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Optimization of TIG welding parameters for enhanced mechanical properties of Al 7075 weldments

Madaniyyu Sulaiman Yahaya*[a, b], Dinesh Kumar[a], Shamsu Tukur Auwal[b], Mahdi Mokoyo[c], Abdulhaq Saleh Gambo[a], Tijjani Aminu Umar[b], and Abubakar Tijjani[b]

[a]Department of Mechanical Engineering, Mewar University, Chittorgarh, India.
[b]Department of Mechanical Engineering, Kano University of Science and Technology, Wudil, Nigeria.
[c]Department of Mechanical Engineering, Bayero University Kano, Nigeria.

Abstract

Al 7075 alloy is widely used in aerospace, automotive, and other high-performance industries due to its excellent strength-to-weight ratio and mechanical properties. However, its weldability, particularly using Tungsten Inert Gas (TIG) welding, presents significant challenges, including softening of the weld zone, solidification cracking, and the formation of defects in the heat-affected zone (HAZ). These challenges degrade mechanical properties such as tensile strength, hardness, and ductility, limiting the use of Al 7075 in critical welded applications. This study investigates the optimization of TIG welding parameters to improve the mechanical performance of Al 7075 weldments. A systematic experimental approach was employed, where key TIG welding parameters, including current (ranging from 120A to 180A), gas flow rate, and heat input, were varied to assess their effects on weld quality. Two plate thicknesses, 6mm, and 16mm, were utilized to explore the influence of material thickness on mechanical properties. Mechanical testing, including hardness, and tensile strength, was performed to quantify the impact of welding parameters. The findings demonstrate that the welding current has a significant effect on the mechanical properties of Al 7075 weldments. For both the 6mm and 16mm thick plates, moderate welding currents, particularly around 150A to 160A, resulted in the best overall mechanical performance. The 6mm plate exhibited a peak tensile strength of 325 MPa at 160A, with minimal hardness reduction in the weld center (18%), weld zone (28%), and HAZ (9.5%). The 16mm plate demonstrated a peak tensile strength of 290 MPa at 160A, with hardness reductions of 25%, 22.2%, and 9% in the weld center, weld zone, and HAZ, respectively. Excessively high currents (170A to 180A) resulted in increased hardness reduction and reduced tensile strength due to overheating and excessive thermal softening. Overall, 160A was found to be the optimal welding current for both plate thicknesses, balancing heat input, and weld quality.

Keywords: Al 7075 alloy; TIG welding optimization; Welding current; Plate thickness; Mechanical properties.

1. Introduction

Developed in 1943, Al 7075 is a high-strength aluminum alloy that is essential for businesses that value strength and low weight [1]. With substantial proportions of zinc, magnesium, and copper, it is mainly composed of aluminum and comes in forms such as T6, T73, T76 sheet plate, and T6511 extrusion [2, 3]. Because of its exceptional strength-to-weight ratio, machinability, and resistance to corrosion, Al 7075 is perfect for automotive parts like engine cylinders and pistons and aeronautical components like fuselages and wings. It also improves fuel efficiency, particularly in electric vehicles (EVs) [4-6]. Unfortunately, its usage in some marine applications is limited by its inferior weldability in comparison to other aluminum alloys and its vulnerability to stress corrosion cracking in conditions high in chloride [7]. Wear problems in hostile locations and surface flaws like burrs and microcracks are additional fabrication hurdles [8, 9]. Notwithstanding these drawbacks, Al 7075 is essential in many industries due to its special blend of strength and lightweight, and its use is anticipated to grow as surface treatment and welding technologies progress [10].

Although combining Al alloys requires welding, the physical characteristics of aluminum make welding difficult. One significant problem is hydrogen porosity, which lowers fatigue resistance and tensile strength. Welding becomes more difficult when hydrogen contamination occurs due to shielding gases, ambient moisture, or other sources [11,12]. Furthermore, aluminum presents thermal management issues because of its tendency for hot ripping and solidification cracking during welding [13]. The oxide layer of aluminum (AlO_3) can prevent arc initiation and result in incomplete fusion because it melts at a greater temperature than the base metal [14]. In addition to the careful selection of shielding gases such as argon, helium, CO_2, and argon/CO_2 mixes, pre-weld cleaning techniques like brushing or more sophisticated techniques like cathodic etching are essential because they alter the welding voltage by influencing the heat input into the gas nozzle [15]. Al 7075 is particularly limited in its industrial use because of its high susceptibility to solidification cracking and hydrogen porosity during welding [16, 17]. It is susceptible to cracking due to its broad solidification range and alloying components, and excessive aging in the heat-affected zone (HAZ) deteriorates mechanical qualities, decreasing joint formability [18]. The ultimate tensile strength (UTS) values that result from softening in the fusion zone (FZ) and HAZ are only 55–70% of the base metal, with little elongation [19, 20]. Porosity and cracking are still problems in spite of improvements in process optimization.

Welding techniques for aluminum alloys include resistance welding (RW) [21], metal inert gas (MIG) [22], tungsten inert gas

*Corresponding author. Email: madaniyyusyahaya@gmail.com

(TIG) [23, 24], laser beam welding (LBW) [25], friction welding [26], friction stir welding (FSW) [27, 28], Electron beam welding (EBW) [29], Cold Metal Transfer (CMT) [30, 31], and Laser hot-wire welding [32]. With its ability to precisely control heat input, gas tungsten arc welding (GTAW), a popular fusion arc welding process for Al 7075, is appropriate for applications that demand less deformation [33] [34]. A tungsten electrode and the workpiece are connected by an electric arc in this procedure, which uses shielding gas to prevent contamination of the weld. The stability and penetration of welds are impacted by shielding gases such as argon, helium, or mixes [15]. Pulsed current is frequently advised over continuous current in order to lessen problems with solidification and grain coarsening [35] [36]. Filler metals from the 5xxx range might be used to lessen hot cracking [37].

To overcome problems including solidification cracking, fusion zone softening, and mechanical property degradation, welding aluminum alloys—especially Al 7075—requires meticulous welding parameter adjustment. Excessive heat input can cause over-aging, the loss of strengthening components, and the formation of coarse grains, all of which impair joint performance [38]. To lessen these difficulties, variables including current, voltage, welding speed, and gas flow rate can be optimized. When Anuradha et al. [39] investigated TIG welding of different materials (AISI 4140 steel and Inconel 718), they showed that mechanical properties were improved by adjusted currents and speeds. TiC-enhanced filler paste was also employed by Abdollahi et al. [40] to remove solidification cracks in Al 7075, and Xiao et al.. [41] demonstrated that post-weld heat treatment increased plasticity and tensile strength. While Pujari et al [42] employed the Taguchi technique to obtain perfect weld pool geometry in AA 7075-T6 through optimized peak and base currents, pulse frequency, and welding speed, Pradhan & Punyakanti discovered that moderate gas flow rates and lower welding currents optimized UTS in Al 7075. The most important aspect influencing joint strength, according to Nandagopal & Kailasanathan's [43] optimization of process parameters for welding titanium and Al 7075, is welding speed. Furthermore, research by Fouad et al. [44] and Abd Ul-Qader [45] demonstrated that the choice of filler material, specifically ER5356, significantly affected the microstructure and weld strength. All things considered, these investigations highlight how important it is to regulate welding parameters including current, speed, filler material, and gas flow to improve the mechanical qualities and weld quality of Al 7075 joints.

Although the effects of welding parameters like current, filler material, and gas flow rate on aluminum alloys have been the subject of several research, little is known about the unique behavior of Al 7075, especially when it comes to different plate thicknesses. Prior research has frequently concentrated on optimizing one parameter at a time, largely ignoring the combined impact of several parameters, including shielding gas flow rate, filler type, and current. Furthermore, another crucial issue that needs more research is how plate thickness affects the mechanical characteristics and quality of the weld in the context of TIG welding. By optimizing TIG welding conditions for both 6mm and 16mm thick Al 7075 plates, this study seeks to close these gaps. It focuses on improving mechanical qualities such as hardness and tensile strength while reducing flaws.

2. Materials and method

The goal of the experimental study was to employ the TIG-200 Sun Power Plus welding machine to optimize TIG welding parameters for Al 7075 alloy (Fig. 1). With this equipment, welding currents between 120A and 180A may be precisely controlled, and CO_2 shielding gas flow rates between 10 to 20 liters per minute can be regulated. To reduce oxidation during the welding process, the

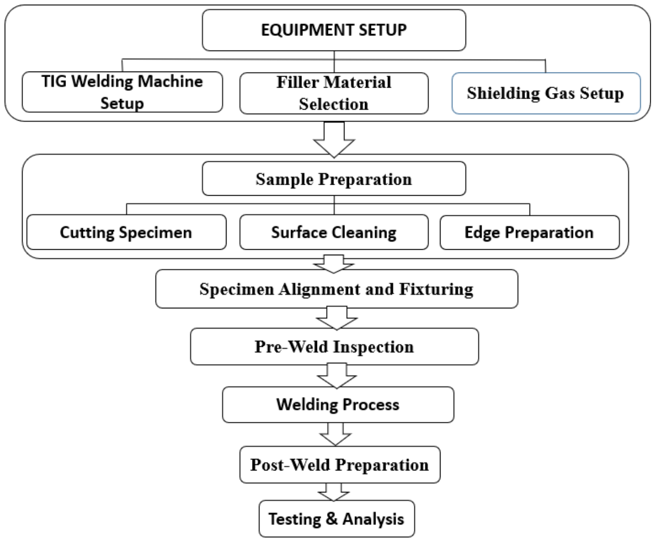

Figure 1: Research methodology.

CO_2 shielding gas was selected. To guarantee the best possible heat penetration and distribution, the welding torch was angled at a 45° angle.

As indicated in Table 1, the ER5356 filler rod was chosen because it is chemically compatible with Al 7075, guaranteeing improved joint quality. Plates with dimensions of 120 x 30 mm and thicknesses of 6 and 16 mm made up the basic materials. The plates were thoroughly cleaned to get rid of impurities before welding, and beveled edges were prepared to improve weld penetration. During the welding process, a specifically made jig was used to keep the plates' alignment and gap constant. Pre-weld inspections were carried out to confirm the accuracy of the setup.

The samples were prepared for mechanical testing to assess their tensile strength and hardness after welding. A Universal Testing Machine (UTM) was used to test specimens that had been manufactured in accordance with ASTM E8 specifications for tensile tests. Tensile strength measurements were noted after the samples were put through uniaxial tension until they failed. In accordance with ASTM E18 guidelines, hardness tests were conducted using the Rockwell B scale, a 100 kgf load, and a 1/16" ball indenter. To examine the distribution of mechanical parameters, hardness measurements were made at 1 mm intervals throughout the heat-affected zone (HAZ), weld zone, and weld center.

The relationship between welding current and the mechanical properties of both plate thicknesses was investigated through the systematic collection of data, which shed light on how these factors affect the distribution of hardness and tensile strength. The results provide insight into how TIG welding parameters affect the mechanical performance of weldments made of Al 7075 alloy.

3. Results and discussion

The hardness distribution across a welded 6 mm and 16 mm thick Al 7075 plate joint is depicted in Fig. 2 and Fig. 3, respectively. With negative numbers on the left and positive values on the right, the weld center is at 0 mm. Hardness is directly impacted in the welding zone, which is between -2 and 2 mm. Representing thermal effects, the Heat Affected Zone (HAZ) is located between 3 and 6 mm on the right and -3 to -6 mm on the left. After these, the substance, which stands in for the base metal, retains its initial hardness.

The impact of welding current on the hardness of the 6mm thick Al 7075 plate is shown in Fig. 2, which clearly shows a relationship between current levels and hardness retention across the weld center, welding zone, and heat-affected zone (HAZ). With the largest

Table 1: Chemical composition of Al 7075T6 and ER5356 filler material used.

Composition	Zn	Mg	Cu	Si	Cr	Mn	Fe	Ti	Al
Al 7075T6 (wt.%)	5.831	2.478	1.689	0.212	0.22	0.121	0.125	0.142	89.80
ER5356 (wt.%)	0.01	4.9	0.15	0.025	0.11	0.14	0.15	0.09	Balance

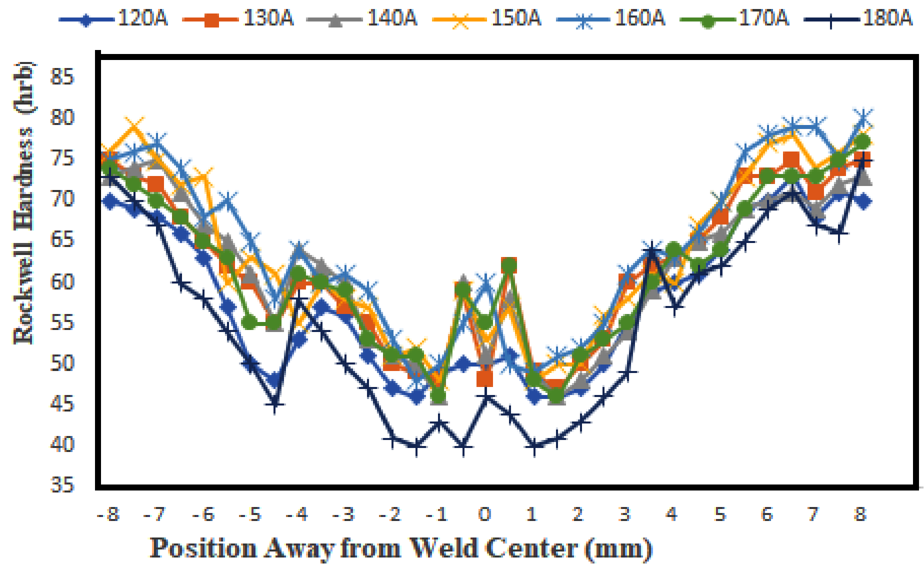

Figure 2: Hardness distribution of 6mm Al 7075 weldments.

loss at 180A (37.16%) and the lowest at 160A (18%), the hardness reduction in the weld center exhibits a rather erratic pattern. According to this, the best heat input is provided by moderate currents, especially those between 150 and 160 amps, which minimize hardness degradation and preserve superior mechanical qualities in the weld core. The decrease is approximately 31.7% and 34.4% at lower currents (120A and 130A), indicating that insufficient heat input may also result in notable softening because of insufficient fusing or irregular microstructure development. High heat input causes excessive softening, as seen by the rise at 180A. At 180A (41.8%), where the softening effect is most noticeable, the hardness drop in the weld zone demonstrates that rising current causes a greater loss in hardness. The loss progressively drops from 35% to 28% at lower currents (120A to 160A), suggesting that moderate currents result in less thermal softening and support improved mechanical property retention. The substantial softening caused by excessive heat input at higher currents may compromise the structural integrity of the weld zone, as evidenced by the precipitous increase in reduction at 170A and 180A (31.4% and 41.8%, respectively). Out of all the currents, the HAZ has the lowest percentage reduction in hardness; the lowest reduction is at 160A (9.5%), while the largest is at 180A (22.6%). In contrast to the weld center and weld zone, this suggests that the HAZ is more resistant to softening. The HAZ maintains its hardness better at moderate currents (150A to 160A), indicating that the temperature gradient is less pronounced in this region. Nevertheless, the heat diffuses deeper into the base material at very high currents (170A and 180A), leading to a discernible rise in the reduction of hardness (15.3% and 22.6%, respectively).

Fig. 3's hardness data for the 16mm thick Al 7075 weldments at various welding currents (120A to 180A) in three zones—weld center, weld zone, and heat-affected zone (HAZ)—offer important information about how welding parameters affect material properties. Significant material softening, particularly at lower currents, is indicated by the % decrease in hardness at the weld center. At 120A, the reduction is greatest (38.6%), and as the current rises, it gradually decreases until it reaches a minimum of 160A (25%). On the other hand, the hardness reduction increases at 170A and 180A (29% and 34.5%, respectively). This pattern implies that higher heat concentration from lower currents leads to more noticeable thermal softening. The rise in hardness reduction at 170A and 180A would suggest that overheating caused by extremely high currents reverses the positive benefits of moderate heat input. The pattern of hardness loss in the weld zone is similar to that in the weld center, but it is less noticeable. Lowering more gradually, the reduction becomes its lowest at 160A (22.2%) after beginning higher at 120A (34.2%). The rates at 170A and 180A (27.7% and 31%, respectively) are slightly higher. It would appear from this those moderate currents reduce the amount of softening by creating a more consistent heat profile in the weld zone. Nevertheless, the weld zone is subjected to more heat at higher currents, which results in a larger hardness loss. In comparison to all other currents, the HAZ shows the lowest percentage drop in hardness, with the smallest reduction (9%), occurring at 150A and 160A. The decrease at 120A and 130A is marginally greater (15.24 and 14.22 percent). These findings suggest that, in contrast to the weld center and zone, the HAZ is less susceptible to changes in welding current. Less heat softening and better preservation of the base material's characteristics are suggested by a lower hardness reduction. According to the figure, moderate welding currents—specifically, 150A to 160A—produce the optimum balance in terms of minimizing hardness loss, particularly in crucial areas like the weld center and weld zone. Hardness decreases are more noticeable at lower and higher currents, maybe as a result of underheating or overheating effects.

3.1. Effect of plate thickness on hardness reduction in Al 7075 weldments

Hardness decrease for the 6mm plate in the weld center varies from 18% to 37.16%, with the lowest reduction occurring at 160A

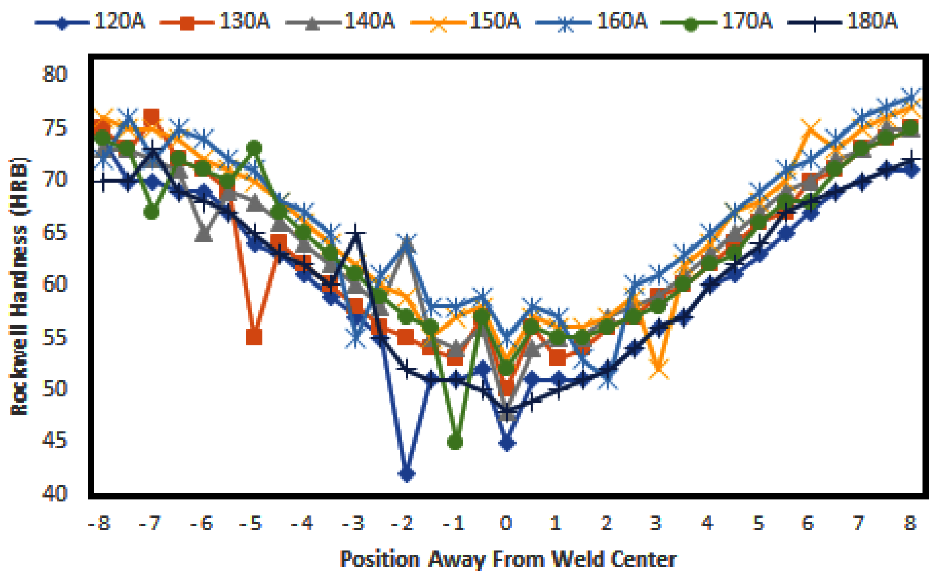

Figure 3: Hardness distribution of 16mm Al 7075 weldment.

(18%) and the largest at 180A (37.16%). The hardness reduction decreases significantly from 120A to 160A, then increases sharply at higher currents (170A and 180A). In contrast, the percentage reduction for the 16mm plate varies from 25% to 38.6%, with the biggest reduction occurring at 120A (38.6%) and the least at 160A (25%). With a noticeable pattern of less softening as the current rises and peaking at lower currents, the hardness decrease is more gradual and steady. In comparison to the 6mm plate, the 16mm plate shows a generally greater loss in hardness at lower currents (120A to 140A). However, with larger currents (170A and 180A), the 6mm plate exhibits a more pronounced softening. Particularly at intermediate currents (150A to 160A), the thicker plate (16mm) exhibits superior hardness retention in the weld core, indicating that greater thickness offers improved heat dissipation and dispersion, hence minimizing the degree of thermal softening. The weld zone's hardness reduction varies from 28% to 41.8%, with 160A having the lowest reduction (28%) and 180A having the highest (41.8%). As the current rises to 160A, the reduction gradually diminishes before abruptly increasing at higher currents. The hardness reduction, on the other hand, varies between 22.2% and 34.4%, with the lowest drop occurring at 160A (22.2%) and the maximum at 120A (34.4%). The weld zone in the thicker plate preserves greater hardness, as evidenced by the continuously smaller reduction across all currents when compared to the 6mm plate. Across all welding currents, the 16mm plate exhibits a consistently smaller hardness reduction, suggesting that the thicker material is less prone to softening in the weld zone. Higher currents have a greater effect on the 6mm plate, which causes a greater drop in hardness. Because it can transport heat more efficiently, the thicker plate resists thermal softening better. Hardness reduction in HAZ varies from 9.5% to 22.6%, with 180A (22.6%) exhibiting the most drop and 160A (9.5%) the least. The decrease peaks at higher currents (170A and 180A) after being largely constant at lower currents (120A to 150A). The hardness reduction varies from 9% to 15.24%, with 120A (15.24%) exhibiting the largest drop and 160A the least. Particularly at higher currents, there is a much smaller reduction than with the 6mm plate. Comparing the 16mm plate to the 6mm plate, the HAZ in the former softens less. At all welding currents, but especially at higher currents, the thicker plate experiences a far smaller drop in hardness. This implies that the 16mm plate has superior heat management compared to the thinner plate, which lessens the effect of thermal cycling on the HAZ and preserves the material characteristics.

3.2. Effect of welding current on the tensile strength of 6mm and 16mm thick plate

As seen in Fig. 4, the tensile strength of Al 7075 plates that are 6 mm and 16 mm thick under various welding currents reveals that the highest tensile strength is produced in both plates by moderate currents, specifically those between 150A and 160A. Tensile strength reaches 290 MPa at the same current for the 16mm plate and hits 325 MPa for the 6mm plate at 160A. This implies that greater mechanical performance results from better fusion, which is encouraged by moderate heat input. But at higher currents (170A and 180A), both plates' tensile strength decreases, suggesting that too much heat can degrade materials and induce softening, coarsening, and coarsening of the grain, all of which can impair the quality of the weld. The 6mm plate continuously shows greater tensile strength than the 16mm plate at all current levels when the two plate thicknesses are compared. This is probably because stronger welds are produced by thinner plates' improved ability to absorb and disperse heat. In contrast, the larger 16mm plate might need more heat for proper fusion, which could result in more thermal softening, even though it still benefits from moderate currents. Therefore, the 6mm plate exhibits superior overall tensile strength, demonstrating the influence of thickness on weld performance, even though both plates function best at 150A to 160A.

3.3. Optimization of parameters

The maximum number recorded across all current levels is 325 MPa at 160A, which is the peak tensile strength for the 6mm plate. This suggests that 160A offers the optimal heat input to accomplish robust weld fusion without resulting in appreciable material deterioration or softening. In comparison to greater or lower currents, the hardness reduction at the same current of 160A is likewise negligible. There is a 28% reduction in the weld zone, an 18% reduction in the weld center, and a 9.5% reduction in the heat-affected zone (HAZ). This combination demonstrates that 160A is the ideal parameter for the 6mm plate since it ensures a strong weld while maintaining a decent balance of hardness retention. The 16mm plate has the maximum tensile strength of any current at 160A, reaching 290 MPa. This suggests once more that 160A is the ideal

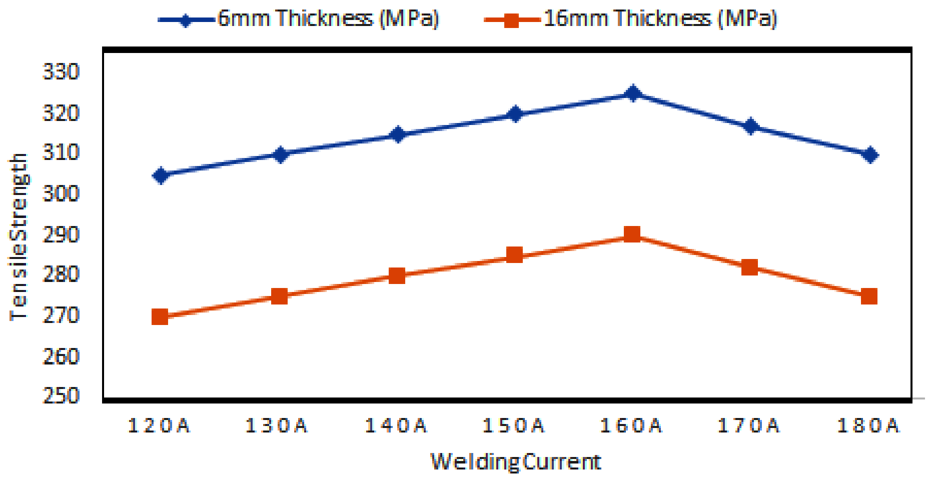

Figure 4: Tensile strength of 6mm and 16mm weldments.

heat input for this thicker plate, enabling efficient weld penetration without warming up or softening. The 16mm plate at 160A has a very low 9% hardness decrease in the HAZ, a weld zone hardness reduction of 22.2%, and a weld center hardness reduction of 25%. This demonstrates that the 160A current offers the optimal balance between weld strength and hardness retention, much like the 6mm plate. The best tensile strength and comparatively modest hardness decrease are shown by both plate thicknesses at 160A, especially in key zones such as the HAZ where minimal softening is essential to preserving overall material integrity. According to the data on hardness and tensile strength, 160A provides the optimum mechanical performance for the 6mm plate, reducing the adverse effects of welding heat while guaranteeing strong welds. The same current yields the maximum tensile strength and the least amount of hardness degradation for the 16mm plate, guaranteeing that the heat dissipation of the thicker plate is adequately controlled. To sum up, 160A is appropriate because it offers the right amount of heat input, preventing too much softening and optimizing the weld strength for both plate thicknesses.

4. Conclusion

According to the study's findings, the ideal balance between tensile strength and hardness retention is achieved for Al 7075 alloy weldments on both 6mm and 16mm thick plates when the TIG welding current is 160A. Both the 6mm and 16mm plates had good hardness decreases, especially in the weld center and heat-affected zones (HAZ), and their tensile strengths were 325 MPa and 290 MPa, respectively. Superior heat dissipation by the thicker plate reduced hardness loss and thermal softening. By preventing oxidation, the effective application of CO_2 as a shielding gas enhanced the weld quality even more. By highlighting the significance of plate thickness in thermal management, determining the ideal welding conditions, and proving that CO_2 is a viable and affordable shielding alternative, this study significantly advances the field. Nevertheless, the study included drawbacks, such as the use of a demonstration welding machine and a lack of sophisticated microstructural analysis, which might have impacted the accuracy of the welding settings. Furthermore, the findings are restricted to two plate thicknesses and a small range of welding currents, indicating that a larger range of factors could be investigated in future studies.

Future studies should examine alternate welding techniques such as Friction Stir Welding (FSW) and Laser Welding to enhance weld quality, as well as post-weld heat treatments like solution heat treatment and aging to restore mechanical characteristics in Al 7075 weldments. While improving welding speed and gas flow rate may improve weld quality, research on welding dissimilar metals with steel or titanium may increase applications in the automotive and aerospace industries. Microstructural investigation utilizing SEM and XRD in conjunction with fatigue testing would reveal grain size variations and durability. Additionally, examining how pre-weld surface treatments affect weld integrity and defect reduction in industrial applications could be beneficial.

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