CHAPTER 6
METALLURGICAL CHARACTERIZATION OF
P-GTA WELDED AA6061 MMC

6.1 INTRODUCTION

Newer automobile designs aim at reducing the vehicle weight. As the use of aluminum as an alternative material grows, manufacturers face newer challenges. These new challenges are fabrication of new aluminium alloys, joining of different cases of aluminium alloys and improvement in weld quality and weld repairs. One of the technologies being explored by the fabricators of aluminum is the pulse gas tungsten arc welding (P-GTAW). GTAW produces significant metallurgical changes along the weld zone. It is essential to study the microstructural changes which influence the mechanical behavior of the joint. This chapter presents the metallurgical characterization of Gas Tungsten Arc Weld AA6061/fly ash MMC. The effect of content of fly ash particulates on microstructure, microhardness is analyzed and the fracture surface of selected specimens is also discussed.

6.2 METALLURGICAL STUDIES OF DEA AND IEA Joints

6.2.1 Macrostructure Characterization of P-GTA Weld Specimen

The Microstructural specimen was prepared perpendicular to the weld zone from the welded plates which had different content of fly ash particles. In order to disclose the microstructure in the weld profile, the HAZ and unaffected parent composite, standard metallographic techniques were used to prepare the samples but the use of water was omitted. Microstructural characterization was
performed by the means of optical microscopy and scanning electron microscopy (SEM). All the specimens were polished using standard metallographic technique and etched with a color etchant containing 4 g potassium permanganate, 1 g sodium hydroxide in 100 ml distilled water. The digital image of the macrostructure of the etched specimens was captured using a digital optical scanner.

6.2.2 Microstructural Analysis

The etched specimens were observed using an optical microscope (OLYMPUS-BX51M) and a scanning electron microscope (JEOL-JSM-6390). Photomicrographs were taken on various zones.

6.2.3 Microhardness Survey

The microhardness was measured using a microhardness tester (MITUTOYO-MVK-H1) at 500 g load applied for 15 seconds along the cross section of specimens obtained perpendicular to the welding direction. The indentation was made up to 15 mm (one indentation/mm) on either side of the center of weld line at 1 mm from top, middle and 1 mm above from the bottom of specimens.

6.2.4 Fracture Morphology

The fracture surfaces of specimens were observed using a scanning electron microscope.

6.3 RESULTS AND DISCUSSIONS FOR DEA AND IEA JOINT

6.3.1 Macrostructure Analysis of DEA and IEA Joint

Figure 6.1 shows the macrostructure of Tungsten inert gas welded AA6061/fly ash_{12p} MMC. The different zones typically present in P-GTA welding of aluminum composite are visible. The macrostructure consists of
parent composite (BM), heat affected zone (HAZ) and weld zone (WZ). Similar zones are observed in other welded joints. Weld zone and HAZ constitute the transition zone. The details of those zones are explained in the following section.

![Macrostructure of P-GTA Welded AA6061/12 wt.% Fly ash MMC by (a). DEA Joint and (b). IEA Joint](image)

Figure 6.1  Macrostructure of P-GTA Welded AA6061/12 wt.% Fly ash MMC by (a). DEA Joint and (b). IEA Joint

### 6.3.2 Microstructural Analysis

#### 6.3.2.1 Microstructure of Parent Metal for DEA and IEA Joint

Figures 6.2-6.5 records the microstructure of base metal (BM) and parent composite of Tungsten inert gas welded AA6061/fly ash AMCs having different amount of fly ash particles. The microstructure of the parent composite and AA6061 alloy are recorded in Figure. 3.7 & 3.8 and keller’s reagent is used as the etchant to reveal the microstructure of the P-GTA welded specimen by DEA and IEA technique.

#### 6.3.2.2 Microstructure of Heat Affected Zone for DEA and IEA Joint

Figures 6.6-6.9 records the microstructure of heat affected zone of tungsten inert gas welded AA6061/fly ash AMCs having different amounts of fly ash particles. The microstructure of HAZ and parent composite are almost identical except in the matrix alloy. The dendrite structure in the matrix alloy is
slightly refined by heat subsequent to welding. Some amount of Mg$_2$Si phase is dissolved and the spacing between dendrite arms is reduced. The grain size and distribution of fly ash particles in HAZ of welded composites does not show an appreciable difference compared to parent composites. Amirizad et al. (2006) attributed this occurrence to the less thermal sensitivity of MMCs. The ceramic particles have lower thermal conductivity compared to the matrix alloy which act as thermal barriers. Hence, the transition zone is limited to TMAZ in tungsten inert gas welded MMCs.

Figure 6.2 Photomicrograph of BM of P-GTA Welded AA6061 by (a). DEA Joint and (b) IEA Joint (T01)

Figure 6.3 Photomicrograph of BM of P-GTA Welded AA6061/4 wt. % Fly ash MMC by (a). DEA Joint and (b). IEA Joint (T02)
Figure 6.4 Photomicrograph of BM of P-GTA Welded AA6061/8 wt.% Fly ash MMC by (a). DEA Joint and (b). IEA Joint (T05)

Figure 6.5 Photomicrograph of BM of P-GTA Welded AA6061/12 wt.% Fly Ash MMC by (a). DEA Joint and (b). IEA Joint (T07)

Figure 6.6 Photomicrograph of HAZ of P-GTA Welded AA6061 by (a). DEA Joint and (b). IEA Joint (T01)
Figure 6.7 Photomicrograph of HAZ of P-GTA Welded AA6061/4 wt.% Fly ash MMC by (a). DEA Joint and (b). IEA Joint (T02)

Figure 6.8 Photomicrograph of HAZ of P-GTA Welded AA6061/8wt.% fly ash MMC by (a). DEA Joint and (b). IEA Joint (T05)

Figure 6.9 Photomicrograph of HAZ of P-GTA Welded AA6061/12 wt.% Fly ash MMC by (a). DEA Joint and (b). IEA Joint (T07)
6.3.2.3 Microstructure of Weld Zone for DEA and IEA Joint

Figures 6.10-6.13 records the microstructure of weld zone of P-GTA welded AA6061/Fly ash MMC having different amount of fly ash particles. The dendrite structure of the matrix alloy is entirely altered during P-GTA welding of AA6061. The presence of magnesium aluminate indicates that dissolution of fly ash occurred. These features are shown in detail in Fig. 6.10.a and 6.10.b. Further to magnesium aluminate being observed and identified previously through SEM and XRD analysis Figure. 3.23, respectively, a complex intermetallic phase Mg$_2$Si and magnesium aluminate is formed around the dendrites during welding was identified mainly in DEA welds.

In IEA specimens, it’s evident from Figure. 3.24 that the diffraction peaks of any other elements except Al, SiO$_2$, Al$_2$O$_3$ and Fe$_2$O$_3$ are not detected. This observation leads to a conclusion that the integrity of fly ash particles is preserved during the IEA weld. Fly ash particles are thermodynamically stable at the applied welding temperature during IEA joint.

Figure 6.10 Photomicrograph of Weld Zone of P-GTA Welded AA6061 by (a). DEA Joint and (b). IEA Joint (T01)
Figure 6.11 Photomicrograph of Weld Zone of P-GTA Welded AA6061/4 wt.% Fly Ash MMC (a). DEA and (b). IEA Joint (T02)

Figure 6.12 Photomicrograph of Weld Zone of P-GTA Welded AA6061/8 wt.% Fly Ash MMC (a). DEA Joint and (b). IEA Joint (T05)

Figure 6.13 Photomicrograph of Weld Zone of P-GTA Welded AA6061/12wt.% Fly Ash MMC (a). DEA Joint and (b). IEA Joint (T06)
6.3.2.4 SEM Microstructure and XRD Analysis of Weld Zone for DEA and IEA Joint

Figure 6.14-6.18 records the SEM microstructure of weld zone of P-GTA welded AA6061/fly ash MMCs having different amount of fly ash particles. Figure 6.16 is the weld zone microstructure of tungsten inert gas welded matrix alloy AA6061. The fine recrystallized grains along with the second phase particles of the alloy are clearly seen in the microstructure. The average grain size is 8 µm in the welded specimen. The grains are not seen in the weld zone microstructure of P-GTA welded AA6061/Fly ash MMCs. The fragmentation of Fly ash clusters is clearly seen. Each cluster present in the parent composite as shown in Figure. 3.9 provided in chapter 3 is thoroughly broken into fine particles of different sizes. The average particle size in the weld zone is approximately 5-8 µm. P-GTA weld results in the redistribution of inter granular particles into intra granular particles. Figure. 6.19 & 6.20 shows the XRD pattern for both IEA and DEA welded joints. In the IEA welded joint the XRD patterns shows the presence of fly ash particles in the welded zone, but DEA welded joints the XRD pattern shows the presence of intermetallic components such as magnesium spinel and etc.

![SEM Photograph of Weld Zone of P-GTA Welded AA6061 by (a). DEA Joint and (b). IEA Joint](image)

Figure 6.14  SEM Photograph of Weld Zone of P-GTA Welded AA6061 by (a). DEA Joint and (b). IEA Joint
Figure 6.15 SEM Photograph of Weld Zone of P-GTA Welded AA6061/4wt.% Fly Ash MMC (a). DEA Joint and (b) IEA Joint

Figure 6.16 SEM Photograph of Weld Zone of P-GTA Welded AA6061/8 wt.% Fly Ash MMC (a). DEA Joint and (b) IEA Joint

Figure 6.17 SEM Photograph of Weld Zone of P-GTA Welded AA6061/12wt.% Fly Ash MMC (a). DEA Joint and (b) IEA Joint
Figure 6.18  SEM Photograph of HAZ of P-GTA Welded AA6061/12wt.% Fly Ash MMC by DEA Joint

Figure 6.19  XRD patterns of AA6061/Fly ash_{12p} MMC by DEA Joint by P-GTA Weld
6.3.3 Microhardness Survey for DEA and IEA Joint

Figure 6.20 XRD patterns of AA6061/Fly ash_{12p} MMC of IEA Joint by P-GTA Weld

Figure. 6.21-6.24 show the microhardness profiles obtained across a tungsten inert gas welded AA6061/Fly ash MMC having different amounts of Fly ash particles. It shows the transverse microhardness profiles carried out on welds deposited on pre-heating temperatures of 75 and 100°C by DEA and IEA processes. It is evident from these figures that the incorporation of fly ash particles significantly enhances the micro hardness and UTS. AA6061/12wt. % fly ash AMC exhibits higher microhardness compared to unreinforced AA6061 alloy.
Figure 6.21 Hardness Profile across P-GTA Welded AA6061Alloy by (a). DEA Joint and (b). IEA Joint
Figure 6.22 Hardness Profile across P-GTA Welded AA6061/4wt.% Fly ash MMC by (a). DEA Joint and (b). IEA Joint
Figure 6.23 Hardness Profile across P-GTA Welded AA6061/8wt.% Fly ash MMC by (a). DEA Joint and (b). IEA Joint
Figure 6.24  Hardness Profile across P-GTA Welded AA6061/12wt.% Fly ash MMC by (a). DEA Joint and (a). IEA Joint

The comparison between DEA and IEA hardness profiles shows that DEA welds are wider than IEA welds, according to weld beads observed. It is also noticeable that average hardness values, within the weld are lower for DEA
welds in Figure. 6.21-6.24. This fact is in direct relation with the chemical composition of the welds. Whilst DEA welds comprise of an Al-4.5 wt% Si filler alloy, IEA welds are a mixture of Al-4.5 wt% Si and Al-1011 filler alloys. The average DEA hardness values are lower than that of the measured values in IEA welds and the base metal. This difference confirms that the direct application of the electric arc on the base composite leads to a greater thermal affection, being reflected in the distortion suffered on the weld zone and parent metal. The non-symmetrical hardness profiles, in Fig. 6.21-6.24 for DEA welds, support these observations. On the other hand, IEA hardness profiles are rather symmetric. Maximum peak hardness values measured next to the weld metal/base composite interface suggest that a little that a heat affected zone exist.

6.3.4 Fracture Surface Morphology for DEA and IEA Joint

Figures 6.25-6.28 records the SEM micrographs of the fracture surface of P-GTA welded AA6061/Fly ash MMCs having different amounts of Fly ash particles. The fracture surfaces of welded composites are relatively flat compared to the fracture surfaces of parent composites as shown in Figures 3.31, which indicates a loss of ductility after welding. The degree of flatness of fracture surfaces increases as the amount of Fly ash particles is increased. The fracture surface of P-GTA welded AA6061/4wt.% Fly ash MMC shows a network of fine dimples. In general, no noticeable differences were observed between DEA and IEA samples. Fractures consisted of shallow dimples and few equiaxial dimples of different sizes, trans-granular breakage and brittle inter-granular decohesion were observed. Shrinkage and trapped gas porosity are likely to have dictated the fracture path. These features along with the shape of the stress-strain curves, which are not shown, evidence the poor ductility of the welds, which might be ascribed to the small volume of ductile weld metal.
Figure 6.25 SEM Micrograph of Fracture Surface of P-GTA Welded AA6061 Alloy by (a). DEA Joint and (b). IEA Joint
Figure 6.26 SEM Micrograph of Fracture Surface of P-GTA Welded AA6061/4wt.% Fly ash MMC by (a). DEA Joint and (b). IEA Joint
Figure 6.27 SEM Micrograph of Fracture Surface of P-GTA Welded AA6061 /8wt.% Fly ash MMC by (a). DEA Joint and (b). IEA Joint
Figure 6.28 SEM Micrograph of Fracture Surface of P-GTA Welded AA6061/12 wt.% Fly ash MMC by (a). DEA Joint and (b). IEA Joint
6.4 SUMMARY

i. Plates of Al-6061/FA_p metal matrix composites were successfully welded using the P-GTA welding process with the direct and indirect application of the electric arc.

ii. For the DEA joints it was necessary three runs is required to deposit the V groove, but for the IEA joint one run is required to deposit the V groove was sufficient to join the plates.

iii. The IEA led to welds with reduced porosity, non-visible signs of reaction and a larger incorporation and fairly good dispersion of Fly ash particulate into the weld pool.

iv. P-GTA welded AA6061/Fly ash MMC joint exhibits the presence of different zones such as weld zone and heat affected zone.

v. The width of heat affected zone in the parent material was reduced with increased content of fly ash particles.

vi. These characteristics were reflected in a greater tensile strength of 251.7 MPa as compared to 227 MPa for the DEA welds in which little incorporation of the fly ash particles into the weld occurred with the moderate dissolution of the clustered Fly ash particles to form the intermetallic components which reduces the tensile strength of the joints. The larger porosity of the DEA welds was determined in its failure during tensile testing.

vii. Thus the P-GTA-IEA technique appears as a good and alternative for direct electric arc welding of Al–Fly ash composites with a minimal thermal affection.