Tensile and Micro structural Characteristics of AC square wave welded and DCSP welded AA2219 Aluminum Alloys

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Abstract— **AA2219 aluminum alloy is a high strength material with less weight and low thermal characteristics. Considering these characteristics, AA2219 aluminium alloy is mainly used for the construction of cryo stage tankages. For the effective welding of AA2219 aluminium alloy TIG welding is used commonly. AC square wave welding and DCSP (Direct current straight polarity) TIG welding are two forms of TIG welding manly used for the joining of Aluminium Alloys. In square wave AC welding the job and electrode are getting connected alternately with positive and negative leads of welding transformer. Hence it offers less heat input in one cycle and in another cycle good cleaning of refractive aluminium oxide cleaning. Hence it give two advantages. In DCSP Welding, the job (weld plate) is connected to positive lead of weld transformer and electrode is connected to negative terminal. The current is steady and the electron flow is from electrode to job. As more electrons are hitting the job, more heat will be produced at job rather than at electrode. This results in melting of job with less heat input and better weld strength. But there arise the problem of refractive oxide layer. However, it can be eliminated by scrapping the weld joint well before welding. Present study investigate the suitability and effectiveness of both welding process for the joining of AA2219 alloy. Tensile and Microstructure characteristics of each welded joint has also been compared. It is found that DCSP TIG welded joints are comparatively better in both aspects.**

Keywords—AA2219; Direct current straight polarity TIG welding AC SQUARE wave TIG welding, Tensile characteristics

I. INTRODUCTION

AA2219 is an Aluminium copper alloy developed by Aluminium Company of America (ALCOA) in 1954 for applications at temperatures up to 315 ^{0}C. This heat treatable alloy also possesses good cryogenic properties. For this reason this alloy is nick named as “wonder alloy”.

AA2219 is basically Al-Cu-Mn turnery alloy with minor additions of Ti, V and Zr. It is the most widely and successfully used cryo aluminium alloy and flown in various launch vehicles. The excellent strength and toughness at cryo temperatures coupled with excellent weldability make this alloy an obvious choice for fabrication of cryo tanks. AA2219 can withstand weld shrinkage strains up to 12% compared to normally encountered weld strains of the order of 4%. This implies that the probability of occurrence of cracks in thin material during welding is minimal compared to other Al alloys. Table 1 shows the chemical composition of AA2219. Different mechanical characteristics of AA2219 alloy are given in Table 2

As AA2219 Alloy has huge applications in Aerospace Industry a number of research papers are available based on its various advantages. R.K Gupta and SVS Narayana Murty [1] have conducted analysis of crack in AA2219 TIG welded joints. They found that even though this alloy is not prone to liquation/ solidification cracking it can crack under certain conditions acting together like improper fixturing, large heat input, large grain size of the materials etc. S.R.Koteswara Rao, G.Madhusudhan Reddy and K Prasad Rao [2] have conducted studies to understand the effect on thermo mechanical treatments on mechanical properties of AA2219 GTA welds. They found that compressive deformation of fusion zone in AA2219 GTA weldments caused for better hardness. S. Malarvizhi and V Balasubramanian[3] conducted studies to understand the effect of post weld ageing treatments on the fatigue behaviour of Friction stir welded (FSW) AA2219 Aluminum Alloys. Li.J and Liu.H [4] have conducted studies to find the improvement in Mechanical and Microstructure properties of FSW joint from AA2219 , by the reverse dual rotation of FSW tool. Jin-kun DING, Dong-po WANG, Ying WANG ,HuiDU [5] also found that the mechanical characteristics of TIG welded joints from AA 2219 have improved with post weld heat treatments. Ch.V.A. Narasayya, P. Rambabu, M.K.Mohan, Rahul Mitra and Eswara Prasad [6] have conducted studies on tensile deformation and Fracture behavior of AA2219 in different ageing conditions. They found that no much variations has been observed in the microstructure under different ageing conditions. G. Venketasubramaniyan, A Shiek Mideen and

Abhay K Jha [7] have conducted microstructural charracterisation and corrosion behavior of top surface of TIG welded AA 2219 –T87 Aluminium Alloy. For this work they have used ER2319 alloy as the filler wire. They have used SEM, potentimetric polarization and electrochemical impedance spectroscopy etc for the study.

Table-1 Chemical Composition of AA2219

Element	Min.	Max.	Element	Min.	Max.
Cu	5.8	6.8	Fe		0.3
Mn	0.2	0.4	Si		0.2
Zr	0.1	0.25	Zn		0.1
V	0.05	0.15	Mg		0.1
Ti	0.02	0.1	Other impurities		0.15
			Al		Remainder

Table.2 Mechanical Charrecterestics of AA2219

Sl	Properties	Value
1	Density	2.6-2.8 x 100Kg/m^3
2	Poissons ratio	0.33
3	Elastic Modulus	70-80GPa
4	Ultimate Tensile Strength	440 MPa
5	0.2% Yield Strength	350 MPa
6	Percentage Elongation	6
7	Fatigue Strength	105 MPa
8	Thermal Conductivity	170 W/m-K

Gas Tungsten Arc Welding (GTAW)[12,14], also known as Tungsten Inert Gas (TIG) welding is a process that produces an electric arc maintained between a non-consumable tungsten electrode and the part to be welded. The heat-affected zone, the molten metal and the tungsten electrode are all shielded from atmospheric contamination by a blanket of inert gas fed through the GTAW torch. Fig.1 show a typical GTAW process.In addition to aluminium alloys GTAW can also weld dissimilar metals to one another such as copper to brass and stainless to mild steel.

A.Filler wire for welding AA2219

The American welding society (AWS) recommended filler wire is ER2319 (E-for electrode and R-for rod)[14]. The chemical composition of ER2319 is same as that of AA2219 except higher titanium content (0.1 - 0.2%). Higher titanium content ensures finer and uniform grain size in solidified weldment. The perfect chemical matching of filler and parent metal ensures minimum differential corrosion potential there by high resistance for the corrosion of the weldment.

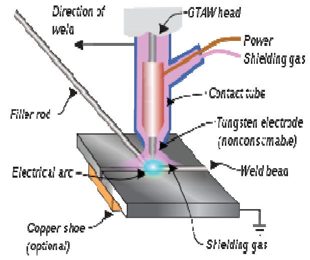

Fig.1 Gas Tungsten Arc welding Process [12]

B.GTAW Power source

Two type of power source can be used for TIGW process depending on the type of material and its thickness to be weld. If the material is aluminum, DC power source is normally used. For all other metals DC or AC power source can be used.

A direct-current welding circuit may be either straight or reverse polarity. When the machine is set on straight polarity, the electrons flow is from the electrode to the plate, concentrating most of the heat on the work. With reverse polarity, the flow of electrons is from the plate to the electrode, thus causing a greater concentration of heat at the electrode. Because of this intense heat, the electrode tends to melt off; therefore, direct-current reverse polarity (DCRP) requires a larger diameter electrode than direct-current straight polarity (DCSP).

The effects of polarity on the weld are shown in the Fig 2. It can be observed that DCSP [8] produces a narrow, deep weld. DCRP forms a wide and shallow weld and is rarely used in the GTAW process. The exception to this is when it is used to weld sections of aluminum or magnesium.

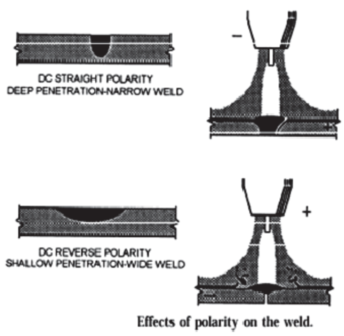

Fig. 2 Effect of polarity on TIGW [10]

AC welding is actually a combination of DCSP and DCRP; however, the electrical characteristics of the oxides on the metal often prevent the current from flowing smoothly in the reverse polarity half of the cycle. This partial or complete stoppage of current flow *(rectification)* causes the arc to be unstable and some-times go out. Hence AC welding machines were developed with a high-frequency current flow unit to prevent this rectification.

C. DCSP Tig Welding For AA 2219

In DCSP welding, the job is connected to positive lead of weld transformer and electrode is connected to negative terminal. The current is steady and the electron flow is from electrode to job. As more electrons are hitting the job, more heat will be produced at job rather than at electrode. It enables the melting of job with less heat input and better weld strength. The problem of the developed refractive oxide layer can be eliminated by scrapping the weld joint well before welding.

D.AC square TIG welding for AA2219

In AC square wave welding the job and electrode are getting connected alternately with positive and negative leads of welding transformer. Hence it offers less heat input in one cycle and in another cycle good cleaning of refractive aluminium oxide cleaning. It gives both the advantages. Square wave form can be attained by adjusting the welding frequency .Fig 3 shows a AC square wave form

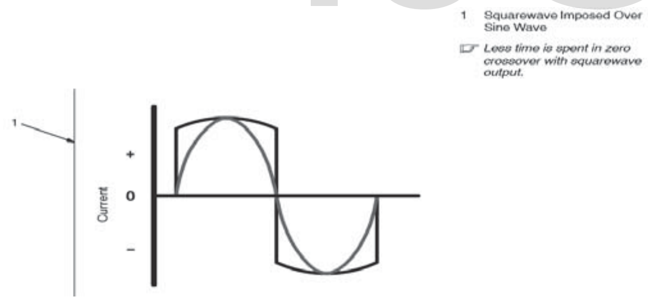

Fig.3 Ac Square Weld Wave Form [10]

II. EXPERIMENTAL INVESTIGATIONS

The different stages in the experimental investigations included planning the set ups of each welding process and preparation of material Al2219, Formation of welded joints, weld inspection and investigation on mechanical and metallurgical characteristics.

Different weld trials and weld characterization were made to arrive optimized weld parameters. Thus three weld coupons per process based on optimized weld parameters have been produced.

*A. **Execution of DCSP TIG welding process***

DCSP TIG welding process has been carried out using the TIG welding unit and the fixture fabricated , as shown in Fig.4. Table.3 shows DCSP welding process parameters

Table-3 DCSP welding process details

Name of welding Machine	Miller make
Material used and size	AA2219,300 X 300 mm
Name of filler material	ER2319
Current and Voltage	220Amp, 20V
Travel speed	100 mm/min
Shielding gas	Helium
Back up bar	Stainless steel

Fig.4 TIG welding unit and Welding Fixture used for the study

Welding fixture consists of back up plate made up of SS304 material and clamping plates. The base plate is having groove of 4mm width and 2mm depth to support the penetration part of weld

B. Execution of AC square wave TIG welding

The welding power source used is the Miller which produces the AC square wave through the converters. In this case, Voltage was selected in the range of 17 to 19 V . Shielding gas is Argon and Helium (80:20). Fig 5 shows the the dimensions of the weld specimen. Fig 6 indicates the welded joints obtained from AC square wave welding, similar to DCSP welded joints.

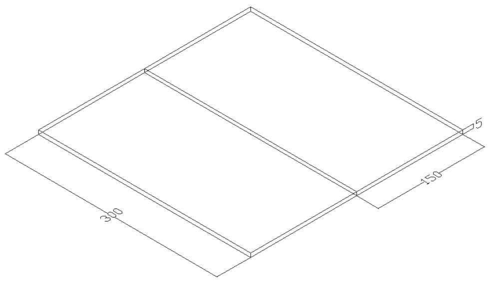

Fig 5. Dimensions of weld specimen

Fig.6 Welded joints by ac Square wave welding

C.Tensile characterization tests

Three tensile test specimens from each weld coupon have been prepared as per **ASTM E8 standard as** shown in Fig 7. The specimens were cut and prepared using wire cut EDM machine and milling machine.

D. Microstructure examination:

The micro structure specimen, 20× 10× 5 mm, have been cut transversely to the welding direction. They then cold mounted and wet grounded using finer grades of SiC impregnated emery papers. Polishing has been done using 6, 3 and finally 1 μm diamond paste as the lubricant on polishing cloths. Macroscopic examination have been carried out by etching the specimen using a caustic etch (i.e. 10g NaOH in 90 ml H2O with 50% HNO3 solution and a final rinse in water.) Microscopic examination was done by using Keller's reagent. The microstructure has been observed under Olympus optical microscope.

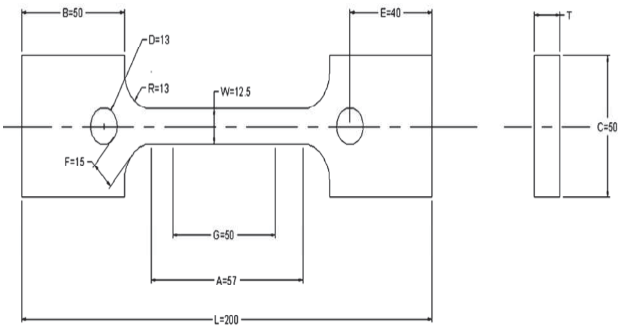

Fig 7. Tensile test specimen as per ASTME8 standard [10]

RESULTS AND SISCUSSION

The results from tensile and Microstructure characteristic of AC Square wave TIG welded and DCSP TIG welded joints are discussed in the following sessions.

A. Results from Tensile tests

The results from tensile characteristic studies for AC Square wave TIG welded joints are presented in Table 4 and 5. For DCSP welded joints it is presented in Table 6 and 7.

Table.4 Tensile Properties –AC Square wave TIG welding

AC square TIG welded joint	Area	Ultimate Load	Gauge Length	Ultimate Tensile Strength	0.2% Yield strength	% Elongation
	mm^2	kN	mm	MPa	MPa	
Weld Coupon No:1	51.5	12.9	50	251	148	5.05
	50.9	12.6	50	248	153	4.95
	51.3	12.7	50	248	156	5
Weld Coupon No:2	51.6	13	50	253	153	5.4
	51.9	12.8	50	247	158	5.3
	52.1	12.8	50	246	153	5.15
Weld Coupon No:3	52.6	12.6	50	239	138	4.9
	52.7	12.5	50	237	146	4.95
	52.6	12.5	50	237	142	5.2

Table-5 Average Tensile test results for AC SQ wave TIG welded coupons:

AC Square wave TIG weld	UTS	Yield Strength	% Elongation
	MPa	MPa	
	245	150	5.07

Table.6 Achieved Mechanical Properties –DCSP TIG welding

DCSP TIG welded joint	Area	Ultimate Load	Gauge Length	Tensile Strength	0.2% Yield strength	% Elongation
	mm^2	kN	mm	Mpa	MPa	
Weld Coupon No:1	49.6	12.9	50	260	156	5.08
	51.1	12.8	50	250	158	5.12
	50.3	12.8	50	254	156	5
Weld Coupon No:2	44.9	12	50	258	158	6.02
	47.8	11.9	50	249	163	5.68
	47.5	12.1	50	255	157	5.7
Weld Coupon No:3	46.4	12.2	50	262	144	5.68
	46.4	12.2	50	263	142	5.54
	46.6	12	50	257	143	5.44

Table. 7 Average Tensile test results for DCSP TIG welded coupons

DCSP TIG Weld	UTS	Yield Strength	% Elongation
	MPa	MPa	
	257	153	5.47

UTS for AC Square wave welded joint obtained 55.68% and DCSP welded joints obtained 58.5 % compared to the parent metal. Similar result can also be observed in the case of 0.2% YS also. Percentage elongation was also found good in the case of DCSP welded joints. Fig-11 to 13 indicates the comparison of UTS,0.2% yield strength and Percentage elongation for the welded joints with the parent metal.

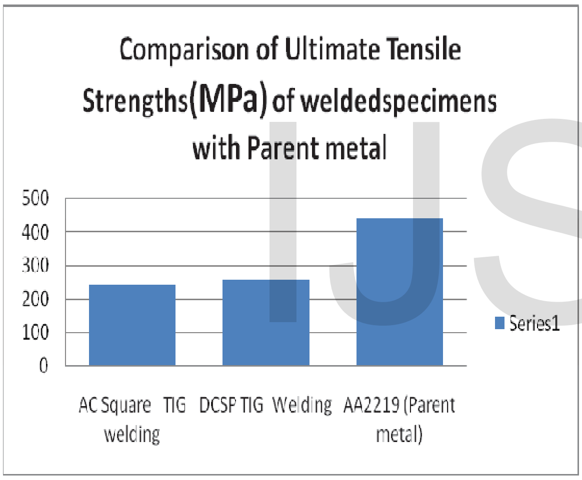

Fig 8 Comparison of Ultimate Tensile strength

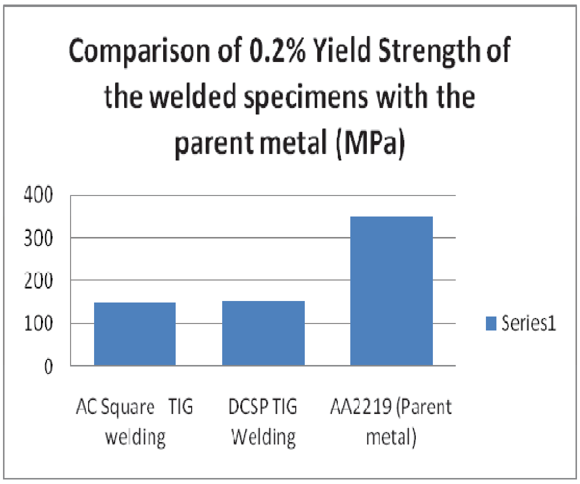

Fig. 9 Comparison of yield strength

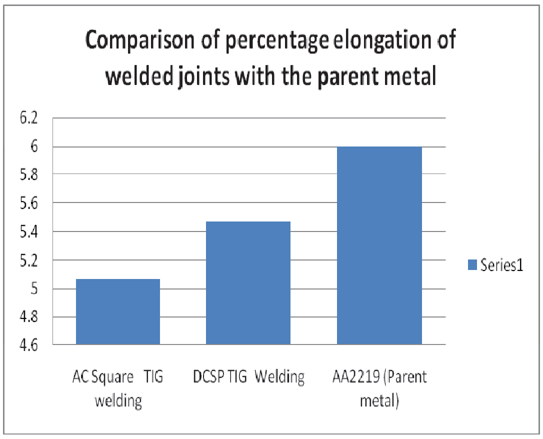

Fig 10 Comparison of percentage elongation

B. *Micro structural Analysis:*

The microstructure of weld cross section was examined at 100 X and photographed using Olympus optical microscopy. Different regions such as weld zone, interface - partially melted zone (PMZ), heat affected zone (HAZ) and parent metal were examined [9,13]. The details of microstructure along with observation of gas porosities and grain boundaries are given below.

A close look at the micro structural and micro constituent phases of the samples would give more insight into the variations in the mechanical properties of AA 2219 alloy fabricated using two modes of TIG welding processes. Optical micrographs of the samples made by the AC SQ wave reveals cluster of micro porosities in the weld region. Both gas porosities and inter dendtric porosities were observed in the sample. Cu rich films were also observed along the grain boundaries in the HAZ region of the sample made by the AC square wave. These films were continuous in nature, forming a network along the grain boundaries.

Optical microstructure of the sample for DCSP process revealed for isolated micro porosities. Discontinuous Cu rich film was observed along the grain boundaries in the HAZ region. Fine, elongated grains was observed in the parent material region. Second phase particles of $(Fe,Mn)_3$, $SiAl_2$ and coarse $CuAl_2$ were also observed in the matrix of the parent material.

From the details of microstructure, it is evident that samples made from AC square wave was observed to contain clusters of porosities. Also, the continuous network of Cu rich film which forms due to the heat of welding in the HAZ would be the cause for the lowest mechanical properties in these samples. Samples made by DCSP shows better mechanical properties compared to the previous one. This is mainly because these samples contain isolated porosities in the weld and discontinuous network of Cu rich films.

The microstructure photographs of DCSP (Fig 11 to 13), AC SQ wave (Fig 14 to 17) welded specimens are given below.

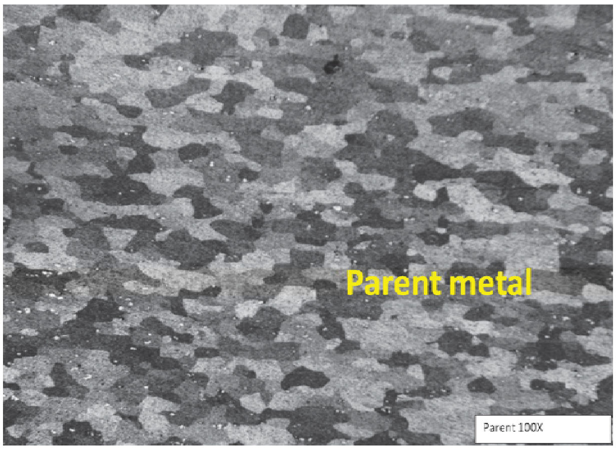

Fig 11 DCSP Weld parent metal

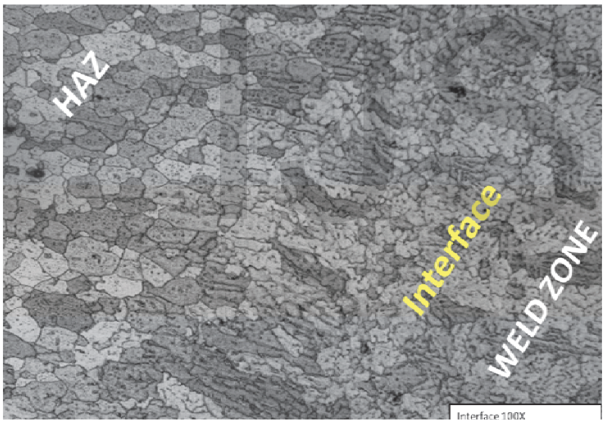

Fig 12 DCSP weld Zone:

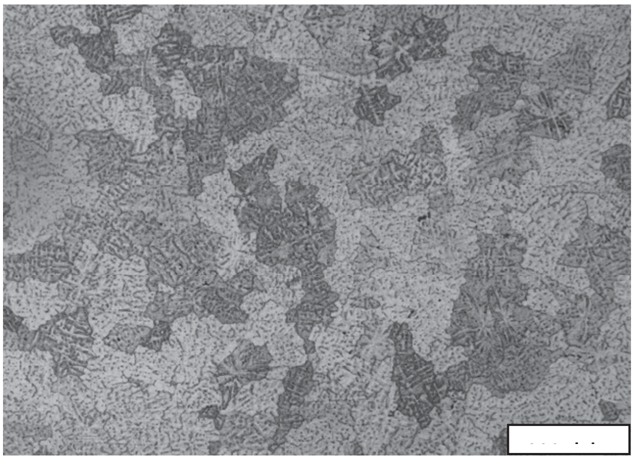

Fig 13 DCSP HAZ

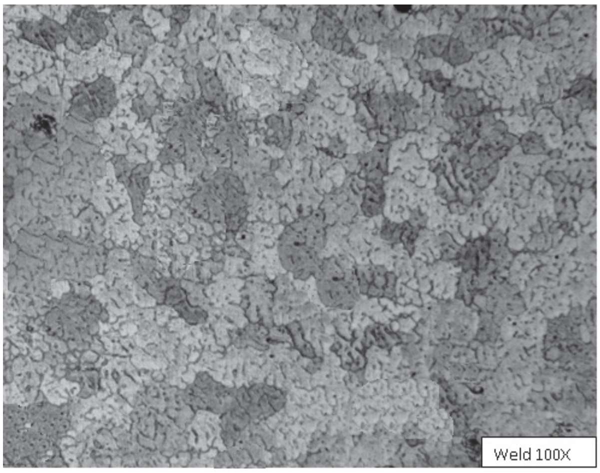

Fig 14 AC Square Wave Microstructure-weld zone

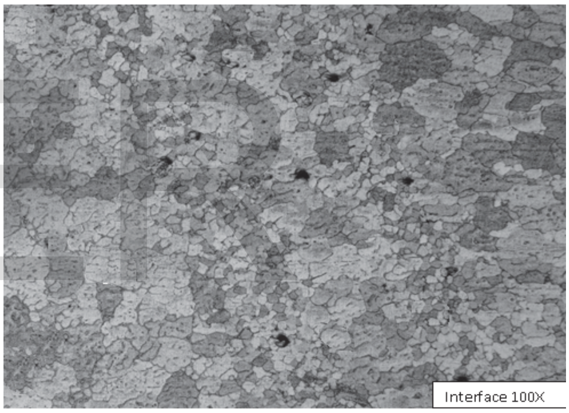

Fig 15 AC Square Wave Microstructure- Interface Zone

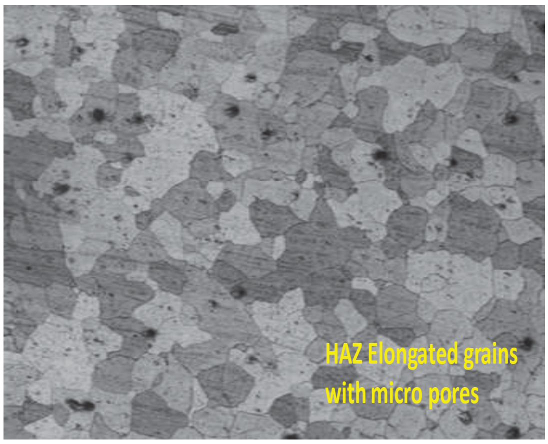

Fig 13 AC Square wave Microstructure - HAZ

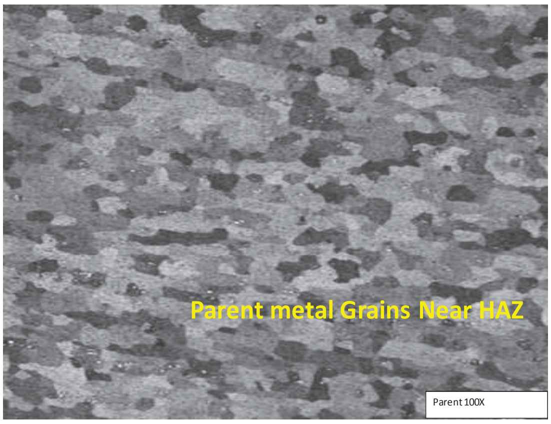

Fig 21 AC Square Wave Microstructure-Parent metal

CONCLUSION

The following conclusions have been made for the present study.

Aluminium copper alloy AA 2219 plates were successfully welded using AC square wave TIG welding process and Direct current straight polarity TIG welding, with optimized weld parameters keeping the weld travel speed constant at 100 mm / min.

The mechanical properties of UTS, 0.2%YS and Percentage elongation were found in the increasing order for the welding process of AC SQ wave and DCSP. The UTS values obtained are 245 and 257.48MPa for the welding techniques of AC and DCSP respectively. When compared to parent metal value of 440MPa, weld strength of UTS values are noted as 55.68% for AC weld technique and 58.5% for DCSP. The 0.2% YS values for weldment when compared to parent metal is 42.7% for AC and 43.8% for DCSP.

Microstructure analysis using Optical microscopes were carried out and the explanation for the observation of increased mechanical properties for each welding process based on microstructure and 2219 metallurgy were well presented.
Achieved results suggest that both welding process are suitable for welding AA 2219 material in their own way and can be adopted based on the availability of facilities and the design strength values adopted by designer. However DCSP TIG welding was found comparatively better.

Scope for future studies

Only tensile characteristics of the joints have been investigated. Further studies can also be carried out to investigate on the other mechanical characteristics to enhance the knowledge on strength and performance of such welded joints suiting to other application . In addition post weld heat treatments can also be done to improve improve the welded joints characteristics.

ACKNOWLEDGEMENT

Authors acknowledges to the Authorities of LPSC (VSSSC) Thiruvananthapuram and BRAHMOSE PVT Ltd, Thiruvananthapuram for their permission to avail the facilities to conduct this study.

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