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Mechanical and microstructural effects of varying welding currents in GTAW of 7075-T62 aluminum

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Abstract

Aircraft structures require diverse joining techniques, including riveting, bolting, bonding, and welding. While welding is less common in aerospace manufacturing due to concerns about the thermal sensitivity of aluminum alloys, it offers potential advantages such as weight reduction and the elimination of mechanical fasteners. This study investigates the effect of welding current on the microstructure and mechanical properties of 7075-T62 aluminum alloy welded using Gas Tungsten Arc Welding (GTAW) with ER 4043 filler metal. Welding currents of 40 A, 50 A, and 60 A were examined to assess their influence on tensile strength, hardness, and weld integrity. Results indicate that 50 A produces the highest tensile strength (34.297 kgf/mm²) and hardness (74.8 HRB), whereas 40 A results in lower tensile strength (26.471 kgf/mm²) and hardness (71.7 HRB). At 60 A, excessive heat input leads to increased porosity and deeper penetration, causing microstructural defects. The findings underscore the importance of optimizing welding parameters to balance mechanical performance and minimize defects. This study provides insights that are particularly relevant to aerospace applications, where reliable and high-strength welded joints are critical.

Keywords:
7075 T62 Aluminum Alloy, mechanical properties, microstructure, welding, current.

1 Introduction

Now, aerospace structures of today's makeup are rather complicated. Pieces, more than one, must be put together [1], [2]. There are many techniques for joining components; they have become quite important [1], [3]. A certain technique, welding, is particularly prominent. It is primarily used on aluminum alloys [4], [5], [6], [7]. These alloys are favored in the manufacture of aircraft; their strength-to-weight ratios are favorable. However, in this sector, welding's usage is limited [4], [8], [9], [10]. Base metals, particularly those high-strength alloys like 7075 T62, face challenges when welding processes are applied to them. This limitation is due to the complex welding behavior of these alloys, which may lead to undesirable defects like cracks and reduced mechanical properties [8], [11], [12].

Properties, mechanical, astounding, this is T62 alloy of aluminum, 7075. Those features, such as admirable resistance to fatigue and superior strength in tension, carry weight when one looks at aerospace use[13]. Nevertheless, the welding behavior of such alloys is often underexplored, particularly in relation to specific welding techniques like Gas Tungsten Arc Welding (GTAW) [14], [15]. For example, GTAW phenomena in this field are still being continually observed [16], [17], [18].

A distinctive thermal cycle is born through the welding procedure, possibly affecting the microstructural and mechanical traits within the joined metal [19]. Integral to the weld's integrity are myriad elements, including the input of heat, the pace of cooldown, and the shape of the weld bead [20], [21]. Thus, examining the impacts of various welding currents on the mechanical attributes of aluminum 7075 T62, which is welded, is mandatory for refinement of aerospace sector welding practices to occur [22].

Welding, a joining mechanism, has several benefits over usual mechanical fasteners like rods and screws [17], [23]. Unneeded are extra substances in welding, or making holes in the metal's base; this brings weight savings and enhanced structure strength [18], [24]. However, welding also presents challenges in terms of structural integrity, such as the potential for cracks and voids. These challenges stress the importance of understanding the optimal welding conditions [25], [26].

Examining what happens when the welding current changes, this research zeroes in 40 A, 50 A, 60 A using the helium gas tungsten arc welding method on 7075 T62 aluminum. The aim of this study is to understand how variations in welding current influence the mechanical properties and microstructure of the welded material. It attempts to shine a light on the entangled relationship between the electrical current used in welding and the resulting material features. High-strength aluminum alloys must be welded in the best possible way; this research tries to establish that as a standard practice through this particular investigation, highlighting its importance.

This research is important because understanding the impact of welding current on aluminum alloy properties is still not fully understood in the context of aerospace applications. Research outcomes of this study affect comprehension the impacts of aluminum alloy weld methods effects that aren't crystal clear. Insights that might be tossed around or are not properly connected to engineers and practitioners working in aerospace are of high importance. With the increasing demand for lightweight and high-performing materials in aircraft construction, the need for reliable weld connections is crucial [27]. Materials with high performances are in demand more and more in aircraft construction [28]. Impacts from this research perhaps won't form a clear picture but will spare some insights for detail-oriented people working in aerospace divisions.

This study aims to fill a significant research gap by providing empirical data on the effect of welding currents on the mechanical properties of high-strength aluminum alloys like 7075 T62. The present study does more than illuminate existing knowledge voids concerning 7075 T62 aluminum welding. Applications of welding in aerospace frameworks, and its wider propagation, are pursued too. Methodical testing and in-depth investigation are contemplated in this research. Ameliorated methods for welding are on the horizon, and standards are seen too. Aircraft parts' performance and safety will become better; such an outcome is anticipated from these endeavors.

2 Research methods

This study utilizes aluminum alloy 7075 T62, known for its composition of Al-Zn-Mg-Cu-Cr and classified as extra super-duralumin. The T62 condition is achieved through a specific heat treatment process, as illustrated in Fig. 1. The chemical composition of Al-7075 T62 is detailed in Table 4.2, highlighting its unique properties that make it suitable for high-performance applications.

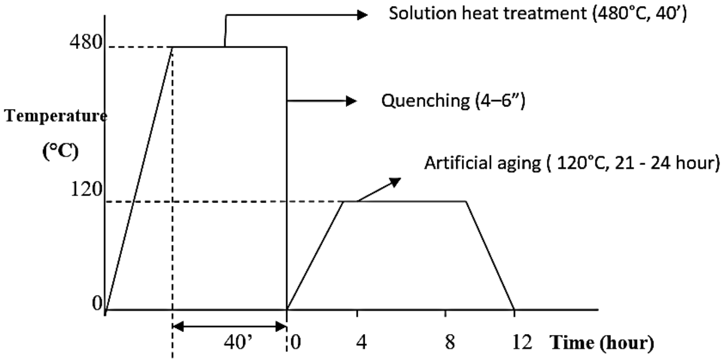

Fig. 1. Heat treatment diagram of Al-7075

In addition, the research includes the 2024 T62 aluminum alloy, recognized for its heat-treatable characteristics and Al-Cu composition. This alloy offers mechanical properties comparable to mild steel, as demonstrated in Table 2, with dimensions measuring 200 x 150 x 3 mm. The welding process incorporates ER 4043 filler metal, characterized by a thickness of 2.4 mm and a silicon content of 5%. Its physical properties, including a melting point range of 1065-1117°F and a tensile strength of 29,000 psi, are critical for ensuring robust weld integrity.

Welding was conducted using a MILLER SYNCROWAVE™ 300 machine in manual mode, employing high-purity argon (99.999%) as the shielding gas and a 1.6 mm tungsten electrode. The parameters included varying currents (40 A, 50 A, and 60 A), which were selected based on existing studies and the need to explore a range of current values to understand their effects on the mechanical properties and microstructure of the welded material. These current levels were chosen to provide a representative spectrum of welding conditions, ensuring an understanding of the relationship between heat input and the resulting material properties. An arc voltage of 22 V and a welding speed of 5 cm/min, with a gas flow rate of 10 lt/min, positioned in 1G for optimal performance. A comprehensive testing approach, including X-ray radiography for internal defect detection, tensile testing with an INSTRON™ 8501 machine, Rockwell B hardness measurement, and microstructural analysis using a Nixon Eclipse Lv150 microscope, was employed to assess the material properties and performance post-welding.

The X-ray radiography was chosen to detect any internal porosity or defects that may compromise the weld's integrity. Tensile testing was used to measure the ultimate strength and ductility of the welds, while hardness testing provided insights into the material's resistance to deformation. Microstructural analysis was employed to examine grain size, phase formation, and other structural changes that occur as a result of welding. Each method was selected to address specific research objectives and validate key hypotheses regarding the mechanical and microstructural effects of varying welding currents.

Chemical Composition of Al-7075 T62 are Cr 0.25%, Cu 1.46%, Fe 0.13%, Mg 2.48%, Mn 0.03%, Si 0.04%, and Al Bal. Mechanical Properties of Al-2024 T62 Material are Tensile Strength is 43,4(Kg/mm^2), Yield Strength is 53,919 (Kgf/mm^2), Elongation is 15%, and Hardness is 75 (HR_B).

3 Results and discussion

In the GTAW process, selecting appropriate welding parameters and filler metal is crucial for achieving optimal results[29]. Approved specifications should guide the determination of welding parameters, while the selection of filler metal should be based on the base material and its alloying composition. In this study, the filler metal used was ER™ 4043, which contains silicon (Si) as an alloying element. The presence of silicon in ER 4043 promotes the formation of Mg_2Si compounds, enhancing the mechanical properties of the welded joint post-welding [30].

Mechanical properties of welded materials typically experience degradation due to the changes in grain shape and size resulting from the heat generated during the welding process [31]. This phenomenon is particularly pronounced in the Heat-Affected Zone (HAZ), where mechanical strength tends to decline because the grain structure becomes coarser and larger. The relationship between welding current and grain size, particularly in the HAZ and weld metal regions, suggests a decrease in mechanical properties due to excessive heat input. The tensile strength results presented in Fig. 2 reflect this degradation, showing a clear inverse correlation between welding current and mechanical strength. This condition is evidenced by a lower tensile strength compared to the base material.

The tensile tests conducted reveal a significant impact of welding current on the strength of welded joints. Different current levels yield distinct joint strengths, as illustrated in Fig. 2. The data shows that the mechanical properties of GTAW-welded Al-7075 T62 differ markedly from those of the base material [31]. Specifically, the tensile strength of welded Al-7075 T62 decreased by 42.2% to 55.4%, and yield strength decreased by 55.8% to 57.1%. This reduction is attributed to the heat input during welding, which adversely affects the grain structure along the weld seam, resulting in larger and coarser grains that compromise strength. A more in-depth analysis of the quantitative relationship between welding current and mechanical properties is illustrated in Fig. 2, where the variations in strength at 40 A, 50 A, and 60 A are clearly delineated, showing a reduction in strength with higher currents.

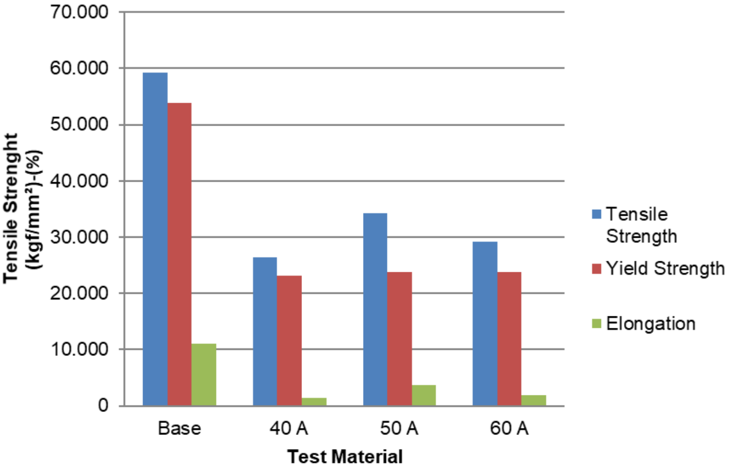

Fig. 2. Tensile strength, yield strength, and elongation of the test material

At 40 A, the welded samples exhibited a tensile strength reduction of 55.4%. In contrast, samples welded at 50 A showed a lesser reduction of 42.2%, while those welded at 60 A demonstrated a 50.7% reduction. The results indicate that an increase in welding current initially enhances joint strength, peaking at 50 A, where the tensile strength reached 34.297 kgf/mm^2. This increase can be explained by the effective transfer of molten metal from the electrode, where lower currents result in larger droplets of molten metal that reduce bonding effectiveness. However, at higher currents (60 A), excessive heat input leads to excessive penetration, resulting in coarser grains and reduced mechanical properties in the welded joint. Thus, 50 A is deemed the optimal current level. However, further increasing the current leads to excessive penetration into the base metal, diminishing joint strength.

Fig. 2. also illustrates a notable decrease in elongation for the welded materials. The base Al-7075 T62 had an elongation value of 12.305%, while the welded specimens, subjected to current levels of 40 A, 50 A, and 60 A, exhibited elongation values ranging from 1.459% to 3.634%. The hardness achieved in the welded joint, HAZ, and base metal is significantly influenced by

the material's hardenability, which is related to cooling rates and the microstructure formed during the heating cycle. The hardness values observed are reflective of the changes in microstructure and the effects of welding parameters, underscoring the importance of careful parameter selection in maintaining desirable mechanical properties in welded joints. This analysis is crucial in understanding how welding current affects the balance between hardness and ductility in the final welded joint. The findings underscore that welding current plays a pivotal role in determining the mechanical performance of GTAW-welded 7075 T62 aluminum [32]. Optimal current settings can enhance joint strength while preventing detrimental effects associated with excessive heat input.

The weld metal exhibits high hardness, which progressively decreases as it approaches the base metal (Fig. 3). This phenomenon occurs due to the heat influence during welding. Additionally, Fig. 3 illustrates that the hardness value in the heat-affected zone (HAZ) is lower than the base metal.

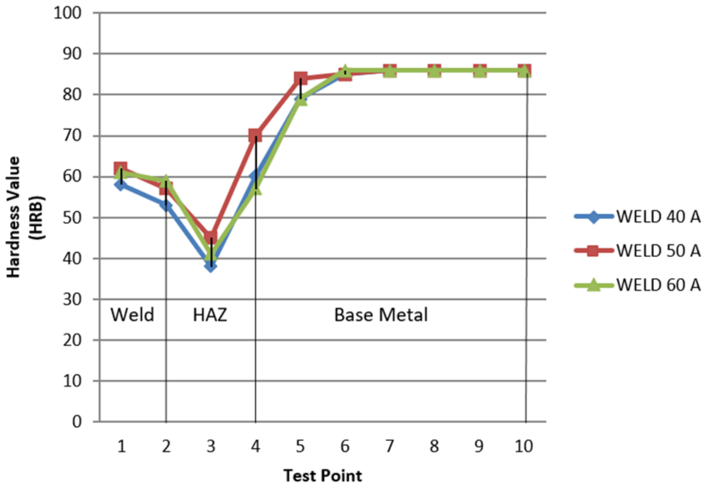

Fig. 3. hardness values of the test material at 40 A, 50 A, and 60 A

This reduction in hardness is attributed to grain growth in the HAZ, leading to larger and coarser grains that decrease hardness or strength. Conversely, in the HAZ near the base metal, there is an increase in hardness or strength, as recrystallization occurs in this region, resulting in finer grains compared to the HAZ. The reduction in hardness in the HAZ can be linked to the formation of coarse Mg_2Si precipitates, which further contributes to the loss of strength [33]. The difference in hardness or strength between the HAZ and base metal is referred to as loss of strength due to the welding process.

The loss of strength in the HAZ occurs because the closer the area is to the fusion zone, the higher the peak temperature experienced, and the longer the material remains at elevated temperatures. This extended exposure facilitates larger grain growth in the HAZ.

Macrostructural observations reveal differences among the weld area, heat-affected zone (HAZ), and base metal. Fig. 4 show that varying current levels result in different weld bead widths. This variation is attributed to the differing heat input received by the specimens due to the different currents used. The specimen using 40 A had a weld bead width of 6.384 mm, while the specimen with 50 A exhibited a width of 7.569 mm, and the specimen with 60 A had a weld bead width of 7.584 mm. Microstructural observations of the welded material were conducted at three locations: the base metal, HAZ, and weld metal. Each of these regions experiences different treatments regarding peak temperature and cooling rates during the welding process [34]. As a result of these differing treatments, the microstructures of the three areas are distinct. This suggests that higher currents lead to deeper penetration and a wider bead, which in turn affects the material properties in the weld zone.

From the microstructure photo shown in Fig. 5. it can be observed that the base metal Al-7075 T62 contains the α phase and Mg_2Zn precipitates formed during the solution treatment, quenching, and artificial aging processes. The Mg_2Zn precipitates enhance the tensile strength compared to the initial material, as they can hinder the movement of the aluminum matrix during deformation caused by tensile stress.

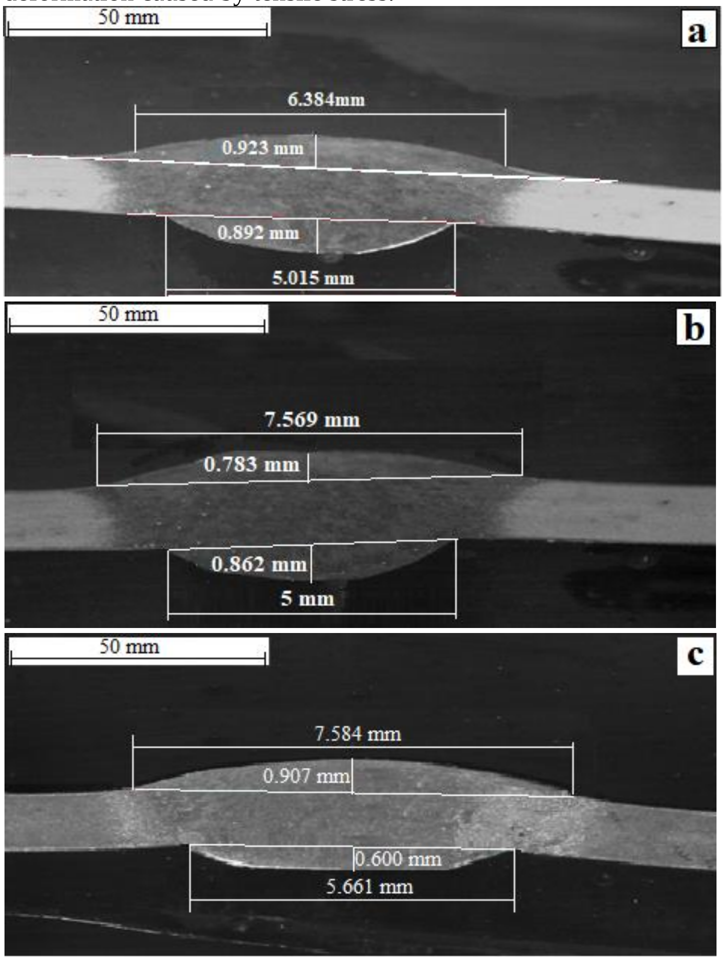

Fig. 4. Macrostructure of weld results with parameters (a) 40 A, (b) 50 A, (c) 60 A.

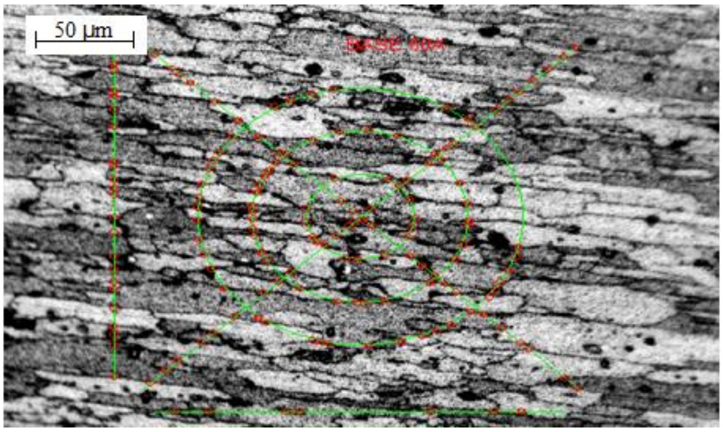

Fig. 5. Microstructure of the base metal Al-7075 T62, featuring the alpha matrix phase with the Mg_2Zn precipitate appearing dark.

In welding with a current parameter of 60 A, cracks occur due to the use of high current, which leads to significant heat input and results in deep penetration into the base metal. Additionally, porosity defects are found in the HAZ, likely due to the high current causing excessive heat input. The specific cause of porosity at 60 A can be attributed to the high heat input, which causes an increase in gas absorption and inadequate shielding, resulting in trapped gas in the weld pool.Porosity defects occur because of the absorption of gases such as hydrogen, unevenness in the surface of the test piece being welded, ineffective shielding gas, and the high heat input that leads to porosity in the welding of Al-7075 T62.

From all the microstructure photos shown in Fig. 6, differences in grain shape and size can be observed between the base metal, HAZ, and weld metal regions. The grain shape and size in the weld metal and HAZ areas are larger and coarser. This indicates that the welding process can decrease the mechanical properties of a material, as the heat input during welding affects the grain shape and size along the weld area.

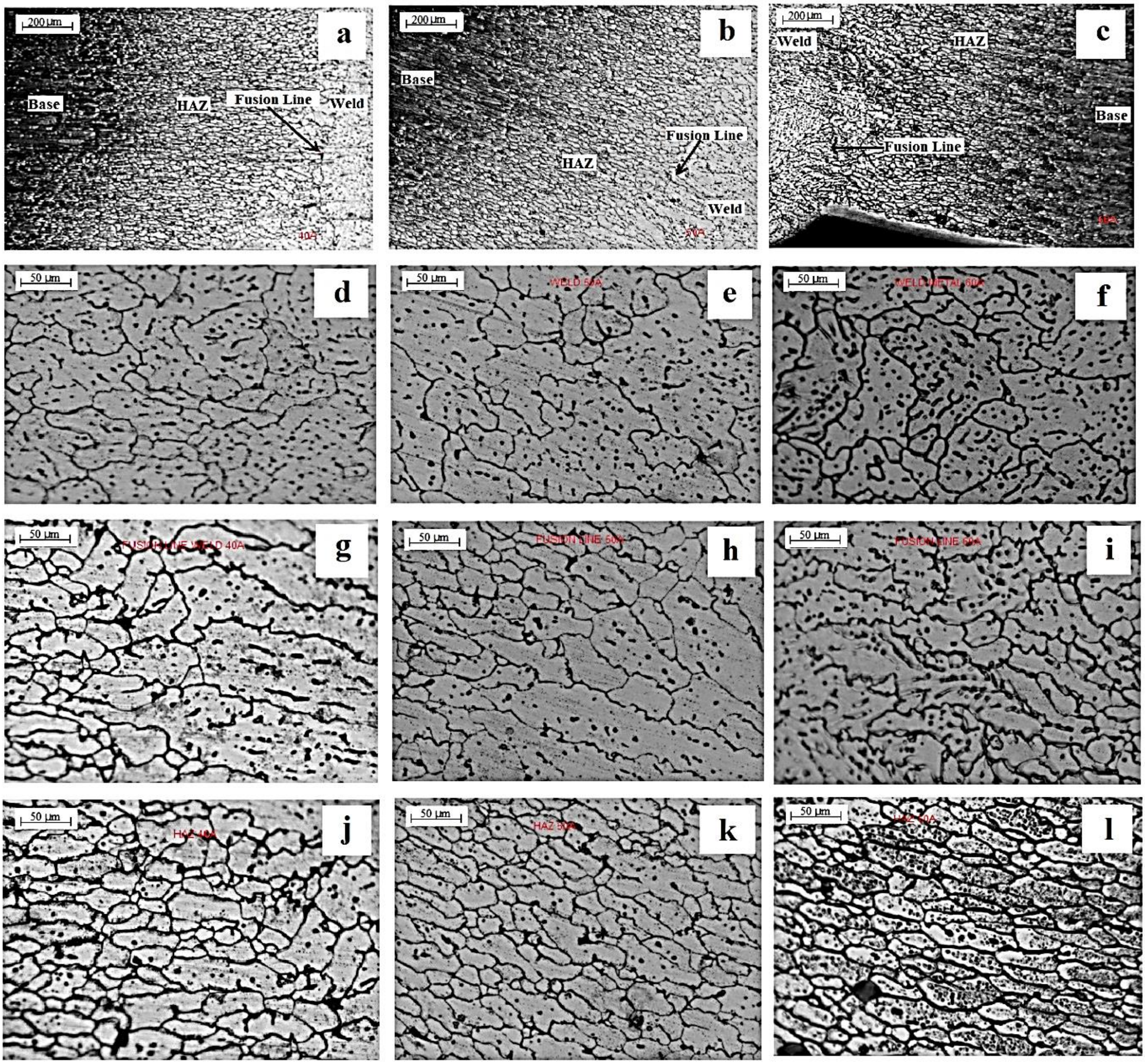

Fig. 6. Microstructure of the test specimens: (a) 40 A, (b) 50 A, (c) 60 A; Microstructure of the weld area: (d) 40 A, (e) 50 A, (f) 60 A; Microstructure of the fusion line area: (g) 40 A, (h) 50 A, (i) 60 A; Microstructure of the HAZ area: (j) 40 A, (k) 50 A, (l) 60 A.

From the microstructure photos of the weld metal area shown in Fig. 6d, 6e, and 6f, it can be noted that each specimen experiences a similar solidification structure formation mechanism. In the weld area, Mg_2Si precipitates are formed from the filler metal ER 4043.

In the fusion line area, as shown in Fig. 6g, 6h, and 6i, a distinct boundary can be observed between the weld metal and the HAZ. The fusion line region has a structure with coarser grains, which is caused by the base metal, which receives more heat, releasing Mg. This Mg will compound with Si, which is an additional element in the filler metal. The formation of Mg_2Si precipitates at the fusion line due to the reaction between Mg from the base metal and Si from the filler metal significantly affects the mechanical properties in this area. The concentration and distribution of Mg in the fusion line are critical in understanding how this region behaves during mechanical testing, as they may promote cracking or embrittlement.

4 Conclusions

This study highlights the significant influence of welding current on the mechanical properties and microstructure of 7075-T62 aluminum alloy welded using GTAW with ER 4043 filler. The results demonstrate that:

1. Optimal mechanical properties were achieved at 50 A, where tensile strength and hardness reached their highest values.

2. Excessive heat input at 60 A resulted in grain coarsening, increased porosity, and microstructural defects, leading to a 55.4% reduction in tensile strength compared to the optimal condition.
3. The HAZ showed significant grain growth, impacting overall weld integrity.
4. The presence of silicon in the filler metal contributed to the formation of Mg_2Si compounds, which enhanced mechanical performance.

Microstructural analyses confirmed distinct variations between the weld metal, HAZ, and base metal, demonstrating the impact of thermal exposure on grain structure. The study emphasizes that precise control of welding parameters, particularly current, is essential for ensuring high-strength and defect-free aluminum welds. These findings have practical implications for aerospace manufacturing, where optimized welding currents can improve joint strength, reliability, and durability in critical aircraft components. Future research should further explore the relationship between welding parameters, alloying elements, and thermal effects to refine welding techniques for high performance applications.

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