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# Electrochemical Corrosion and Mechanical properties of welded AA 6061 joined by TIG and MIG welding methods

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## Abstract

Aluminium alloy 6061 T6 circular specimens were joined using TIG and MIG welding methods. Heat Affected Zone (HAZ) and Base Metal (BM) were separated from each other. Potentiodynamic polarization and open circuit potential were employed to investigate the corrosion properties. Mechanical properties were evaluated using tensile, and hardness tests. It was shown that corrosion resistance was less for the HAZ of TIG and MIG welded specimens. The BM showed better corrosion resistance. The corrosion potential of HAZs was largely fluctuated; the corrosion potential for BM was relatively stable. Both welding procedures affected the mechanical properties of the specimens. The ultimate tensile strength of the TIG welded AA 6061 T6 specimens was 193.107 MPa which is 54% that of the base metal. The ultimate tensile strength of the MIG welded AA 6061 T6 specimens was 155.725 MPa which is less than 50% that of the BM. The HAZ of TIG welded specimens had the lowest hardness, for MIG welding the welded zone was shown to have the lowest hardness values due to the presence of pores which confirm using Scanning Electron Microscopy (SEM).

Key words

TIG, MIG, Potentiodynamic, Scanning Electron Microscopy, Mechanical properties

## Introduction

In order to join two pieces of any metal, they have to be welded. The heat that generated during the welding process may cause the mechanical properties of a metal or an alloy to deteriorate due to phase transformations and softening induced in these materials [1]. Many welding strategies for Aluminium and Aluminium alloys have been reported in the literature [2]. Tungsten Arc welding (TIG) is one of the most important welding strategies; it uses a non-consumable tungsten electrode to produce the weld [3]. Metal Inert Gas (MIG) welding has been used widely to join pieces of Aluminium alloys in different industries such as construction of rail vehicles, ships, steel bridges and pressure vessels [4]. In the MIG welding process [5], a gas shield is usually used to protect the arc and the weld from atmospheric impurities, and an electric potential is established between the electrode and the work piece that needs to be welded, such electric potential will cause the current to flow and consequently a thermal energy will be generated in the partially ionised inert gas. Welding process exhibited a partially melted zone (PMZ), in other words the heat affected zone (HAZ) adjacent to the fusion zone (FZ) where the metal melts and solidifies. Beyond the HAZ is that part of the metal which has not been subjected to thermal alteration and it is called the base or parent metal (BM). Wadeson et al [6] found that the corrosion resistance of the welded materials at different regions that formed during the welding process are not the same; their study showed that the HAZ of most joints are more susceptible to corrosion. Due to the importance of Aluminium and its alloys in different aspects of our life, we concluded that it is vital to investigate the difficulties and challenges that associated with the welding of AA 6061 T6 and others in order to broaden our understanding of the behavior of these materials. In the first paper in this series [7], the influence of TIG welding on the corrosion and mechanical properties of AA 6061 T6 was investigated, it was found that TIG welding causes the alloy to be more susceptible to corrosion particularly the HAZ which is in agreement with the work that conducted by many authors [8,9], the welding was also found to have an impact on the mechanical properties of the alloy which was attributed to the modification and softening induced in the alloy. Based on the second paper in this series [10-13] MIG welding was also found to have some negative impact on both the corrosion and mechanical properties of the alloy. However, the degree of effects is varies. The current study is a comparative study and it focuses on the impact of TIG and MIG welding strategies on the corrosion and mechanical behavior of AA 6061 T6.

## 2. Experimental

The composition of the alloy used and detailed experimental procedure was mentioned in earlier publications [7,10,11].

## 3. Results and Discussion

3.1Corrosion evaluation

Figure 1 shows Tafel polarization plot for the base metal (BM) and the heat affected zones (HAZ) of both TIG and MIG welded specimens. The data that extracted from these plots are shown in table 3. It can be seen that the BM has a corrosion potential of -0.725V and a corrosion current of 24.02µA. The corrosion potential for HAZ of both TIG and MIG welded specimens were -1.237V and -1.35V respectively whereas the corrosion currents were 82.44 µA and 94.86 µA respectively. Based on figure 1, it is apparent that the corrosion resistance of HAZ for TIG and MIG welded specimens was less than the BM. As can be seen from figure 2a and figure 2b, severe pitting corrosion of the HAZ occurred while on the base metal relatively less corrosion took place, this observation was attributed to the formation of dendritic structure with heterogeneous concentration distribution on the HAZ of TIG and MIG welded specimens [14,15] The extent of corrosion that observed on BM and HAZ is an indicating that the BM has a better corrosion resistance comparing to the HAZ (figures 2c).

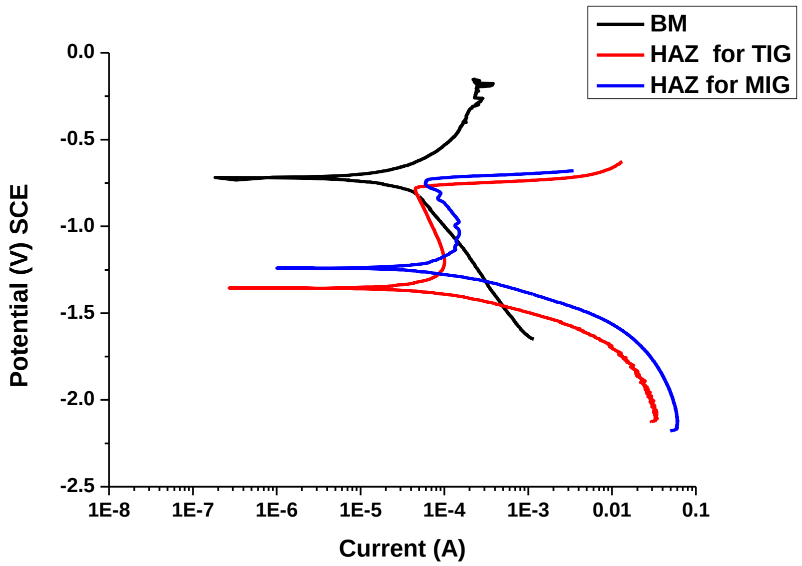
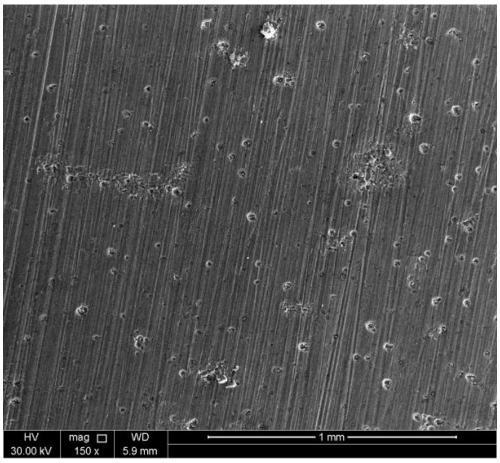
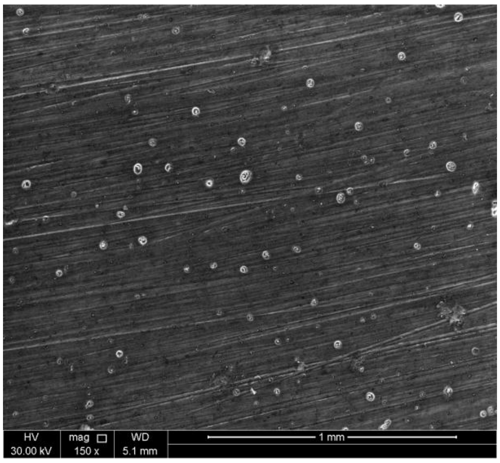


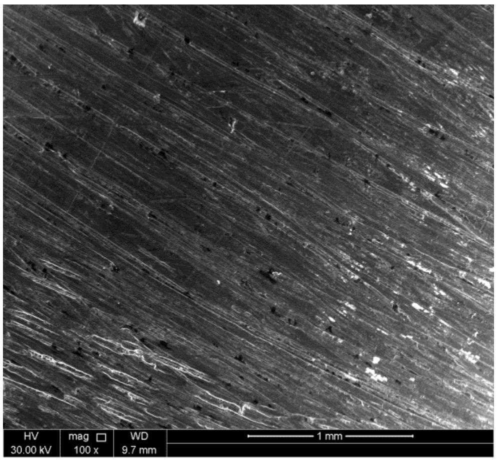

Figure 1 Potentiodynamic polarization curves for TIG/MIG, and BM




(a)



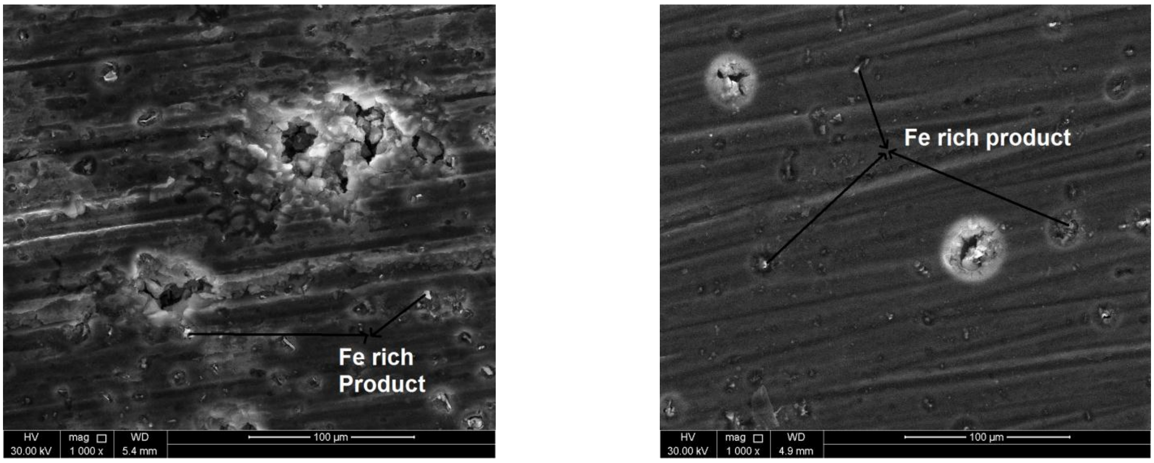

(b)




(c)

Figure 2 Extent of corrosion on a, and b: MIG welded AA 6061 T6 specimens, c: BM after immersion in 3.5% NaCl media

Figure 3 illustrates micrograph of surfaces of HAZ after potentiodynamic polarization test. It is clear that dissolution of Aluminium matrix has mostly occurred on the neighbourhood of the precipitates. This indicates that the coarse particles are cathodic with respect to the surrounding Al matrix. Examination of the coarse particles by EDS showed that it is Fe-rich. Because the composition of these particles are different from the Al matrix, a potential variations is expected between them. The cathodic reaction, typically oxygen reduction is expected to take place at the Fe-rich particles and the anodic reaction will take place at the Al matrix. The cathodic reaction usually generates $OH^-$ ions which will increase the solution pH and accelerate the dissolution of Al matrix around these particles [16]. SEM observations for HAZ show that the specimens suffered from localised corrosion (figure 3). The morphology of the attack confirms that the coarse particles act as nucleation sites for pitting corrosion in areas adjacent to these particles while Fe-rich particles remained un-attacked.




(a) (b)

Figure 3 Micrograph of HAZ for a: TIG welded specimen, and b: MIG welded specimen after potentiodynamic polarization.

Corrosion potential usually depends on the electrochemical behavior of the elements that formed the alloy, this directly stem from the nature and quantity of the present phases. Coarse intermetallic particles enriched from iron and silicon lead to the dissolution of the matrix of theses alloying elements. The ranking of solid solubility of various elements in the Aluminium matrix is: Mg >Si >Fe [17]. Figure 4 illustrates a typical corrosion potential behavior for HAZ of TIG/MIG, and BM over a period of four hours, as can be seen the corrosion potential behavior of the HAZ for TIG welded specimens was relatively negative comparing to the HAZ of MIG welded one and the BM suggesting anodic behavior and consequently high corrosion rate [18-20]. The corrosion potential of HAZ for MIG welded specimens fluctuated largely with many positive and negative peaks reflecting poor corrosion resistance as a result of the alteration of the microstructure and corrosion properties due to the heat input during the welding process. On immersion, the corrosion potential of BM was around -0.84V vs SCE then it was slightly fluctuated in the first 100 minutes. No big change was observed afterward. Based on the corrosion potential data, it is obvious that both TIG and MIG welding had affected the corrosion properties of the HAZ and caused it to be anodic with respect to BM and consequently more corrosion has taken place (figure 2 and figure 3)

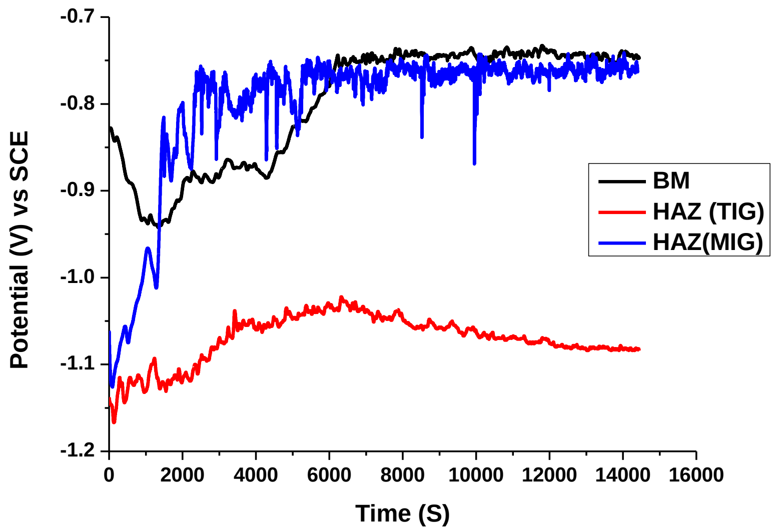



Figure 4 Corrosion potential of HAZ for TIG/MIG welded specimens and BM

3.2 Tensile properties

Figure 5 is showing the impact of welding on the tensile properties of AA 6061 T6 specimens. Based on figure 5, the tensile strength has declined significantly to less than 50% comparing to the un-welded specimens. The tensile strength for un-welded and TIG welded specimens was 357.747 and 193.107 Mpa respectively indicating lower mechanical properties for the welded specimens. It is reported in the literature that the welding process may leave some pores and defects on the welded area, such defects may cause some kinds of weakness in terms of mechanical properties which is the case in the current study. The utilization of SEM has clearly reveals the presence of some defects. Thus the welded zone is the weakest zone and consequently all specimens tested for tensile were failed at the same area.

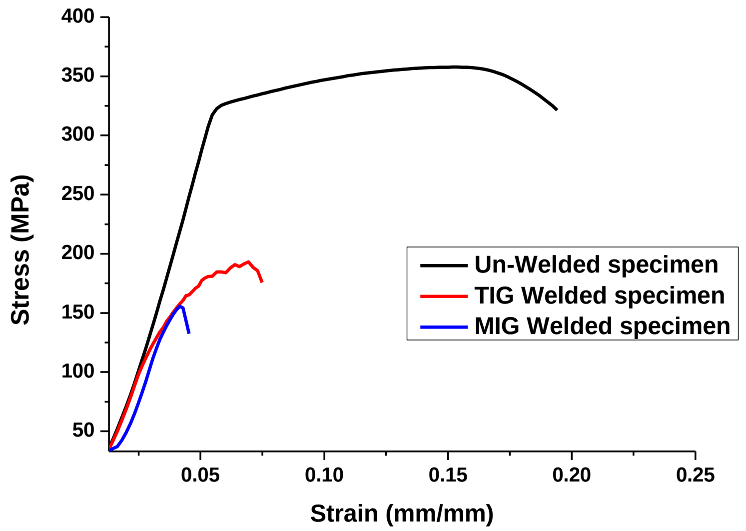



Figure 5 Stress vs Strain for welded and un-welded AA 6061 T6

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3.3Hardness test

The results of the current study reveals that the HAZ of TIG welded specimens has the lowest hardness value recording 23.4 HRF at a distance of 5mm away from the weld centre (figure 6). Surprisingly the welded zone of MIG welded specimens has the lowest hardness value recording 25.13 (figure 6), this result is very interesting as it was expected that the HAZ may have the lowest value as in TIG method. The results found in this study encouraged us to further investigate the reason behind this observation; it was found that large voids were formed at the welded zone during the MIG welding process causing the welded zone to be brittle and have lower mechanical properties.

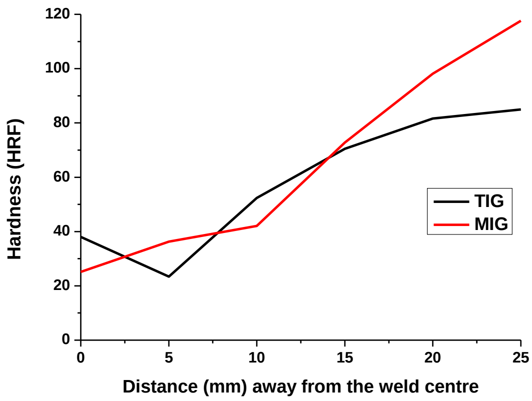
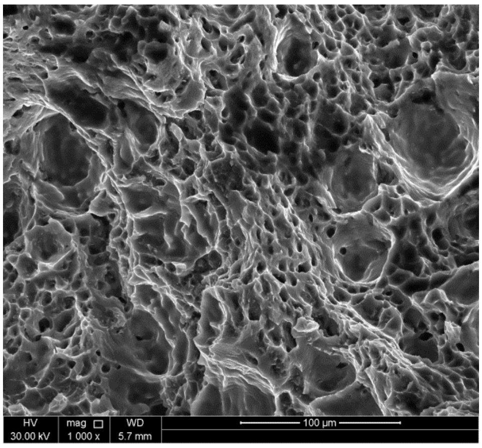


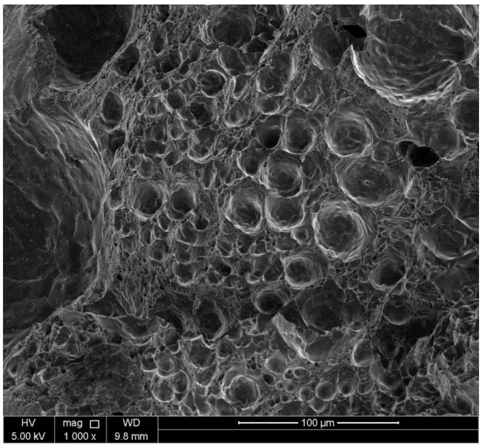

Figure 6 Hardness profile for TIG/MIG welded AA 6061 T6

3.4 Fracture analysis

Figure 7 a shows fracture surface of TIG welded specimen, feature of ductile fracture is apparent, in addition to that, the size and the spacing between the grains produced at welded area were big which considered as an indicative of the ductility of the welded area. Based on fig 7 a, it can be observed that dimples dominated the fracture surfaces reflecting the fact that most of the failure was a result of a ductile fracture, this interpretation agrees with the work that done by many authors [21,22]. SEM fractograph of failed MIG welded specimens clearly reveals the presence of large pores and columnar dendrites within the pores (figure 7 b).The pores was distributed randomly over the fractured surface indicating poor mechanical properties [23].




(a)




(b)

Figure 7 SEM micrographs of failed tensile specimens a: TIG welded, b: MIG welded

## Conclusions

The properties of TIG/MIG, and un-welded AA 6061 T6 specimens were investigated using a series of electrochemical measurements and mechanical tests. Based on the results obtained in the current research study the following conclusions have been drawn:

- The heat affected zone has lower corrosion resistance comparing to the rest of the base metal due to thermal alteration that resulted from the welding process.
- The corrosion potential of the HAZs fluctuated and it was more negative than the potential of the base metal
- Both base metal and HAZ undergo pitting corrosion. However, severe pitting corrosion was observed on the HAZ
- The ultimate tensile strength of TIG and MIG welded AA 6061 T6 specimens was reduced by 54% and 50% respectively
- The HAZ has the lowest hardness value for TIG welded specimens, whereas the welded zone was found to have the lowest hardness value for MIG welded specimens
- SEM results reveals large pores and defects on fractured MIG tensile specimens

## Acknowledgement

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