle suggests excessive precipitate formation, which can adversely affect the ductility of the material. A similar trend of increased hardness was also observed when the soaking duration was extended from 18 to 24 hours in this study.

Impact Testing

The toughness evaluation of welding joints involved conducting Charpy Impact testing both before and after

subjecting them to artificial aging. In Figure 8, x axis indicated artificial aging durations and y axis represented absorbed impact energy during Charpy test. The absorbed impact energy ultimately reveals toughness of samples. Hence, the toughness of the welding joints without artificial aging was determined to be 7.4 J/cm², as depicted in Figure 7.

The material was not as strong as it should have been because of what happened when it was welded. The welding process provides larger heat input, this heat changed the material's structure at the weld and around that area. The material became stronger after it was treated with aging. For example, after the material was treated for 18 hours, it became much stronger, and impact energy measured was around 10.3 J/cm². After 24 hours, weld joints absorbed 8.8 J/cm² of energy. This showed that the material became much stronger after it was treated. The material became 40% stronger after 18 hours and slightly stronger after 24 hours due to excessive aging.

The material's ability to bend was measured by something called ductility. Ductility is how much the material can bend without breaking. So, when the material became more ductile, it meant it could bend more without breaking. After the material was treated for 18 hours, it became ductile. The artificial aging process made the material better at bending without breaking than it had been before. The material was better at bending without breaking after it was treated. The artificial aging process really helped the material become more ductile than it had been after welding. The material became better at bending without breaking because of the aging process.

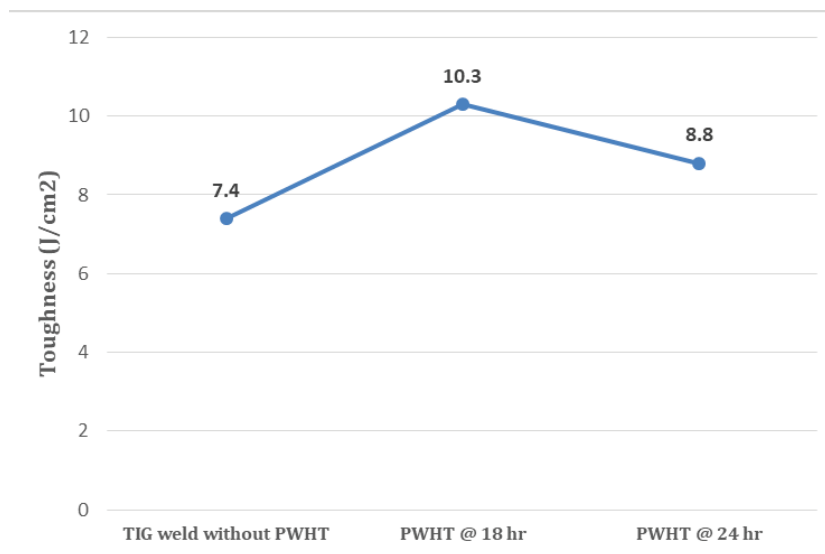


Figure 8. Toughness of welding joints.

CONCLUSION

The goal of this study was to see how a special kind of heat treatment called aging affected the properties of welded aluminum joints. The way tiny particles formed inside the metal depended on the temperature and the time it spent at that temperature. Most recent researches indicated short times and different temperatures for various types of aluminium alloys. The behaviour of this specific alloy under larger exposure to heat was crucial for figuring out how artificial aging affected its properties. In this study, the welded joints exposed to heat at 190 °C for 18 hours and 24 hours. A microscopic analysis was conducted to examine variations in microstructure and grain size. The HAZ of the joints subjected to 18 hours of treatment exhibited uniformly sized and shaped grains, whereas the region treated for 24 hours developed elongated grains, which introduced internal stresses. During testing, it was found that it got much stronger after 18 hours of heat treatment. The yield strength increased from 150 MPa to 240 MPa and tensile strength from 238 MPa to 310 MPa. After 24 hours, the tensile strength slightly enhanced to 260 Mpa and yield strength improved to 200 MPa. The efficiency of the weld improved by 30% after 18 hours and by 9.5% after 24 hours compared to joints that were not treated. The heat treatment also made the joint more flexible and tougher. Similarly, the percent elongation of joint increased by 90% after 18 hours. The toughness improved by 40% after 18 hours and by 19% after 24 hours. These results showed how much the properties depended on the duration of heat treatment, even if the temperature maintained same. More than 18 hours artificial aging did not seem to be much effective because it caused excessive hardening, which made the Al 2219 joint less flexible and less tough. Overall, findings showed that it was crucial to choose the heat treatment parameters. For

welded aluminum joints used in airplanes and spacecraft, finding the balance of heat treatment could make them much stronger, more flexible, and tougher, without weakening the structure. The TIG-welded Al 2219-T87 joints benefited significantly from optimized aging. Artificial aging improved the properties of TIG-welded Al 2219-T87 joints. Al 2219-T87 joints exhibited improved properties after artificial aging.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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