Effect of Weld Current and Weld Speed on the Microstructure and Tensile Properties of Magnesium Alloy Specimens during Tungsten Inert Gas Welding

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Abstract-Magnesium (Mg) and its alloys are considered the best materials for aerospace applications due its high strength to weight ratio[1]. In this paper, the effects of weld current and weld speed on the microstructures and mechanical properties of tungsten inert gas arc (TIG) welded magnesium alloy pieces were investigated by micro structural observations and tensile tests. The results showed that, the formation of porosity increased at higher values of weld current (170 & 180 A) and with further increase in the amount of the weld current (Heat input) the tendency of the formation of solidification cracking also increased. The ultimate tensile strength(UTS) of the samples increased with the increase in the weld current from 150 A to 160 A. However, a decrease in the value of ultimate tensile strength was observed when the current was further increased from 170 A to 180 A. At higher temperatures the Heat Affected Zone receives more heat, thus the grains grow faster under excessive heat and become coarse, resulting in a decrease in the UTS values. Samples were also welded using automatic mechanism with variable speeds ranging from 2 cm/sec to 4 cm/sec. Quality weld bead geometry was achieved at weld speed of 3.5 cm/sec, whereas, discontinuities were observed in samples prepared at 2, 2.5 and 4 cm/sec. The ultimate tensile strength of the welded samples at 3.5 cm/sec was higher than weldments at other welding speeds.

Keywords-TIG Welding, Weld Current and Speed, Magnesium Alloys.

I. INTRODUCTION

Magnesium alloys have a wide range of applications in the aerospace, automotive and electronic industry due to its light weight and high strength [2]. However, the wide applications of magnesium alloys needs improved weldability, since the production of complicated work pieces is difficult and expensive due to poor ductility of Mg alloys [3]. Problems, such as formation of coarse grains, oxidation, volatilization and thermal cracking, occur during welding as magnesium alloys have a low melting point, high thermal and electrical conductivity and large thermal expansion coefficient. Joining of Mg alloys requires extra care to obtain a sound weld with good quality [4]. The most common and widely applied method throughout the world for joining of Mg alloys is conventional Gas Tungsten Arc Welding (GTAW) [5]. These parts get deteriorated in service and require repair for achieving dimensional restorations. Tungsten inert gas (TIG) welding is usually preferred for Mg alloy parts during repair [6]. Welding defects and discontinuities are generally encountered during manual TIG welding. These discontinuities include porosity, voids, cracks (Hot cracking) and pin holes. Due to these defects critical Mg alloy parts fail to qualify the requisite quality checks/tests and get discarded [7]. Replacement of a discarded part with a new one is very expensive, whereas successful repair process is quite economical. To avoid discontinuities and obtain desirable weld bead geometry, selection of appropriate welding parameters is very important [8].

Welding input parameters play a very significant role in determining the quality of a weld joint. The joint quality can be defined in terms of properties such as weld-bead geometry, mechanical properties, and discontinuities [9]. Unfortunately, a serious problem during welding is the improper selection of input parameters which leads to discontinuities including lack of fusion, improper penetration, formation of pores, voids etc. [10]

Reference [11] performed TIG welding on Mg alloy AZ91D and observed hot cracking in the weld bead and Heat Affected Zone. Reference [12] observed that an increase in heat (welding current) leads to an increase in both the Heat Affected Zone and the grain size, on performing tests on AZ61 Mg alloy. Reference [13] performed manual tungsten inert gas welding on AZ61 Mg alloy and observed changes in the microstructure on varying the heat input. The increase in the heat input may cause low cooling rate for the Heat Affected Zone (HAZ) leading to formation of coarse grains and hence porosities, cracks and discontinuities. Reference [14] in a set of experiments, performed on AZ61 Mg alloy, identified that effect of weld current initially increased the tensile properties, however at higher value of current tensile strenght was decreased. Reference [15] carried out experimental study on AZ91D Mg alloy and observed that the grain size increases when the welding speed is reduced and vice versa. It is clear from the above studies that the quality of a welded joint depends on the heat input, which is a function of the weld current, and weld speed. The work presented here is focused on determining the effect of weld current and weld speed on development of microstructures and mechanical properties of Mg alloys undergoing TIG welding.

II. Experimental Work and Methodology

Experimental work included manual and automatic TIG welding performed on the Mg alloy test pieces. Metallographic images were taken at 500x and 200x magnifications using “Leice DMI” 5000 metallurgical inverted microscope, in order to analyze the micro-structural behavior and metallurgical effects on the overall geometry of weld bead and heat affected zone. Moreover, tensile tests were performed to examine the mechanical properties of the material and weld strength, using tensile tester model “WAW-100B” capable to undertake metallic, non metallic samples and composites materials exposed to maximum of 100KN force. Chemical composition of the Mg alloy base material studied is given in Table I. GTH3Z2 BUILD-UP welding rod, with a diameter of 4 mm was used for welding of Mg alloy samples.

TABLE I
Chemical Composition of Mg Alloy By Wt %

Mg	*Th*	*Zn*	*Zr*	*Mn*
95%	*2.7%*	1.5%	0.5%	0.2%
Cu	*Si*	*Fe*	*Ni*	*Al*
0.03%	*0.01%*	0.01%	0.005%	0.045%

The quality of TIG weld greatly depends on the selection of appropriate process parameters. These parameters include welding current, welding speed, welding arc voltage, welding wire diameter, distance between arc and base material, shielding gas flow rate. TIG welding was performed on the Mg alloy test pieces in two phases. In the first phase, manual TIG welding was performed by keeping welding current as variable. During the second phase automatic speed controlled TIG welding was performed by taking weld speed as variable. A number of inspections including non-destructive as well as destructive tests were performed in accordance with American Welding Society AWS D17-1 and ISO 9001-C. The non-destructive tests included micro structural analysis (metallographic images) aimed to investigate the metallurgical changes, discontinuities like cracks, porosity, voids etc. in the weld heat affected zone. Another important test carried out was destructive inspection i-e tensile test to determine the strength of the test samples.

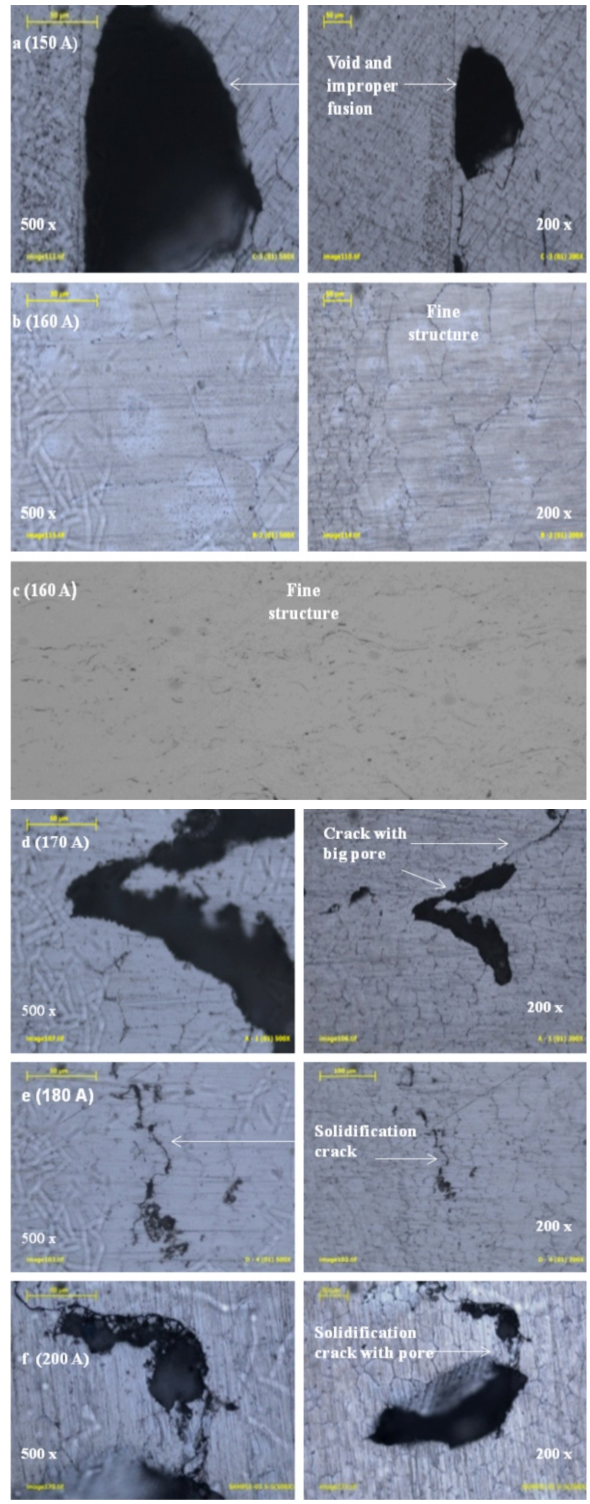

Fig. 1. Manual TIG welding at (a) 150, (b&c) 160, (d) 170, (e) 180 and (f) 200 A

III. Observations

Fig. 1. shows Metallographic images of Mg alloy samples welded manually at different weld currents. The Metallographic image in Fig.1 (a), welded at 150A, clearly shows lack of penetration and lack of fusion appearing just at the edge of weld bead in the heat affected zone which is adjacent to base metal, bifurcated by a thin visible line. The weld bead geometry in the area of HAZ has a coarse grain structure. This lack of penetration is caused due to relatively low current. The metallographic image in Fig.1 (b)&(c), welded at 160 A, revealed no discontinuities or defects. It is evident from these images that the grains of weld portion have fine structure and there is no evidence of presence of any discontinuities such as pores, voids, holes or cracks.

Further increase in the weld current to 170 A led to porosity spreading throughout the weld bead Fig.1(d). A large void was created and on the top side of the void, a number of clustered type porosities are clearly visible. A crater type crack is also visible which shows poor quality weld. For Mg alloy test piece welded at welding current of 180 A Fig.1(e), Clustered porosity is observed at different locations throughout the HAZ. A significant line has been observed which may be termed as solidification crack. For test piece welded at 200 A, micro structure showed a significant thick crack and porosities. The crack is a solidification type of crack. From the above experiments, the value of the best weld current can be determined as 160 A, since the sample welded at this current had no discontinuities and highest value of UTS. At higher current more heat is generated in the fusion zone and the grains get coarsen due to slow cooling rate which results in lower UTS values. Furthermore, excessive heat input at higher weld current values results in release of some stirred materials in the weld bead which produces flaws including cracks, pores etc.

Fig. 2. shows Mg alloy samples welded at weld current of 160 A, but at variable speeds. The metallographic image of Fig.2(a) illustrates a solid crack developed due to welding at slow speed (2 cm/sec). This is because more time is required to complete a pass at slow speed, resulting in large amount of heat received per unit length by the grains. A significant crack is visible in the weld which resulted due to excessive heat input. The Metallographic image in Fig.2(b) illustrates coarse grain size structure of Mg alloy specimen welded at weld speed of 2.5 cm/sec. There is no evident formation of cracks or defects like porosity and voids. At the edges of few grains granular flakes and dendrite growth is observed. Next Mg alloy piece was prepared with torch speed was set at 3.5 cm/sec. The metallographic image shown in Fig.2(c) has equiaxed grain structure extended from center of the image towards the right.

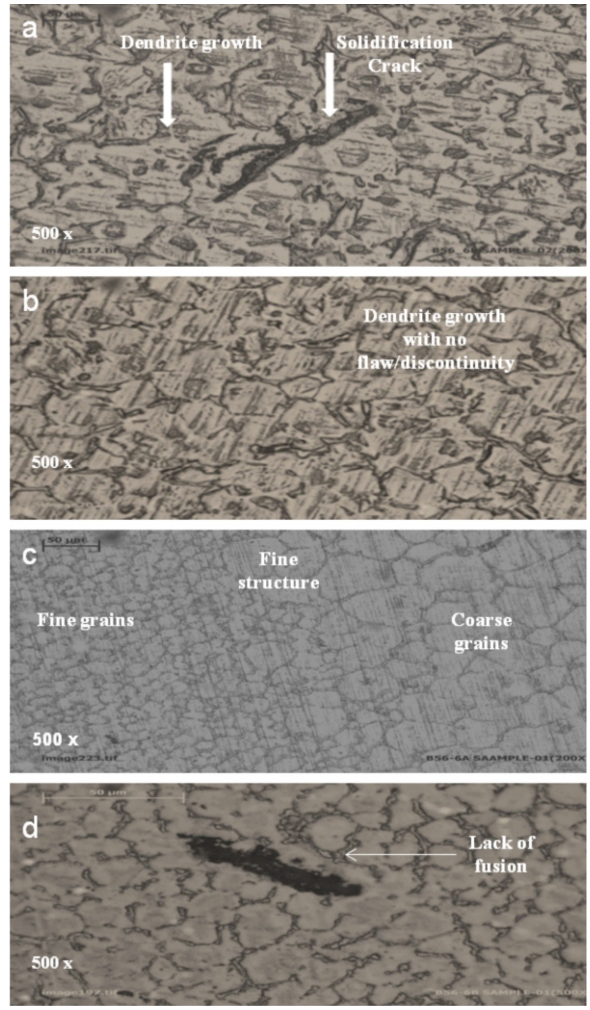

Fig. 2. Automatic TIG welding with weld current of 160 A and weld speeds of (a) 2, (b) 2.5 (c) 3 & (d) 4 cm/sec

The weld bead geometry from the center towards the left side of the image is even better and sound. It depicts properly oriented grains having fine crystal like structure. No discontinuities like voids, porosity or cracks are observed.

Metallographic result of Fig. 2(d) for Mg alloy sample welded at 160 A and weld speed of 4 cm/sec, illustrates lack of fusion with metallic inclusions welded at a relatively higher speed. Cellular dendrite is observed throughout the structure which is not properly oriented.

From the graph of Fig.3(a) it can be determined that at moderate welding current of 150A the value of tensile stress is 87.5 MPa, which increases to 95.8MPa when the current is increased to 160 A. The lowest value of UTS is at welding current of 180 A. The graph of Fig.3 (b) illustrates relationship between Tensile stress and weld speed.

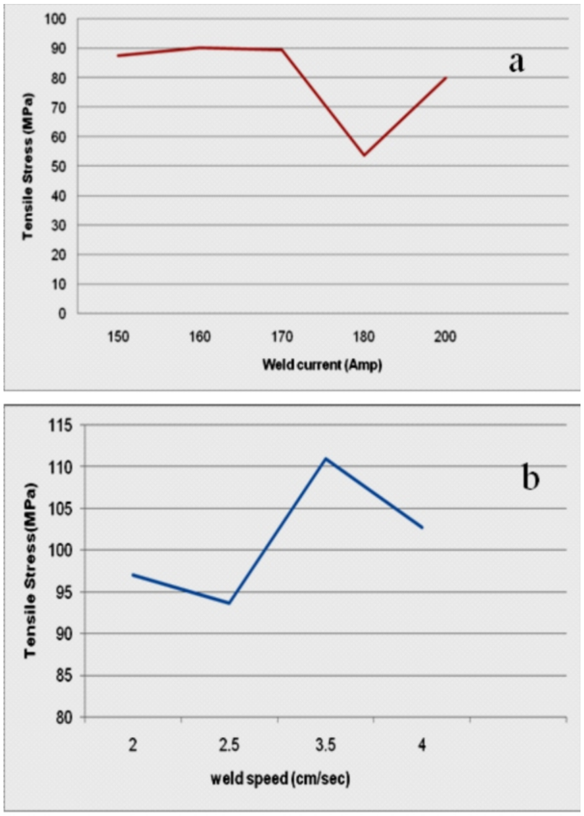

Fig. 3. UTS vs Weld current and Weld speed (A) Manual welding (b) Automatic welding

It has been observed that UTS of the piece welded at a speed of 2 cm/sec is slightly higher than the strength of piece welded at 2.5cm/sec. When the speed is further increased to 3.5 cm/sec, UTS reached it maximum value of 111 MPa, however, when the speed is increased to 4cm/sec the UTS of the weld specimen dropped to a value of 102.7 MPa. At slow speeds there is more time available for the weld torch to deposit the molten material on to the substrate surface, thus the amount of heat energy generated and received by the grains at slow speeds is more per unit length, as more time is available to complete the pass.

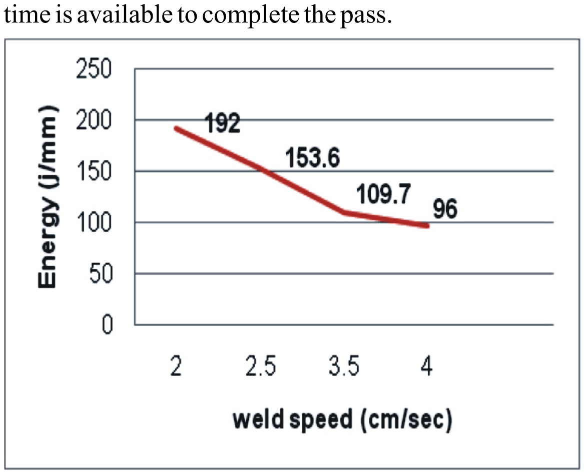

Fig. 4. Heat energy vs Weld speed

The graph in Fig.4 illustrates relationship between weld speed and heat energy produced during the process. It shows that with the increase in the speed the heat energy produced during the process decreases linearly. This shows that a linear relationship exists between weld speed and energy produced. At weld speed of 3.5cm/sec the amount of heat energy generated and received in the heat affected zone is 109.7 joules/mm at which a sound, stable and quality weld bead profile having better tensile strength has been obtained.

Due to excessive heat generation at slower weld speeds the possibility of discontinuities increases. The values of heat energy generated during the two slow speed processes at 2 and 2.5 cm/sec are 192 and 153.6 joules / mm. It is pertinent to mention that all the test pieces prepared by automatic welding speed had better results than the ones produced with manual welding.

IV. Conclusions

During manual TIG welding, at weld current of 150 A discontinuities like lack of penetration and improper fusion were observed. A sound and good quality weld bead was obtained at weld current of 160 A. At 170 A, moderate porosity, small voids and air traps have been observed in the weld bead heat affected zone of the test sample. Further increase in the amount of welding current(180 A) increased the heat input which consequently increased the amount of discontinuities porosities, pin holes, crater cracks and voids to a certain extent where those discontinuities were not acceptable and declared defects. An increase in the amount of welding current from 180 to 200 A increased the amount of weld discontinuities further. A significant crack was also observed in the Heat Affected Zone (HAZ) upon solidification of the molten metal. It may be termed as solidification crack. A decreasing trend in the values of UTS has been observed at 170, 180 and 200 A of current. The microstructure and mechanical properties of sample prepared by manual TIG welding by setting the value of welding current at 160 A showed best results having absolutely minimum amount of discontinuities. A sound quality of weld bead geometry with better mechanical properties having better UTS values of 95.6 MPa has been observed. Automatic TIG welding was done in the second phase by keeping optimal weld current value of 160 A and different weld speeds, 2cm/sec, 2.5cm/sec, 3.5cm/sec and 4cm/sec speeds were selected. At weld speed of 3.5cm/sec a sound, stable and quality weld bead profile was obtained which also had good mechanical properties as determined by the tensile testing. Test pieces welded with auto controlled variable speed have far better results than those produced manually. this is because a very smooth and precise passes were performed during auto mode that resulted in a fine weld bead geometry. Moreover complete fusion and proper penetration is also possible with smooth flow during welding pass, however same is not possible in manual welding.

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