IMPACT: International Journal of Research in Engineering & Technology (IMPACT: IJRET)
ISSN(E): 2321-8843; ISSN(P): 2347-4599
Special Edition, Mar 2014, 53-64

PROPERTY EVALUATION OF PULSED CURRENT GAS TUNGSTEN ARC WELDED ALUMINIUM ALLOY

KORA T SUNNY[1], JOBY JOSEPH[2], BOBIN CHERIAN JOS[3] & SONI KURIAKOSE[4]

[1,2,3]Assistant Professor, Department of Mechanical Engineering, M A College of Engineering, Kothamangalam, Kerala, India

[4]Associate Professor, Department of Mechanical Engineering, M A College of Engineering, Kothamangalam, Kerala, India

ABSTRACT

In the present context of advancement of technologies and researches, new alloys with exceptional properties are made every day. Due to this, the importance of fabrication or joining of these alloys is also increasing. Latest researches on Aluminium lead to invention of its alloys with remarkable properties such as low density, high strength-to-weight ratio and ability to resist wear and corrosion. Advantages of invention of new aluminium alloys can be utilized efficiently only by using proper fabrication process.

The conventional joining process of aluminium alloy is Gas Tungsten Arc (GTA) welding due to its comparatively easier accessibility and better economy. The detailed literature review conducted revealed that Pulsed Current Gas Tungsten Arc Welding (PCGTAW) has been found beneficial due to its advantages over the Continuous Current Gas Tungsten Arc Welding (CCGTAW) of aluminium alloys. The use of pulsed current parameters has been found to improve the mechanical & microstructural properties of the welds compared to those of continuous current welds due to grain refinement occurring in the fusion zone. Hence, in this investigation an attempt has been made to prepare a defect free weld joint of PCGTA welded AA 5083 using AA 5356 as filler metal and to evaluate the microstructural properties of the weldment by conducting macro imaging, micro structural study & SEM imaging and compare it with the same of the base metal.

KEYWORDS: Aluminium 5083 Alloy, Pulsed Current Gas Tungsten Arc Welding (PCGTAW), Continuous Current Gas Tungsten Arc Welding (CCGTAW), Microstructural Properties

INTRODUCTION TO ALUMINIUM AND ITS ALLOYS

Aluminium is a chemical element in the boron group with symbol Al and atomic number 13. It is silvery white, and is not soluble in water under normal circumstances. Aluminium is the third most abundant element (after oxygen and silicon), and the most abundant metal, in the Earth's crust. It makes up about 8% by weight of the Earth's solid surface. Aluminium metal is so chemically reactive that native specimens are rare and limited to extreme reducing environments. Instead, it is found combined in over 270 different minerals. The main ore of aluminium is bauxite.

Aluminium is remarkable for its low density and ability to resist corrosion due to the phenomenon of passivation. Structural components made from aluminium and its alloys are vital to the aerospace industry and are important in other areas of transportation and structural materials. The most useful compounds of aluminium, at least on a weight basis, are the oxides and sulphates.

Physical Characteristics of Aluminium

Aluminium is a relatively soft, durable, lightweight, ductile and malleable metal with appearance ranging from silvery to dull gray, depending on the surface roughness. It is nonmagnetic and does not easily ignite. A fresh film of aluminium serves as a good reflector (approximately 92%) of visible light and an excellent reflector (as much as 98%) of medium and far infrared radiation. The yield strength of pure aluminium is 7–11 MPa, while aluminium alloys have yield strengths ranging from 200 MPa to 600 MPa. Aluminium has about one-third the density and stiffness of steel. It is easily machined, cast, drawn and extruded. Aluminium atoms are arranged in a face-centered cubic (FCC) structure. Aluminium has stacking-fault energy of approximately 200 MJ/m^2. Aluminium is a good thermal and electrical conductor, having 59% the conductivity of copper, both thermal and electrical, while having only 30% of copper's density.

Chemical Characteristics of Aluminium

Corrosion resistance can be excellent due to a thin surface layer of aluminium oxide that forms when the metal is exposed to air, effectively preventing further oxidation. The strongest aluminium alloys are less corrosion resistant due to galvanic reactions with alloyed copper. This corrosion resistance is also often greatly reduced by aqueous salts, particularly in the presence of dissimilar metals.

Owing to its resistance to corrosion, aluminium is one of the few metals that retain silvery reflectance in finely powdered form, making it an important component of silver-colored paints. Aluminium mirror finish has the highest reflectance of any metal in the 200–400 nm (UV) and the 3,000–10,000 nm (far IR) regions; in the 400–700 nm visible range it is slightly outperformed by tin and silver and in the 700–3000 (near IR) by silver, gold, and copper

Aluminium Alloys

Aluminium alloys are alloys in which aluminium (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminium alloys yield cost effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is Al-Si, where the high levels of silicon (4.0% to 13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required.

Alloys composed mostly of aluminium have been very important in aerospace manufacturing since the introduction of metal skinned aircraft. Aluminium-magnesium alloys are both lighter than other aluminium alloys and much less flammable than alloys that contain a very high percentage of magnesium. Aluminium alloy surfaces will keep their apparent shine in a dry environment due to the formation of a clear, protective layer of aluminium oxide. In a wet environment, galvanic corrosion can occur when an aluminium alloy is placed in electrical contact with other metals with more negative corrosion potentials than aluminium.

Aluminium 5083 Alloy

Aluminium 5083 is a high strength non-heat treatable alloy in commercial use. The major additive in the alloy is Magnesium. It has good formability and weldability and retains excellent tensile strength in the weld zone. It has excellent resistance to corrosion and high strength-to-weight ratio. Reduction of mass is a prime concern for many industries involved in transportation especially the automobile industry, which has become significant because of fuel saving, reduction of emission, and recyclability. Hence the focus on lightweight materials like aluminium and magnesium has become predominant.

Chemical Composition of Aluminium 5083 Alloy

The chemical composition of Aluminium 5083 alloy is given in Table 1

Table 1: Chemical Composition of Aluminium 5083 Alloy

Element	% Present
Si	0.4
Fe	0.4
Cu	0.1
Mn	0.4-1.0
Mg	4.0-4.9
Zn	0.25
Ti	0.15
Cr	0.05-0.25
Al	Balance

Mechanical Properties of Aluminium 5083 Alloy

The Mechanical properties of Aluminium 5083 alloy is given in Table 2

Table 2: Mechanical Properties of Aluminium 5083 Alloy

Property	Value
Tensile Strength (MPa)	330
Shear Strength (MPa)	185
Elongation (%)	17
Hardness Vickers (HV)	95

Applications of Aluminium 5083 Alloy

Due to high strength, good welding properties, increased wear and corrosion resistance and high strength-to-weight ratio, Aluminium 5083 is widely used in

- Ship building
- Rail cars
- Vehicle bodies
- Tip truck bodies
- Pressure vessels

LITERATURE REVIEW

Literature review briefly describes about literatures on welding of aluminium alloys. Literature survey was carried out for understanding methods for refining weld fusion zones and influences of welding parameters on mechanical & microstructural properties. Detailed study was conducted to find out the most suitable method for welding aluminium alloys and finalize the process parameters.

Methods for Improving Mechanical & Microstructural Properties of Weldment & for Refining Weld Fusion Zones

- Dongxia Yang *et al*.[1] in 2010 Studied on microstructure and mechanical properties of Al–Mg–Mn–Er alloy joints welded by TIG and laser beam. Al-4.7Mg-0.7Mn-0.3Er alloy plates were welded by laser beam welding (LBW) and tungsten inert gas (TIG). Mechanical properties and microstructures of both welded joints were analyzed. The results showed that the tensile strength of TIG joint was 315 MPa, which was approximately 10% higher than that of LBW welded joint. This was attributed to the fine grains, dispersed primary Al_3Er phase and low Mg evaporation in TIG weld. Equiaxed grains with average size of 30 μm were obtained in the fusion zone, which were much smaller than that of 90 μm in the fusion zone of LBW joint. The result clearly indicates that TIG welding improves mechanical & microstructural properties of Aluminium alloy weldment.
- Sindo Kou,[2] 2003 "Welding Metallurgy", A John Willey & Sons publication explains several methods of refining weld fusion zones which have been tried such as
  - Surface nucleation induced by gas impingement
  - Micro cooler additions
  - Introduction of physical disturbance technique such as torch vibration
  - Inoculation with heterogeneous nucleants
  - Pulsed Current Welding

The result reveals that, new technique namely pulsed current welding have gained wide popularity due to its striking promise and the relative ease of application, can be effectively used for a refined weld fusion zone. This technique can be applied to actual industrial situations with only minor modifications to the existing welding equipment.

Gas Tungsten Arc Welding (GTAW) on Aluminium

- Dongxia Yang *et al.*[3] in 2011 studied the microstructural and mechanical property characterization of Er modified Al-Mg-Mn alloy TIG welds. Al-Mg-Mn-Zr-Er alloy samples have been welded using TIG welding. Tensile test and hardness test was conducted. Optical microscopy (OM) was conducted to characterize microstructures. Test results revealed the relationship between mechanical properties and microstructures. Result indicates that the tensile strength of joints is 72% of that of base metal. The fusion zone is mainly made up of dendrite grains. A characteristic equiaxed zone is obtained at the fusion boundary between the base metal and fusion zone. So from the tests, it is clear that TIG welding is the most suitable process for joining aluminium alloys.
- J M Kuk *et al.* [4]in 2004 studied the effects of temperature and shielding gas mixture on fatigue life of 5083 aluminium alloy. The study was conducted to evaluate fatigue life of 5083 alloy according to the shielding gas mixing ratio and temperature change. The gas tungsten arc welding of the base metal was carried out with different ratios of shielding gas wiz Ar100% + He0%, Ar67% + He33%, Ar50% + He50% and Ar33% + He67%. The results indicate that the fusion line and HAZ were not influenced greatly with change in mixing ratios of shielding gas.

Pulsed Current Gas Tungsten Arc Welding (PCGTAW) on Aluminium

- T Senthil Kumar *et al.*[5] in 2007 studied influences of pulsed current TIG welding parameters on the tensile properties of AA 6061 aluminium alloy. Pulsed current TIG welding process utilizes arc energy more efficiently by reducing the wastage of heat energy by conduction into the adjacent parent metal. In PCTIG welding heat required to melt the base metal is supplied only during peak current pulses for brief intervals of time, allows the heat to dissipate leading to a narrower HAZ. The results reveal that the refinement of microstructure is due to pulsed current welding is more compared to conventional continuous current welding. It is also observed that the pulsed current welding also improves mechanical properties like tensile strength & hardness.
- N Karunakaran and V Balasubramanian[6] in 2010 studied the effect of pulsed current on temperature distribution, weld bead profiles and characteristics of gas tungsten arc welded aluminium alloy joints. The result reveals that use of pulsed current technique is found to improve the tensile properties of the weld compared with continuous current welding due to grain refinement occurring in fusion zone.
- Sanjeevkumar[7] in 2010 conducted an experimental investigation on pulsed TIG welding of Aluminium plate. The study compared the conventional continuous current welding and pulsed current welding. Results indicate that maximum reported tensile strength of PCTIG welding is 92 MPa while that of CCTIG welding is only 32 MPa. Results also reveal that maximum reported shear strength of PCTIG welding is 85 MPa while that of CCTIG welding is 80 MPa. So it is clear from the study that PCTIG welding is advantageous compared to CCTIG welding
- Madusudan Reddy G *et al.*[8] in 1998 carried out optimization of pulse frequency in pulsed current gas tungsten inert gas welding of Al-Li alloy sheets.
- S Babu *et al.*[9] in 2007 optimized pulsed current gas tungsten arc welding parameters of AA6061 aluminium alloy using Hooke and Jeeves algorithm. Results indicate that PCGTA welding yield finer fusion zone grains, which leads to higher strength of AA 6061 aluminium alloy joints compared to CCGTA welding. It was also revealed that the peak current (Ip) and base current (Ib) are the most significant parameters, which decide the fusion zone grain size and the tensile strength of the aluminium alloy joints.
- A Kumar and S Sundarrajan[10] in 2009 studied influences of pulsed TIG welding process parameters on mechanical properties of AA5456 Al alloy weldment. The important process parameters were found as shielding gas flow rate, electrode diameter, electrode material and pulse ratio. The study also revealed the most important process parameters which are having greater influence are peak current (Ip) and base current (Ib), pulse frequency and pulse on time.
- Ravisankar V and Balasubramanian V[11] in 2003 studied the influences of pulsed current welding parameters on tensile and impact behavior of Al-Mg-Si alloy weldments and found the important process parameters.

FINDINGS FROM THE REVIEW

- The literature review reveals that research have been carried out in the field of welding of aluminium alloys. However very few studies have been carried out in pulsed current gas tungsten arc welding on aluminium.

- Moreover, no systematic study has been reported so far to analyze the mechanical & microstructural properties of AA 5083 weldment with AA 5356 as filler metal.
- AA 5083 was selected as the base metal as it has gathered wide acceptance in the fabrication of light weight structures requiring a high strength-to-weight ratio and excellent weldability, such as transportable bridge girders, military vehicles, road tankers and ship building.
- The GTA welding was found more beneficial compared to other welding process as the mechanical properties found to increase. Further studies revealed that the pulsed current gas tungsten arc welding (PCGTAW) produces less HAZ and improved mechanical & micro structural properties compared to conventional continuous current gas tungsten arc welding (CCGTAW) process.
- AA 5356 was selected as the filler material due to its similarities in properties with AA 5083 and ease of availability.
- Process parameters of PCGTAW

  The following are the process parameters of PCGTAW

  - Peak current 220-290 Amp
  - Base current- 50 % of peak current
  - Voltage- 24 V
  - Filler diameter- 4.8 mm
  - Tungsten electrode diameter- 4.8 mm
  - Inert gas flow rate 14 Lit/min.
  - Arc travel speed 4 mm/sec.
  - Gas cup inside diameter- 12.7 mm
  - Pulse on time- 50% of total time
  - Pulse frequency 4 Hz
  - Pulse width 60 µs

DISCUSSIONS

Pulsed Current Gas Tungsten Arc Welding (PCGTAW) Process

Pulsed current gas tungsten arc welding, developed in 1950's, is a variation of gas tungsten arc welding which involves cycling of the welding current from a high level to a low level at a selected regular frequency. The high level of peak current (Ip) is generally selected to give adequate penetration and bead contour, while the low level of background current (Ib) is set at a level sufficient to maintain a stable arc. This permits arc energy to be used efficiently to fuse a spot of controlled dimensions in a short time producing the weld as a series of over lapping nuggets and limits the wastage of heat by conduction into the adjacent parent material as in normal constant current welding, the fact that heat energy required to melt the base material is supplied only during peak current pulses for brief intervals of time allows the heat affected zone (HAZ). The technique has secured a niche for itself in specific applications such as in welding of root passes of tubes and in welding thin sheets, where precise control over penetration and heat input are required to avoid burn through.

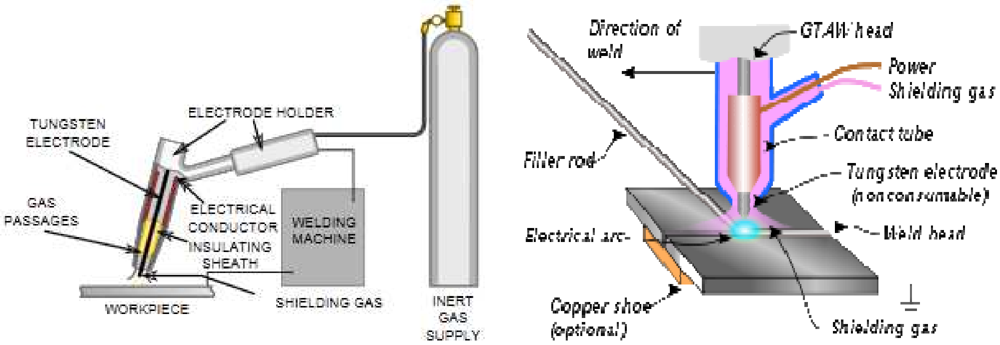


Figure 1: Gas Tungsten Arc Welding (GTAW) Process

PCGTAW on Aluminium 5083 Alloy

For finalizing the process parameters trial and error method is adopted. For evaluating properties of the weldment various tests are to be conducted.

Tests to be Conducted

For evaluating micro structural properties SEM imaging, macro imaging & micro structural study is to be performed.

Equipments to be Used

Equipments to be used consist of a Pulsed current gas tungsten arc welding machine for performing the welding process. For evaluating microstructural properties an optical microscope & scanning electron microscope (SEM) is required.

Scheme of Investigation

The work was conducted in the following sequence

- Selection of base metal and filler material
- Weld joint preparation
- Identify the pulsed current welding process parameters
- Find the range of pulsed current welding process parameters
- Perform the welding process
- Conduct various tests for evaluating microstructural properties of the weldment & base metal
- Record the results
- Compare and analyze the microstructural properties of the weldment with that of base metal.

Selection of Base Material & Filler Material

The base metal employed is AA 5083 alloy. Filler material used is AA 5356 alloy. The selection of filler material is based on the mechanical properties, resistance offered during welding process and similarity in properties to that of parent metal. The chemical composition of the filler metal AA 5356 is shown in Table 3

Chemical Composition of Aluminium 5356 Alloy

Chemical composition of aluminium 5356 alloy is given in Table 3

Table 3: Chemical Composition of Aluminium 5356 Alloy

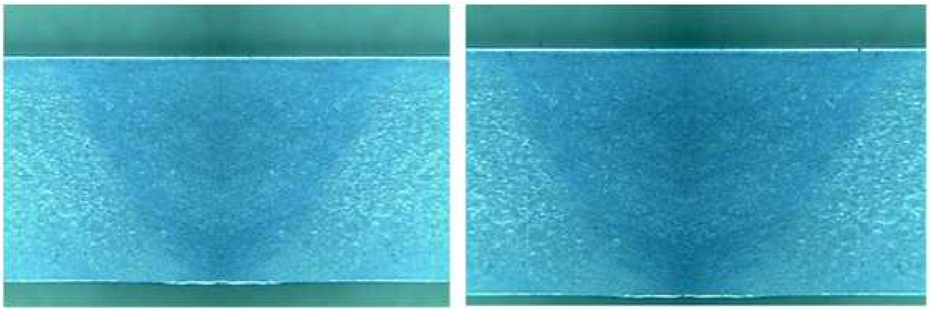
Element	%Present
Si	0.25
Fe	0.40
Cu	0.10
Mn	0.05-0.2
Mg	4.5-5.5
Zn	0.10
Ti	0.06-0.2
Cr	0.05-0.20
Others	0.15
Al	Balance

RESULTS & DISCUSSIONS

Macro Structure

After welding, samples were cut into suitable size along cross-sectional direction for metallographic examination. The samples were grounded and polished according to standard process starting with 120 grit silicon carbide belt grinder followed by 1, 2, 3, 4 grade emery papers.

And finally the samples were cloth polished on disk polishing machine with alumina and diamond paste. Then the samples were etched in Keller's Reagent (2.5 ml HNO_3+ 1.5 ml HCL + 1 ml HF + 95 ml Distilled Water) for 15 seconds before they were examined by optical microscopy at 10X and 15X zoom levels.



(a) (b)

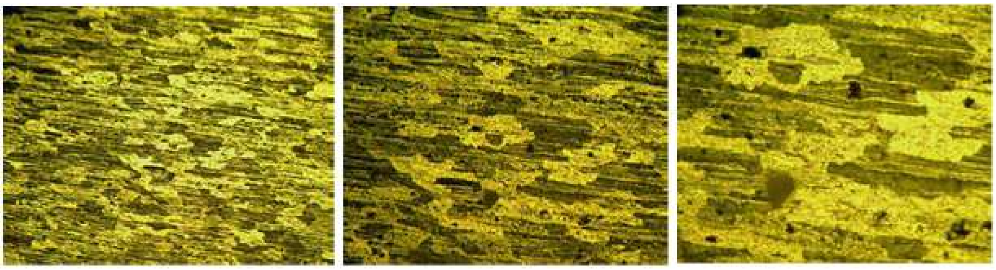
Figure 2: Macrostructure (a) 10X Zoom, (b) 15X Zoom

Macro structural study revealed that

- Proper weld penetration has occurred,
- Weldment is free from pores,

- Proper bead contour is obtained,
- Less HAZ,
- Weldment is free from cracks & defects.

Micro Structural Study

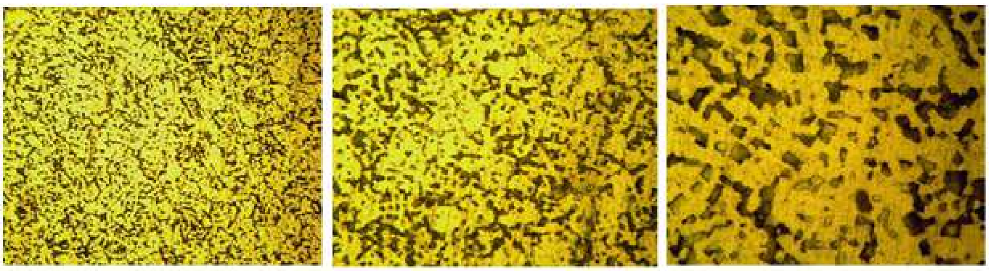


(a) (b) (c)

Figure 3: Microstructure of Base Metal (a) 100X Zoom, (b) 200X Zoom, (c) 400X Zoom

(a) (b) (c)

Figure 4: Microstructure of HAZ (a) 100X Zoom, (b) 200X Zoom, (c) 400X Zoom



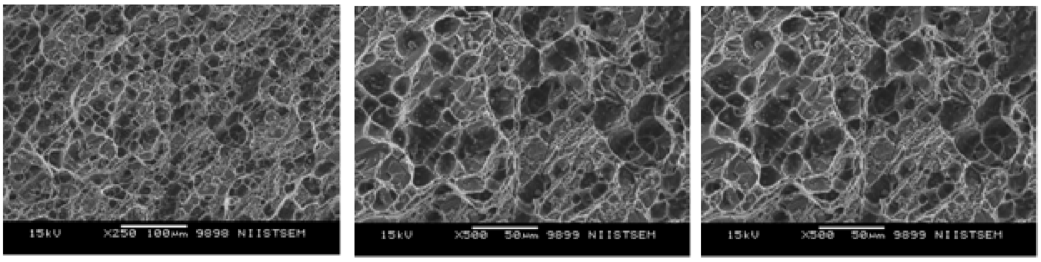
(a) (b) (c)

Figure 5: Microstructure of Weldment (a) 100X Zoom, (b) 200X Zoom, (c) 400X Zoom

A detailed optical microscope study was conducted to reveal the micro structural details of base metal, HAZ and the weldment. Comparing the grain sizes, the grains of base metal is coarse and elongated (Figure 3) while the weldment is having fine grains (Figure 5). In base metal, elongated grains are along the rolled direction. This is due to strain hardening during rolling. The HAZ is having intermediate grain size compared to the same of base metal and weldment (Figure 4).

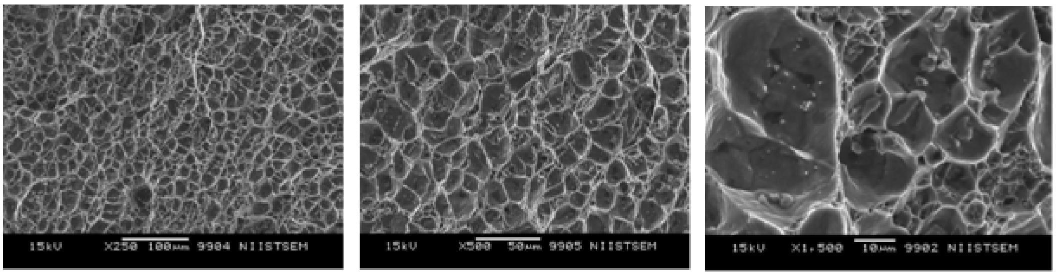
On correlating the mechanical and microstructural properties, the tensile sample fractured at the HAZ which showed maximum hardness value (Hv) and moderate grain size. This may be due to the formation of precipitates at the HAZ during welding. Traces of Magnesium are uniformly distributed throughout the weldment. Misorientation of grains between weldment and base metal may be one of the cause for failure of weld sample. The details about precipitate formation and reason for failure may be revealed only by conducting advanced tests like SEM with EDS and XRD. The weldment is having fine grains. As fineness of grains increases, the mechanical as well as micro structural properties improve. So presence of fine grains of the weldment indicates the perfect weld joint preparation, adoption of proper welding technique and usage of suitable filler material.

Scanning Electron Microscope (SEM) Imaging



(a) (b) (c)

Figure 6: SEM Images of Fractured Face of Weld Sample (a) 250X Zoom, (b) 500X Zoom, (c) 1500X Zoom



(a) (b) (c)

Figure 7: SEM Images of Fractured Face of Base Metal (a) 250X Zoom, (b) 500X Zoom, (c) 1500X Zoom

SEM images of fractured faces of tensile samples details about the grain structure and reasons for fracture. On comparison, the base metal shows regular shaped grains compared to that of weld sample. (Figure 6(a) & 7(a)). The presence of mixed or distorted grains on weld sample may be due to the heat treatment occurred during the welding. Figure 6(b) & 7(b) clearly shows the differences in grain structure and boundaries between weld sample and base metal. The base metal is having clear grain boundaries while weld sample shows irregular boundaries.

On analyzing 1500X zoom images, (Figure 6(c) & 7(c)) the reasons for fracture of samples is revealed. The weld sample failed due to shearing of grains (Figure 6(c)). This may be due to the formation of precipitates, which increased the hardness of HAZ. Due to this phenomenon weld sample showed somewhat brittle fracture. Upon examining the SEM image of base metal, (Figure 7(c)) it become evident that failure occurred due to complete pull out of grains. Pulling out of grains occurs when the elastic limit of material is reached. Due to this, the base metal showed somewhat elastic behaviour during tensile testing compared to the weld sample.

CONCLUSIONS & FUTURE SCOPE

The effect of pulsed current gas tungsten arc welding (PCGTAW) on microstructural properties of AA 5083 aluminium alloy weldment welded with AA 5356 as filler material has been studied and the following conclusions are made.

Macro imaging of the weld sample revealed the proper weld penetration, less HAZ and quality of welding. Micro structural study indicates that the weldment has got fine grains while the base metal has got coarse and elongated grains. HAZ has got intermediate grain size. Fine grains of the weldment indicate perfect weld joint preparation, adoption of proper welding technique and usage of suitable filler material.

SEM images of the tensile specimens revealed the reasons for brittle failure of the weld sample. The base metal is having fine and arranged grain structure with clear grain boundaries while weld sample is having mixed grains. It may be due to the post weld heat treatment. On analyzing the SEM images it is clear that base metal failed due to pull out of grains while weld sample failed at HAZ due to shearing of grains. Due to this phenomenon weld sample showed brittle fracture compared to base metal.

As a future scope, application of optical micrograph test will give better idea about the surface topography of the weld zone and heat affected zone. Optimization of process parameters can be utilized to predict the effect of pulsed current welding parameters on tensile properties of PCGTA welded aluminium alloy joints. Optimization of process parameters can be also employed for improving the mechanical and micro structural properties of the weldment. A double V butt weld joint can be used to improve the penetration during welding with thick plates. Advanced SEM imaging techniques such as SEM with EDS and XRD should be adopted to reveal the exact reason for the failure of tensile sample.

REFERENCES

1. Dongxia Yang, Xiaoyan Li, Dingyong He, Zuoren Nie, Hui Huang, (2011) "Microstructural & Mechanical property characterization of Al-Mg-Mn alloy TIG welds" *International Journal of Advance Manufacturing Technology*, vol. 14, pp. 549-554.
2. Sindo Kou (2010), Text book "Welding Metallurgy", *John Willey & Sons publication*. 3rd Edition, Chapter V, pp. 207-226.
3. Dongxia Yang, Xiaoyan Li, Jiayan Ning, (2009) "Mechanical property evaluation of Al-Mg-Mn-Zr-Er alloy TIG welds" *International Journal of Material Joining*, vol. 33, pp. 431-439.
4. J M Kuk, K C Jang, D G Lee, I S Kimb, (2004) "The effects of temperature & shielding gas mixing ratio on fatigue life of AA 5083*" Journal of Material Process Technology"*, vol. 122, No. 1, pp. 30-38.
5. T Senthil Kumar, V Balasubramanian, M Y Sanavullah, (2007), "Influences of Pulsed Current TIG Welding parameters on the tensile properties of AA 6061 aluminium alloy*", International Journal of welding technology*; PP: 1182-1199.
6. N Karunakaran, V Balasubramanian, (2010), "Effect of Pulsed Current on temperature distribution, weld bead profiles and characteristics of Gas Tungsten Arc Welded aluminium alloy joints.*" International Journal of Material Science and Technology*. vol. 97, No. 14, pp. 88-97.
7. Sanjeevkumar R, (2009), "Evaluation of Mechanical Properties of Pulsed Current TIG Welded Aluminium Plates" *Journal of Metal Joining*". Volume 17, No. 117, pp. 818-829.
8. Madusudan Reddy, R C Sharma, (2008), "Optimization of pulse frequency in pulsed current gas tungsten inert gas welding of Al-Li alloy sheets" *International Journal of Manufacturing Technology*, vol. 11, No. 172, pp. 64-73.

9. S Babu, T Senthil Kumar, V Balasubramanian, (2009), "Optimization pulsed current gas tungsten arc welding parameters of AA 6061" *International Journal on Metals & Materials*, Volume 29, issue 4, pp 28-37.

10. A Kumar, S Sundarrajan, (2009) " Optimization of pulsed TIG welding process parameters on mechanical properties of AA 5456 aluminium alloy weldments" *Journal on Materials and Design*, vol. 30, No. 4, pp. 1288-1297.

11. Ravisankar V, V Balasubramanian, (2003), "Influences of Pulsed Current welding parameters on tensile & impact behavior on Al-Mg-Si alloy weldments" *Indian society of welding technology*, vol. 29, Part B 30, pp. 831-839.

12. S Katsas, J Nikolaou, G Papadimitriou, (2004) "A microstructural changes of welding in 5xxx aluminium alloys and their effect on the mechanical properties" *International Journal of Material Joining*, vol. 332, No. 14, pp. 313-327.

13. Kumar A, Nageshwar Rao GVS, Sundarrajan S (2007) "Modeling and simulation of pulsed TIG welding process of aluminium alloy" *International Journal on Materials and Manufacturing Process*, vol. 21, No. 8, pp. 789-793.

14. *ASM Metals Handbook* - *Volume 06* - Welding, Brazing, and Soldering.

15. Davis J R, "Tensile Testing", *ASM international* [2004], pp. 1-136.

16. "*Annual Book of ASTM Standards Designation: E8/E8M – 11*" Standard Test Methods for Tension Testing of Metallic Materials "American society for testing of materials".

17. "*Annual Book of ASTM Standards Designation: B557*" Test Methods for Tension Testing Wrought and Cast Aluminum and Magnesium Alloy Products.