The Effect of the Weld Current Types on Microstructure and Hardness in Tungsten Inert Gas Welding of the AZ31 Magnesium Alloy Sheet

Bilge Demir, Ahmet Durgutlu, Mustafa Acarer

***Abstract*—**In this study, the butt welding of the commercial AZ31 magnesium alloy sheets have been carried out by using Tungsten Inert Gas (TIG) welding process with alternative and pulsed current. Welded samples were examined with regards to hardness and microstructure. Despite some recent developments in welding of magnesium alloys, they have some problems such as porosity, hot cracking, oxide formation and so on. Samples of the welded parts have undergone metallographic and mechanical examination. Porosities and homogeneous micron grain oxides were rarely observed. Orientations of the weld microstructure in terms of heat transfer also were rarely observed and equiaxed grain morphology was dominant grain structure as in the base metal. As results, fusion zone and few locations of the HAZ of the welded samples have shown twin's grains. Hot cracking was not observed for any samples. Weld bead geometry of the welded samples were evaluated as normal according to welding parameters. In the results, conditions of alternative and pulsed current and the samples were compared to each other with regards to microstructure and hardness.

***Keywords*—**AZ31 magnesium alloy, microstructures, micro hardness TIG welding.

I. INTRODUCTION

As magnesium came into commercial production in 1886 in Germany it did not take long before engineers took a liking for its low weight. Amongst the metallic materials magnesium became a star performer and many of the first applications were closely associated with transport both on the ground and in the air. It should come as no surprise that magnesium became a strategic material during two world wars and that most of the technological advances were made under conditions where time was the only limiting factor. Funds and resources were not limited [1]-[7]. Magnesium alloys are attractive materials due to having high strength/weight ratio compared with steels and other metallic materials. They also have superior recyclability properties compared with plastics. Because of the characteristics of low density, and specific strength, good damping and recycle, magnesium alloys are praised of the green engineering material [6], having a widely applied prospect in the fields of automotive industry, motor vehicle industry and aviation. The use of magnesium has increased significantly in the past ten years, and continues to rise in the automotive industry. With the application of magnesium alloy structure components increasing, the welding of magnesium alloys need be resolved [1], [9].

Magnesium and its alloys are attractive in automobile, aircraft and electronic housing due to their superior specific, strength and recyclability. However, it is hard to weld magnesium alloys by commercial fusion welding processes such as arc welding since magnesium is an extremely active metal. Therefore, recently provided developments have shown that like Al alloys, also Mg alloys could be welded by using different welding methods such as RSW. In the literature [9]-[15] there are a lot of studies to solve joining problems in magnesium alloys. Nevertheless, there are limited studies about the Tungsten Inert Gas (TIG) welding of AZ31 magnesium alloys. Hot cracking is the most common problem in welding of magnesium alloy AZ31 [4]. Mg–Al intermetallic is another important factor for the characteristics of the dissimilar joint in Mg alloy and Al alloy welding [1]-[4]. The formation of Mg–Al intermetallic is nearly unavoidable in the Mg and Al welding process and this has been actively attended by researchers. Another subject may be the twinning in magnesium alloys welding but unfortunately this has not been mentioned enough before, but Barnett [6] stated the relationship between the orientations of twins in HAZ metal in position of heat transfer. It could be inquired that how the twinning takes place in weld metal in other words in the fusion zone but that is not clear in the literature.

This study is concentrated on hardness and microstructures of the commercial AZ31 magnesium alloy materials in different welding conditions especially in different current types. Two current types were used in this study. One of these is pulsed current which is very popular in refining the weldment recently [17]. However, there are not enough studies on this technique's use with magnesium; therefore, this study has been carried out.

II. EXPERIMENTAL PROCEDURE

Composition is seen at Table I. The welding processes used in this study were TIG welding method with alternative and pulse currents.

TIG welding was used to join Mg alloy. In magnesium welding, weld parts had to be cleared from all nonmetallic factors such as oxide, and all impurity such as oil and so forth.

Bilge Demir is with the Manufacturing Department of Technology Faculty of Karabuk University, Demir Celik Kampusu, Balıklarkayası, Karabuk, Turkey (Corresponding author to provide phone: +90 505 503 36 17; fax: +90 370 433 82 04; e-mail: bdemir@karabuk.edu.tr).

Ahmet Durgutlu is with Materials and Metallurgy Department of the Technology Faculty of Gazi University, Besevler, Ankara (e-mail: durgutlu@gazi.edu.tr).

Mustafa Acarer is with the Materials and Metallurgy Department of the Technology Faculty of Selcuk University, Turkey (e-mail: macarer@selcuk.edu.tr).

Because of this, welding samples were cleared by grinding and they were wiped by acetone and methyl alcohol.

TABLE I
CHEMICAL COMPOSITION OF THE AZ31 ALLOY USED IN THIS STUDY (WEIGHT %)

Al	Zn	Si	Mn	Other elements	Mg
2,88	1.04	0,030	0,15	Cu – 0.004; Fe – 0.020; Be – 0.002	95

TIG Welding parameters which have been used in this study are presented at Table II. As seen in the table, two different current methods were applied. These are selected depending on several real applications. Heat inputs were calculated by using (Voltage X current / weld speed X 1000) X 0,6 [17] formula well known for understanding the heat input which is considered very important for all properties of the joining by the researchers.

The torch of the welding was fixed on a supporting surrounding. In work stage with butted sheets upon reserved moving straightforward to wire feeding forward in welding. The optical and stereo microscopes were used to examine the microstructure and defects of welded joints. For microstructure examinations the welded joints were prepared via typical metallographic applications. The specimens were etched in a well-known solution containing 10 ml acetic acid+5 g picric acid+10% ml alcohol and 70% water. Vickers micro hardness measurement was applied at vertical and horizontal axes throughout from the base metal, HAZ and weld metal (fusion zone) by using 100 gr loading.

TABLE II
PARAMETERS OF WELDING PROCESS APPLIED IN THIS STUDY

Parameters	Alternative current	Pulsed current
Tungsten electrodes (mm)	3	3
Filler metal (mm)	From base metal	From base metal
Voltage (V)	28	28
Amp (A)	95	Upper 60- lover 95
Pulse frequency (Hz)	-	3
Heat input (kj/mm)	12,28	10
Shielding gas	Argon	Argon
Shielding gas flow rate (Lt/dk.)	14	14
Welding speed (mm/dk.)	130	130

III. RESULTS AND DISCUSSIONS

A. Microstructure

Microstructures of the welding zone of the pulsed current samples have been seen in Fig. 1 (A) in which base metal has alfa magnesium phase having equiaxial grain. The base metal grains have showed some coarseness and some small grains which stemmed from warmish condition of the last rolling stage for enough formability. These are accompanied by new crystallization due to some grain growth. In addition to that it has some Al-Mg intermetallic.

The microstructures of the weld metal have had bigger equiaxial grains with high twins' boundary. HAZ of these samples shows also bigger equiaxial grain and lesser twins and amount of these lessens towards the base metal. It could be interpreted that twinning particularly occurs in metals having low stacking fault energies [1] for example hexagonal materials, such as magnesium and titanium and other such as twinning induced plasticity (TWIP) steels as well as, in which numbers of slip systems are limited [1]. Liu Jun-wei et al. [19] also reported that {1012} tension twins occur in the weld HAZ of Mg ZK21 during laser welding process. Different from this study, they did not report that any twins occurring in weld metal.

As it is seen in Figs. 1 and 2; the main difference between these samples is that alternative current samples contain bigger grains compared to pulsed current welded samples. This is attributed to the higher heat input [17]-[20]. Twins are also observed in alternative current weld metal. Direction of twinning is different from the welding direction reported by [19]. However, they explained that, the controlled thermal shrinkage of the weld pool during cooling in welding direction parallels to the fusion line, the fusion zone contains tensile residual stresses while the base material far away from the fusion zone is under balancing compressive residual stresses. This result is showing that stress have been occurring in all areas of the fusion zone and HAZ due to fast solidification and cooling resulting in heterogenic solidification [16], [18], [19]. So probably twinning's occurred as mentioned before by [6], during solidification in the weld metal and thermal cycles in the HAZ, residual stresses are formed and the stresses can be the cause of twinning forms [7]-[8]. As mentioned by [6], weld HAZ but together with weld metal it could be said that heterogenic nucleation and solidification are very effective on the formation of twins.

For general microstructure formation, it could be said that weld metal contains equiaxial grains and twin's grain. It could be said according to the results of this study, heat input and heterogenic solidification, whose quantitative amount changes according to weld current type [20].

It is a very important point of this study. In the literature [6]-[9], it was reported that forming of microstructure was that the rapid cooling stimulated due to thermal properties of magnesium has deprived the growth of grains in fusion zone. But compared with that of pulsed current welded joint [1], [17], grain is more coarse in the fusion region was welded by alternative current welded joint, which is attributed to the high heat input (Table I) and following by the extended cooling time of melted pool [3], [9]-[15]. Therefore, it is essential to suppress the pore development. It could be said that, because of the same metal filler and welded samples interface fixing very well and any defects are rarely observed at these study as seen Figs. 1 and 2.

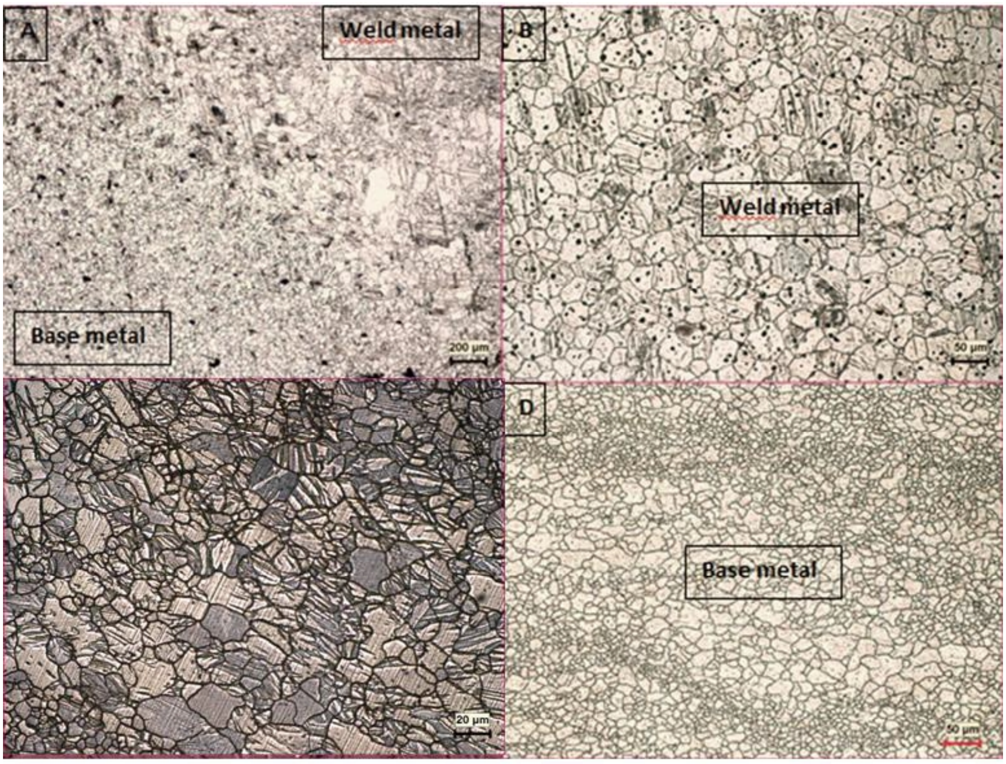

Fig. 1 The microstructure of samples of the gas tungsten-arc pulsed current with base metal AZ31 Mg alloy

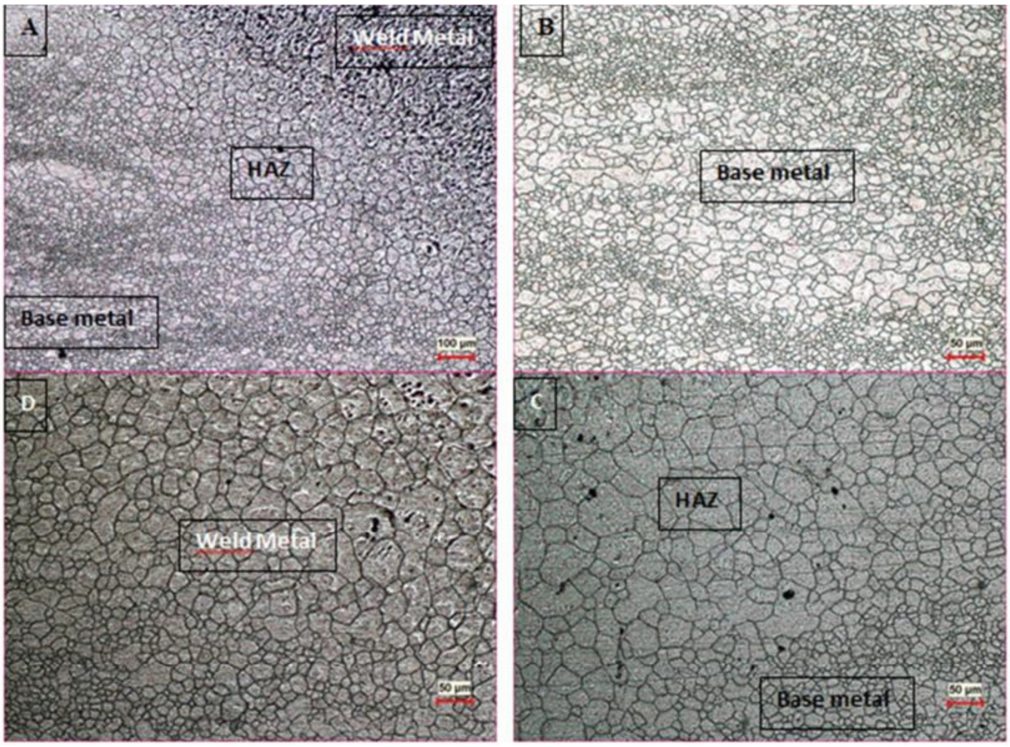

Fig. 2 The microstructure of samples of the alternative current welded samples with base metal AZ31 Mg alloy

B. Microhardness

The microhardness is measured alongside the mid-thickness line of the cross-section of all samples of the TIG welded joint of the AZ 31 magnesium alloy horizontally and vertically. In fact, for as-cold rolled alloys, it was not observed as significantly different in hardness among base material, heat affected zone and fusion zone. Fusion zones of both group samples have coarser grain due to melting and solidification during TIG welding which have high heat compared to laser welding which reported that laser welding also results grain growing however not as big as TIG welding. Although grain coarsening occurs in the HAZ and of AZ31 alloy sheet, hardness results showed the hardness in the HAZ is close to that of in the base metal. It could be said that AZ31 magnesium alloys have not had high hardness thus hardness changes were not observed as clearly so this proves contrast between them. However, we could make some evaluation according to hardness measuring of samples.

Results showed that hardness of the weld metal, heat affected zone and base metal as Vickers for pulsed current samples are nearly 66, 65 and 72 HV0,1 and for alternative current samples 66, 63 and 67 HV0,1 respectively. The micro hardness relationships between the micro hardness of the base metal, the heat affected zone and the weld metal of all welded joints samples have been as follows: weld metal > base metal > heat affected zone. As seen from the results heat affected zones of both group showed nearly same hardness value with base metal. However, some researchers [9], [17] showed that there is a bit lower hardness value of the heat affected zone although their lower heat input and welding parameter such as current compared in this study. And they explain this hall-patch equation due to grain coarsening. In contrast to them this study used higher heat input. Thus it can be expected that lower hardness and bigger grain due to high input. But here, there are two strong factors which are twinning and intermetallic characteristics that are changing due to heat input characters. It can be interpreted that this has a very strong effect on hardness according to literature [1]-[9]. In this study as explained before, results of hardness showed that weld metals of both samples have little higher values compared to base metal. We can understand this by intermetallic and twinning characteristics which have a strong effect on hardness of samples. Min et al. [5] also reported that, throughout a process of TIG welding in the magnesium alloys, the weld metal has fine grains and the HAZ has coarse grains due to the high cooling rate and the effect of the thermal cycling respectively. They concluded that the grain sizes of the zones are weld metal > base metal > HAZ. But this study showed that weld metal of samples showed higher grain size compared to base and HAZ. However, it showed the same relationship between hardness value of base metal, HAZ. In addition to that, they have reminded the relation between strength and hardness that the smaller the grain size is, the higher the micro hardness is. Therefore, the change of the micro hardness should be inversely proportional to the square root of the grain size [5]. It can be said that the results of this study showed twinned grains. It is known that hardness and strength are also dependent on twins.

In the fusion welding, magnesium could be vaporized at a higher temperature because of its lower melting and vaporization temperature [5]. Thus, the vaporization of the elements due to an over high heat input, weakens the effect of solution strengthening by aluminum and zinc and this decreased the hardness of the welded joint [5]. However, the main factors affecting the hardness of the welded samples are microstructure phase, their morphology and intermetallic. For this study's results, we could say that all of these factors had been effective.

IV. Conclusion

In this study, the microstructural development and mechanical properties of the TIG welded AZ31 3 mm thick plates have been determined. The results obtained are summarized as follows.

1. The microstructure of the weld metal is showing bigger equiaxial grains with high twins' boundary area in it. HAZ of the samples show also bigger equiaxial grain and lesser twins and amount of that lessens towards the base metal. Twins and equiaxial grains dominate structure in weld metal and at its HAZ it is smaller than weld metal.
2. Qualitatively, samples of the pulsed current showed little grains size and many twins in weld metal than alternative current samples.
3. Little porosity could be seen which some micro size oxide in weld metal are.
4. Hardness of the pulsed current samples favor with regards to strength.
5. HAZ of the alternative current samples showed bigger grain and they are larger than HAZ of the samples of the pulsed current.

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