An investigation of the weld current characteristics on twining and tensile strength of the AZ31 alloy sheet joint welded by GTAW

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Abstract - *The main focus of this study is to conclude on the twinning of welded joint and the alteration of the tensile properties of the AZ31 magnesium alloy by the processing of the Gas Tungsten Arc Welding with two dissimilar current types, which were alternative and pulsed current, and four altered values of them, Compared to steels, welding of the magnesium alloys may be a very challenging owing to porosity, crack resistance and inter metallic formation and so forth. The technique of metallograph and tensile test were used to assessment the parts of welding joint. The weld microstructure orientation in heat transfer direction was exceptional and equiaxial shaped grain was the prominent grain structure like microstructure of the base metal. Conversely, the grains were bigger in welded metal owing to heat input throughout the welding process. moreover, fusion zone and HAZ of the welded specimens infrequently displayed twin grains. This is the main grain structure kind mainly in pulsed current specimens. It can be determined from the outcomes that the pulsed current is more promising than alternative current for welding of the two mm magnesium alloys sheet with higher accuracy due to the pulsed current cause smaller grains of Alfa-Mg (matrix) and smaller precipitated particle size than alternative current.*

Key Words: magnesium AZ31 alloy, GTAW, weld current and microstructures.

1. INTRODUCTION:

Magnesium alloys were knowledge, to be very significant lightweight metals and numerous academics are focusing on this lightweight structural engineering, The substance has a crest strength of the weight relation and process characteristics. Improvement of structural accessibility of this material strongly counts on the volume of construction as for instance welding procedure performance. The perfect desirability of 1.633 for the solid atomic packing of spheres is as the same as the unalloyed magnesium, which enjoys a hexagonal close-packed (HCP), structure, with a/c ratio of 1.6236. The chief mechanism through which magnesium alloys may be reinforced is precipitation reinforcing, which typically comprises aluminum compounds [1-9].
Many reports concern joint issues of the magnesium alloys [9-15]. On the contrary, there is a little information on accessible works regarding the (GTAW) of magnesium alloys AZ31 utilizing pulsed and alternative current. In addition, high heat generation throughout GTAW is thought to be one reason; however, GTAW can be considered a very useful and laid-back way to connect all metal plates in other methods. GTAW of magnesium alloys has some issues, and the most important of them is the issue of hot cracking [4], however, this issue is seldom stated in works on welding of magnesium alloy AZ31. It can be stated that if the manufacturers offer best conditions for welding magnesium alloys, it will present no problem. Amongst of a general sound techniques for Mg alloys such as the laser beam and electron beam welding techniques. However, as stated previously, these approaches primarily electron beam welding, are not very applicable in terms of preparing the application circumstances. Their significance and benefits come from being high in energy density welding procedures, and hot cracking does not stand severe and attacking difficulties since the little heat input results in comparatively very small alteration and consequently little stresses. Another imperative theme or phenomenon for Mg alloys, mainly comprising Al is Mg–Al intermetallics (IMCs) [1-4]. The formation of Mg–Al IMCs is practically inevitable in Mg and Al welding procedures and features since the morphology of this intermetallics is very operative on mechanical properties. Another topic may be twining for magnesium alloys welding. Barnett [6,7]. Barnett [6] described this for laser beam welding. He cited that the connection between the orientations of twins in HAZ metal is in the orientate of heat transfer. It is not fully obvious in the literature how twinning occurs in weld metal or infusion zone. Though, appreciating this mechanism is very vital as it is well recognized that twinning could be playing a central part in the deformation of hexagonal magnesium[16]. This work concentrates on the parameters of the GTAW welding, which affect the properties of the welded marketable AZ31 magnesium alloy joints and weldability.
The AZ31, In addition to the fact that it is a magnesium alloy with decent room-temperature strength, it has so many advantages such as good ductility, corrosion resistance and finally a sensible level of weldability.
It is been utilized widely in many applications such as the airplane industry, mobile phones modern technology,

computer accessories, speaking devices and solid devices. It is made at comparatively high temperatures to produce a wide diversity of intricate constituents for locomotive usages. For that aims for different parameters like the current of the welding procedures were used to utilized. Being a welding sort, pulsed current as a very communal for increasing welding features was employed together with alternatively pulsed current [17].

2. EXPERIMENTAL PROCEDURE

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A common interpretation of the welding application of manual GTA welding is displayed in Fig. 1. The equivalent method had been used in this study. The specimens were fine and emptied by the grinder and acetone beforehand the welding in order to ensure all nonmetallic aspects are detached. The status of affairs of the welding and parameters were utilized in this work are abridged in Table 1. Two sorts of dissimilar current and dissimilar weld voltages (as lower and upper) were employed [17]. Looks of welded joint are provided in Fig 2.

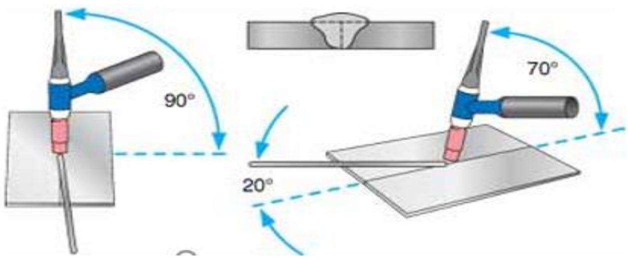

Figure-1: Schematic explanation of the welding with the sample view [18].

Table-1: parameters of the Welding

Parameters*	Alternative current	Pulsed current
Tungsten electrodes (mm)	2-4	2-4
Filler metal (mm)	From base metal	From base metal
Voltage (V)	28	28
Ampere (A)	70-95	lover 45-60- Upper 70-95
Pulse frequency (Hz)	-	3
Heat input (kJ/mm)	9,8-16	8,5-11
Shielding gas	Argon	Argon
Shielding gas flow rate (l/m.)	14	14
Welding speed (mm/m.)	120	120
Air conditions	Atmosphere	-

*All welding procedures were performed at the open atmospheric condition.

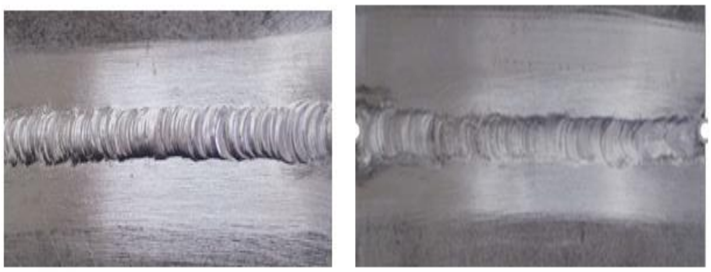

Figure-2: Form of welded joint samples. a) Alternative current. b) Pulsed current.

2.1. General Examination Procedure

The microstructure of the welding joint inspected by the devices of the microscopic and optical microscopy. When consider the microstructure inspections, the specimens which are welded were divided and attached, and then the specimens were then arranged by means of standard metallographic practice. The specimens were scratched in a popular solution comprising 10 ml acetic acid +5 g picric acid +10% ml alcohol and 70% water. Tensile specimens with bounded in-between were flattened and have been certified by the tensile mechanism. The optimizing of the average of three specimens, which are deprived of any issues, the ultimate, tensile strength has been calculated (UTS). The microhardness vickers dimensions were conducted at vertical and horizontal advice on the base metal, HAZ and weld metal (fusion zone) utilizing HV $_{0.1}$ gr loading. Moreover, Ideal values were specified for the intact weld area, as a subsequence.

3. THE RESULTS AND DISCUSSIONS

3.1. Microstructure

The figure 3. consists of some welds of the microstructure for accessible specimens, Base metal has a α-Mg phase, which display the equiaxial grains. Grains of the base metal have revealed some bigger size and smaller size grains which are accredited to the warmish state of the last rolling phase for enough formability. In addition, to that it has some Al-Mg oxide formations nonetheless; it is not in the space of this work. Extra work will be carried out for assessment [1].

As perceived in Fig. 3. HAZ of the pulsed current specimen exhibited big equiaxial grains and quite few twin grains and boundaries. For this property cause, it can be stated that the twin structure has taken place in welded metal subsequent to the welding process. The weld microstructure metal has got bigger equiaxial grains with a higher quantity of twin grain boundary region than HAZ. However, base metal has not demonstrated any twin. HAZ also displays bigger equiaxial grains and more twins, and the quantity becomes fewer near base metal. Consequently, The twinning of the welding were experienced mostly after the welding in the weld metal.

The alternative current welded samples of microstructure in gas-tungsten-arc-welding (95 A-16 kJ/mm) with base metal AZ31 Mg alloy and pulsed current welded samples (45-60A and 8,5 kJ/mm) of AZ31 Mg alloy have been shown at Fig. 3 and 4. As comprehended in these Figures; commonly weld metals of the specimens have equiaxial and bigger grains equivalent to weld HAZ. Another central variance is that alternative current specimens comprise bigger grains than pulsed current welding specimens, which is accredited to higher heat input owing to alternative current [17]. The twins were detected in pulsed current principally in the weld metal. The direction of the twinning bands is not almost corresponding to the welding direction as stated in the work [5]. However, the reserved thermal reduction of the weld liquid throughout cooling in welding direction is happened to be similar to the fusion line. The fusion area includes the tensile and residual stresses, although the base metal that is distant from the fusion area is under balancing compressive residual stresses. This outcome illustrates that stress occurs in all region of the fusion zone and HAZ owing to quick solidification and cooling so heterogenic solidification in which pulsed circumstance is governing, which in turn possibly forces the twinning to come about. Barnett et. al. [6], stated that compression vertical to the HCP *c*-axis prefers the creation of twins on the {1012} plane and the flow stress stays low. though, the compression parallel to the HCP c-axis prefers the development of twins on the {1011} plane. Fig.4. display the correlation among the desirable {1012} twinning and utilized loading directions with reference to the c-axis of an HCP cell. Balancing compressive residual stress in HAZ enjoys the capability for encouraging the prevalence of {1012} twinning [7,8].

It is been mentioned that the weld HAZ but together with the weld metal and that the heterogenic nucleation and solidification are very operative on twin incidence. Xiao et. al. [19] testified that twinning was more problematic with a minor quantity of twinning in a fine-grained material than in a coarse-grained.

Therefore, it can be assumed that weld metal of the specimens, like this clarification, enjoy bigger grains and obvious twin grains. Nevertheless, in this work on weld metal, there is an entire reverse that is brought about owing to tapping pulse influence, which has resulted in unbalanced solidification.

Fundamentally, developing microstructure has occurred when that the fast cooling encouraged by decent thermal conductivity and the evolution of grains infusion region was prevented by low thermal capacity of magnesium. Then again, matched with that of alternative current welded joint [17], grain size in weld metal of pulsed current welded joint is higher, which may instigated by means of high heat contribution (Table 1) and then the extended cooling interval of the molten pool. The alternative current welded specimens of microstructure in gas-tungsten arc welding (95 A-16 kJ/mm) with base metal AZ31 Mg alloy and the pulsed current welded samples (45-60A and 8,5 kJ/mm) of AZ31 Mg alloy are revealed in Fig. 3 and 4.

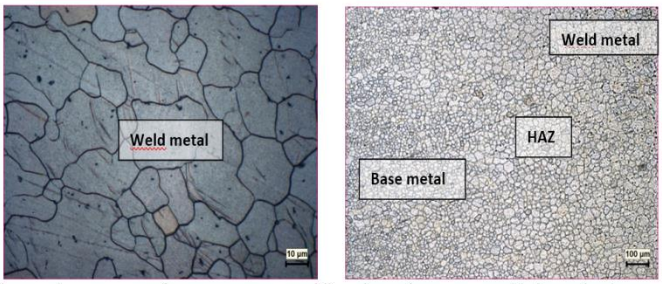

Figure- 3: The microstructure of gas-tungsten-arc welding alternative current welded samples (95 A-16 kJ/mm) with base metal AZ31 Mg alloy

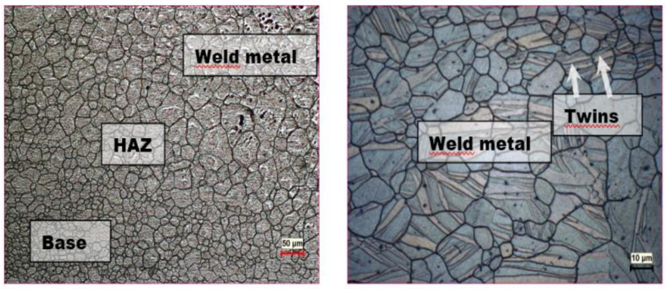

Fig. 4. Microstructure of the gas-tungsten-arc weldingpulsed current welded samples (45-60A and 8-5 kJ/mm) of AZ31 Mg alloy.

3.2. Mechanical Properties

3.2.1. Microhardness

With the helping of the device microhardness vickers, testing has determined the hardness with the mid-thickness line of the cross-section of all specimens of the GTAW of the AZ31 magnesium alloy. Weld metal typical values, HAZ, and base metal are 64, 66,5 and 70,5 HV for minimum pulse current. However, the heat input and current for the existing values (8,5 kJ/mm and 45-60A) demonstrations and for the alternative current demonstrations maximum heat input and current (16 kJ/mm - 95 A) 64, 64-5 and 65,4 HV consistently. These outcomes display that the weld zone of pulsed current specimens enjoy greater hardness than the alternative current specimens.
The micro hardness associations midst the micro hardness of the base metal, the heat heart-rending region and the weld metal of all welded joint illustrations are as follows: weld metal > HAZ > base metal. During the course of GTAW welding in the magnesium alloys, the weld metal comprised of fine equiaxial grains owing to the extraordinary cooling rate, whereas grain coarsing created in the HAZ caused by the impact of the thermal cycling. The grains contains of the three zones were weld metal > base metal > HAZ. As the grain size begin small, So the measurement of the micro hardness becomes higher, demonstrating the Hall-Petch equation. Accordingly, The modification of the micro hardness contain an contrary relationship with the square root of the grain amount. Another note worthy issue is that in overall, the intensification of the hardness can be accredited to the grain modification and the consolidation influential of the brittle and hard, β-Mg_{17} Al_{12} phase [22]. Throughout the welding course, grain coarsening happened in both the HAZ and the FZ with an upsurge of the heat input. Hence forth, a higher micro hardness values were attain with lower heat inputs for alternative current specimens. In addition, it can be realized that with supplementary upsurge in the heat input, that the micro hardness of the FZ and HAZ improved to some extent. The reason being is that a moderately extraordinary heat input could result in more granular β-Mg17Al12 phase to form in the HAZ and FZ, which partly balances, the effective of the grain coarsening on the diminution of the micro hardness of the HAZ and FZ of the welded joint. The twins were An important factors for hardness and strength. For pulsed current, this period is not proper for using welding parameters. It is possible to say that likewise for pulsed current at higher welding parameters, the same result would take place as mentioned above.
The result of the twins in a further rise in micro hardness of the weld metal. Some works dealing with the topic of twinning were shown below. According to some works concerning fusion zone twins of the welded magnesium alloys, all twinning mechanisms are considered to be imperative provided that control such as the mechanisms were conceivable.
Additionally, further works and optimization studies are required for this purpose. Specimens of the pulsed current presented sophisticated hardness as stated beforehand and this is thought to be one reason behind this twining. Unless, the specimens of the alternative current disclosed less level of hardness. Thus, micro hardness is a noticeably comprehensible phenomenon, which ascends from twining, and heat input circumstances.
Plentiful investigators have attempted to clarify the twinning in Mg alloys in some circumstances. In research Assahana et. al. [20] the work has been carried out on AZ31 magnesium alloy sheet with 4 mm in thickness and dissimilar from this study, without filler wire, by means of just a pulsed current. The paper concluded on the micro hardness of the fusion region of the welded joints is approximately identical to that of the base metal. Midst the welding with no pulse current can get the similar values of tensile strength and elongation such as those of the base metal.
Tatami et. al. [23] stated that favored twinning in favorite grains was thought to be the basis of heterogeneous dynamic recrystallization. Dynamic recrystallization happening in AZ31 alloy material was acknowledged as a vital issue that encourages strain localization.
The remains in the grain refining were recognized in the shear bands, which is thought to be the result of continuous dynamic recrystallization. The later may be result in the large of the strain to form inside the shear bands.
The Shear banding might related to the substantial heterogeneity in mechanical properties at areas inside and outside the bands. If it is well dispersed alongside the distorted material, shear banding phenomenon may be thought of as a grain refining mechanism throughout plain circumstances concerning the AZ31 alloy welding. Liu and another worker [21] has testified that they studied the microstructure and properties of Mg ZK21 laser beam weld deprived of filler by means of optical microscopy (OM), electron microscopy and mechanical investigation. Their outcomes display that the fracture strain of the joints once laser beam welding lessens by about 10.7% at normal temperature. The practice of laser beam welding together with the detached base material have been concluded to behave undergone balancing compressive residual stress (RS). However, fusion area was found the tensile residual stress (RS). The microstructure of the welding is classified by the area of the fine heat affected and the twins. Note worthy {1012} tension twins took place in HAZ throughout laser welding handling. Owing to the effect of stresses and temperature field on morphologies, most the twins developed twinning bands that are approximately equivalent to the welding direction. Different to this study, they have not stated twin arising for weld metal.

In the HAZ of a low carbon high strength alloyed steel, Poorhaydari et al. [9] were established two sorts of transformation twins. moreover, it has been recommended that twinning might take place, in the ferritic fine-grained HAZ when the top temperature and cooling rate were low.
By inspecting the microstructures of carbon steels, the suspension of precipitates and local enhancement of the matrix could not be the core cause for twinning.
Barnett [10], worked on the connection between the orientations of preferable {1012}, {1011} twinning and the practical loading directions of the *c*-axis of the cell of HCP-Mg (*c*/*e* liken to 1.624). Nonetheless, the connection between the orientation of twins in the weld HAZ and the applied loading directions was not cited beforehand. From the overhead investigation, the significance of twining and orientation possibly has the influence on the mechanical properties.
In fact, for as cold rolled alloys, slight dissimilarity in hardness is experienced between base material, HAZ, and FZ.
Although noteworthy grain coarsening happens in the HAZ of AZ31 alloy sheet, the hardness in the HAZ is still nearly similar as that of the base metal.
The alike hardness is accredited to the thorough recompense for the loss in work hardening thru grain modification. Due to this cause, the microhardness specified in diverse detachments to the weld top surface is not meaningfully dissimilar from each other.

3.2.2. Tensile Strength

The outcome of the tensile test for all the specimen, Which were considered in the study, were presented in Table 2. As comprehended in this table, tensile strength is growing with growing heat input at pulsed current circumstances but lessening for alternative current specimens.
Their tendency presented dissimilar behaviors relying on the weld current sort.
One is demonstrating an increase in Table 2. The pulse current is obtainable than alternative current, due to the improvement of their tensile properties.

Table 2. Results of tensile

Samples according to current	Heat Input (kJ/mm)	Hardness of weld metal HV0,1	UTS, (Mpa) Base metal vs welded condition	Elongation, (%)
Alternative 70 A	*9,8*	67,6	230-197	6
Alternative 95 A	16	63,2	230-191	7
Pulsed 45-60 A	8,5	68,9	230-205	7
Pulsed 70-95 A	11	73,5	230-221	7,5

In this work, at the lowest heat input (8,5 kJ/mm), the UTS of the specimens is 205 Mpa, which merely accounted for 89% of that of BM (230 Mpa). This outcome illustrates that in the GTAW welding of magnesium alloy AZ31, a too low heat input effortlessly has resulted in the low incidence of welding flaws, Which sense did not reduce in the strength of tensile of the welded joints. This was a pulsed current specimen. With an upsurge of the heat input, the UTS of the welded joints very little diminished in alternative current specimens but not in pulsed current specimens. The UTS of the alternative current welded joint specimens, with 85-83 % of that of the BM (230), were attained at a heat input of 9.8 - 16 kJ/mm owing to fewer welding flaws (such as partial penetration and pores) in the welded seam (seen Fig. 3). And the UTS of pulsed current welded joint specimens with 89-96 % of that of the BM (230), were attained at a heat input of 8.5 – 11 kJ/mm owing to fewer in welding flaws (such as partial penetration and pores) in the welded seam (seen Fig 4). In the welding procedures, magnesium and zinc could be evaporate merely at a high temperature due to the inferior melting points/boiling points and the higher vapor pressure of these components compare to that with aluminum. In overall, the strengthening influence of zinc on Mg–Al–Zn alloys is mutual thru solution strengthening and through growing the solubility of aluminum in the magnesium alloy.

4. CONCLUSIONS

Throughout of this study, the emphasis has been made in order to employ microstructural observations, tensile tests and microhardness tests for the sake of determining the outcomes of weld current type and heat input on the microstructural advance and mechanical features of the GTAW welded 3 mm thickness AZ31 sheet. In addition, can be the conclusion as follows:

1. By means of GTAW welding technique, AZ31 magnesium alloys have the potential to be welded very easily.
2. The prevailing structure in the weld metal and less in HAZ are certainly the twins and equiaxial grains.
3. The strength in base metal found higher than in weld metal of the samples.
4. The microstructure of the alternative current for the samples have been concluded to contain fewer finger grains than the pulsed current samples
5. For pulse, has been concluded that strength increased with increase the weld current. The same conclusion is untrue for alternative current.
6. As the heat supplement increased, the was matching increase in the width of HAZ and the grain coarsening of α-Mg in both the HAZ and FZ. Overall, As there an upsurge in the heat provision, an equivalent upsurge would take place in the UTS of welded joints. The cause being, that is a very low heat provision shall result in partial penetration and pores.

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