Effect of Pulsed and Non-pulsed current on welding characteristics of AA6061 Aluminium alloy welded joints using Tig welding

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Abstract— *In this experimental work tests were conducted on the weldments of AA6061 aluminium alloy using TIG/GTAW with pulsed current at constant frequency of 6HZ and non-pulsed current on 3mm thick sheets. Destructive and non-destructive tests like Hardness test, tensile test, microstructure, radiography and liquid penetrate tests conducted, evaluated and compared with pulsed and non-pulsed current welding. Aim of the experimental work is to see the effect of pulsed current on characteristics of weldments. The experimental results pertaining to different welding parameters for the above material using pulsed and non-pulsed current GTAW are discussed and compared.*

Keywords*— *AA6061, Tungsten Inert Gas Welding/Gas Tungsten Arc Welding, Pulsed current, Non-pulsed current, Heat Affected Zone

I. INTRODUCTION

Reduction of mass is a prime concern for many industries like the automobile industry, aerospace applications; hence the focus on light materials like aluminium has became predominant. The demand is increasing for aluminium alloy welded products where high quality is required. Aluminium alloy can be welded easily by conventional arc welding methods like Metal Inert Gas Welding (MIGW) and Tungsten Inert Gas Welding (TIGW/GTAW).Among these two methods, The Gas Tungsten Arc Welding (GTAW) process has proved for many years to be suitable for welding aluminum alloy since it gives best quality welds. GTAW process (AC) is used in this study for welding of AA6061aluminium alloy.

Further development has been Pulsed current GTA welding, developed in 1950s, is a variation of GTA 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 is generally selected to give adequate penetration and bead contour, while the low level of background current is set at a level sufficient to maintain stable arc. Pulsed current welding process has many advantages over non-pulsed current (constant current) welding, including enhanced arc stability, increased weld depth/width ratio, narrower HAZ range, reduced hot cracking sensitivity, refined grain size, reduced porosity, low heat input, lower distortion of gas by weld pool and better control of the fusion zone. All these factors will help to improve mechanical properties. Pulsed current welding technology has been widely used in Fabrication of high pressure air bottles, high pressure gas storage tanks, rocket motors, structures in aerospace applications such as aircrafts, rockets and missiles. Switching between predetermined high and low level of welding current can be used to produce pulsed current gas tungsten arc welds.

Some progress is done on pulsed current GTAW of aluminium alloy. So far the pulsed current welding is used to study the effect of pulse current, shielding gas composition, weld speed and bead shape, the incidence of welding defects, joint strength, using alloy sheets of 5083type, angular distortion in SS310 type, to study the microstructure and weld bead geometry. Usually the pulsed waves are in rectangular shape and the parameters used for pulsed GTA welding are in shown in figure 1. The main characteristics of Pulsed Current Welding are determined by peak current Ip, base current I_b, peak time tp and base time t_b. The present study was carried out to understand the effect of pulsed current welding technique on the hardness, the microstructure and the tensile properties of gas tungsten arc welded AA6061 aluminium joints.

II. EXPERIMENTAL PROCEDURE

In this investigation, AA6061 aluminium alloy plates with 3mm in thickness were used as the base materials. The chemical compositions and mechanical properties of base metal are presented in Table 1 and 2. These plates of aluminum alloy were cut to required size (150mm × 150mm) by power hacksaw cutting and grinding. High purity (99.999%) argon gas was used as shielding gas. The plates were welded with pulsed and non-pulsed current GTAW process.

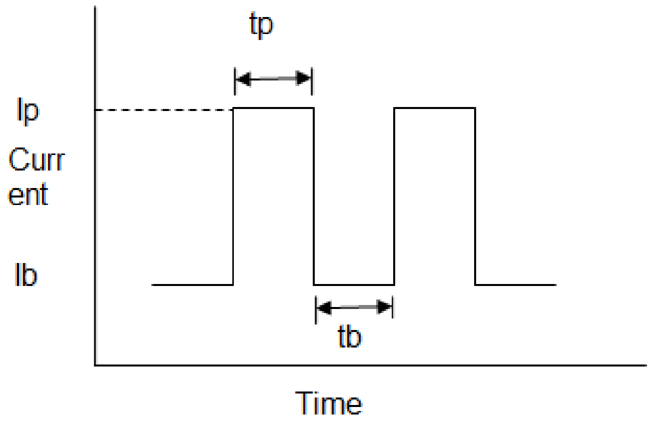

FIG. 1 PARAMETERS USED FOR PULSED GTAW: PEAK CURRENT IP, BASE CURRENT IB, PEAK TIME TP, BASE TIME TB

Filler wire material of ER4043 with 2mm diameter was used during the welding, which reduced the weld cracks and produced the good strength and ductility than other filler metals. These filler metals melt at a temperature lower than that of the base metal, for this reason it yields during cooling, since it remains more plastic than the base metal and relieves the contraction stresses that might cause cracking.

The aluminium alloy work pieces were chemically cleaned in hot Sodium Hydroxide for 10 minutes followed by dipping in Nitric Acid solution for about 15 minutes and then washed in water. A Master TIG AC/DC 3500W GTAW machine with AC was used for welding of AA6061 aluminium alloy test specimens .The choice of tungsten electrode depends upon the type of welding current selected for the application. Zirconated tungsten (EWZr) electrodes are best suited for AC wherein they keep hemispherical shape. This welding process was conducted with 2.4 mm diameter 2% Zirconated tungsten electrode. The welding parameters used for this welding process both in pulsed current and non-pulsed current of the above material are given in Tables 4 and 5. The edge preparation of the tested AA6061 aluminum alloy specimens are shown in fig.2.

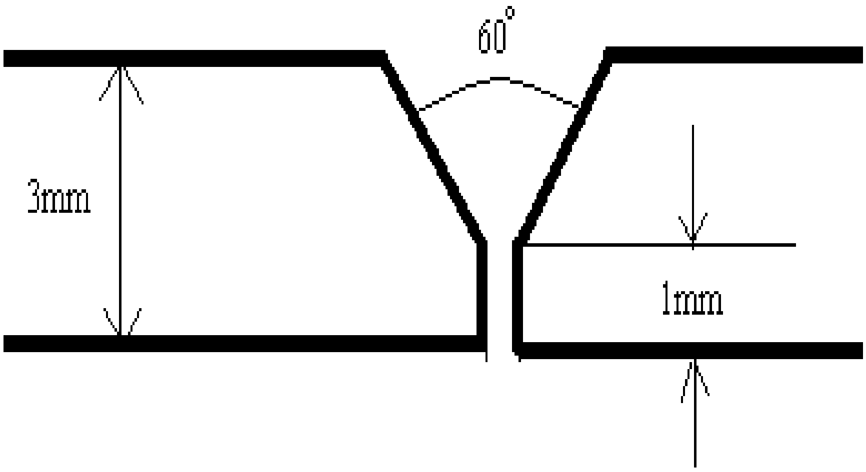

FIG. 2 EDGE PREPARATION OF WELD SPECIMENS

After welding process is over, the radiography, liquid penetrant test were carried out on the weldments according to the ASTM standards, Section IX, Division 2 for radiography and ASTM E-1417 for liquid penetrant test. The parameters used in the non-destructive testing are given in the Tables 6 and 7.

FIG. 3 ALUMINIUM PLATES

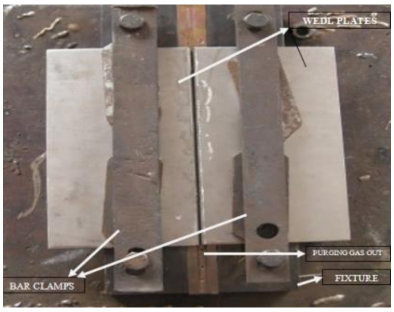

FIG. 4 FIXTURES

FIG. 5 ROOT OF WELDING

FIG. 6 ARC GUN

FIG. 7 GTAW MACHINE

FIG. 8 AC/DC PULSED PANEL

TABLE 1
CHEMICAL COMPOSITION OF WORK MATERIAL AA6061

	Chemical Composition % wt								
Materil	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
AA 6061	0.40-0.80	0-0.70	0.15-0.40	0-0.15	0.80-1.20	0-0.25	0-0.15	0.04-0.35	Balancd

TABLE 2
MECHANICAL PROPERTIES OF WORK MATERIAL AA6061

Material	UTS(MPa)	TYS(MPa)	% Elongation
AA6061	310 MPa	145 MPa	22%

TABLE 3
CHEMICAL COMPOSITION OF FILLER WIRE ER4043

	Chemical Composition % wt						
Material	Cu	Si	Mn	Mg	Fe	Cr	Ti	Al
ER4043	0.17	4.5-6.0	0.24	0.05	0.05	0.05	0.05	Balanced

TABLE 4
WELDING PARAMETERS FOR PULSED CURRENT WELDING OF AA6061

Exp No.	Weld layer	Peak Current/ A	Base Current/ A	Voltage/ V	Pulse on time/ %	Frequency/ HZ	Welding speed (mm /sec)
1	Root	100	50	14.4 -15.2	50	6	2.66
	1st layer	100	50	12.9-14.3	50	6	2.40
2	Root	110	55	14.2-15.3	50	6	2.88
	1st layer	110	55	13.9-15.0	50	6	2.41
3	Root	120	60	12.6-14.2	50	6	4.03
	1st layer	120	60	14.7-16.1	50	6	3.70
4	Root	130	65	14.5-18.3	50	6	3.91
	1st layer	130	65	14.9-16.1	50	6	3.87

TABLE 5
WELDING PARAMETERS FOR NON-PULSED CURRENT WELDING OF AA6061

Exp No.	Weld layer	Current/ A	Voltage/ V	Welding speed (mm/sec)
1	Root	100	14.4 – 15.2	2.02
	1st layer	100	14.3 – 15.3	2.84
2	Root	110	12.9 – 14.1	3.01
	1st layer	110	15.9 – 16.9	3.26
3	Root	120	13.9 – 15.1	2.78
	1st layer	120	15.1 – 16.0	3.14
4	Root	130	12.9 – 14.1	3.32
	1st layer	130	15.2 – 16.4	1.72

Images of pulsed current welded Aluminium plates

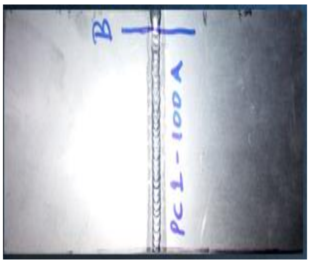

FIG. 9
PULSED CURRENT (100A)

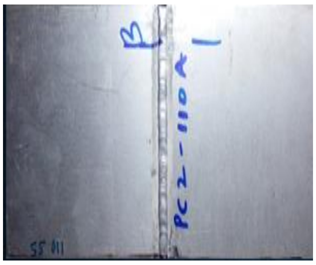

FIG. 10
PULSED CURRENT (110A)

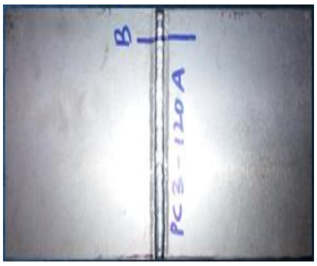

FIG. 11
PULSED CURRENT (120A)

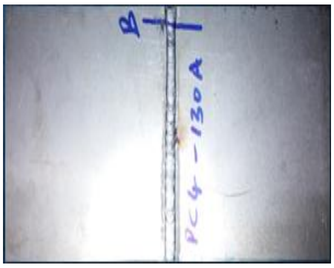

FIG. 12
PULSED CURRENT (130A)

Images of non-pulsed current welded Aluminium plates

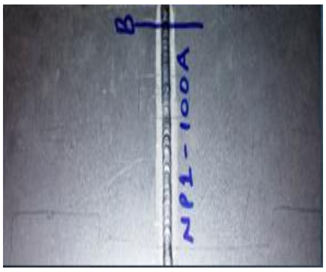

FIG. 13
NON-PULSED CURRENT (100A)

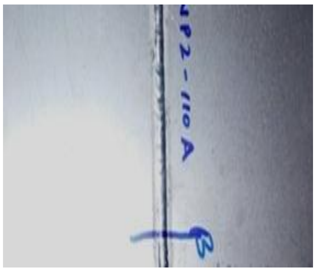

FIG. 14
NON-PULSED CURRENT (110A)

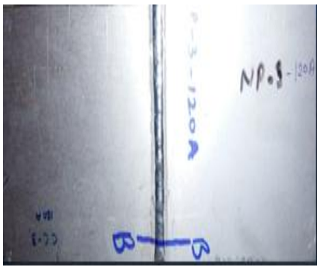

FIG. 15
NON-PULSED CURRENT (120A)

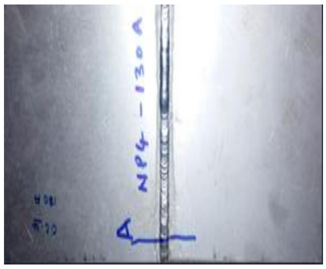

FIG. 16
NON-PULSED CURRENT (130A)

TABLE 6
LIQUID PENETRANT TEST PARAMETERS OF AA6061

Aluminum Alloy 6061	
DP DIT	MAGNA FLUX
Penetrant Used	SKL-SP
Cleaner Used	SKC-1
Developer Used	SKD-S2
Dwell time (at room temp)	10 Min
Viewing Media	Normal light
Sensitivity	30 micron

TABLE 7
RADIOGRAPHY TEST PARAMETERS OF AA6061

	Technique	Single wall single image
Exposure parameters	Source	X-Ray
	Voltage (Kv)	150 KV
	Current (mA)	5 mA
	Exposer Time	1 min
	Film type	KODAK - DY
	S.F.D./F.F.D. (mm)	1000 mm
	I.Q.I.	DIN-AL10-16
Processing parameters	Developer Time (min)	5.0
	Stop Bath Time (min)	1.0
	Fixer Time (min)	10
	Sensitivity	2%

III. RESULTS AND DISCUSSION

TABLE 8
LIQUID PENETRANT TEST RESULTS OF AA6061

S.no.	Material thickness (mm)	Pulsed/non-pulsed welding	Frequency (HZ)	Observations
1	3	Pulsed 100A	6	No defect observed on welded area
2	3	Non-Pulsed 100A	-	No defect observed on welded area
3	3	Pulsed 110A	6	No defect observed on welded area
4	3	Non-Pulsed 110A	-	No defect observed on welded area
5	3	Pulsed 120A	6	No defect observed on welded area
6	3	Non-Pulsed 120A	-	No defect observed on welded area
7	3	Pulsed 130A	6	No defect observed on welded area
8	3	Non-Pulsed 130A	-	No defect observed on welded area

TABLE 9
RADIOGRAPHY TEST RESULTS OF AA6061

S.no.	Material thickness (mm)	Pulsed/non-pulsed welding	Frequency (HZ)	Observations
1	3	Pulsed 100A	6	No significance defect
2	3	Non-Pulsed 100A	-	No significance defect
3	3	Pulsed 110A	6	No significance defect
4	3	Non-Pulsed 110A	-	No significance defect
5	3	Pulsed 120A	6	No significance defect
6	3	Non-Pulsed 120A	-	No significance defect
7	3	Pulsed 130A	6	No significance defect
8	3	Non-Pulsed 130A	-	No significance defect

Radiography images of AA6061 aluminium alloy

FIG. 17 PULSED CURRENT (100A)

FIG. 18 PULSED CURRENT (110A)

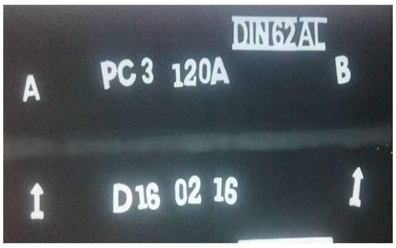

FIG. 19
PULSED CURRENT (120A)

FIG. 20
PULSED CURRENT (130A)

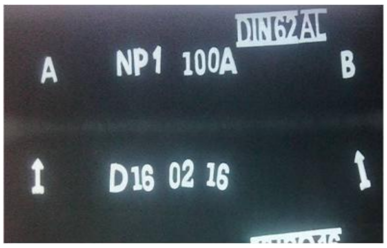

FIG. 21
NON-PULSED CURRENT (100A)

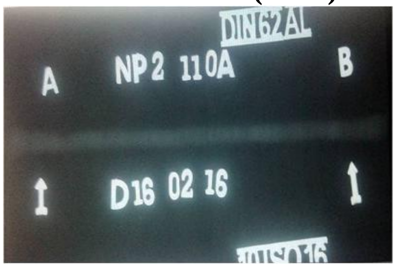

FIG. 22
NON-PULSED CURRENT (110)

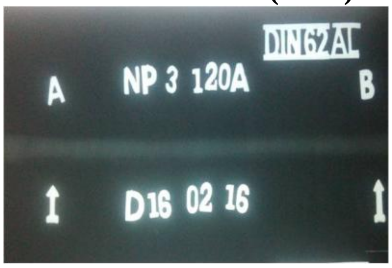

FIG. 23
NON-PULSED CURRENT (120)

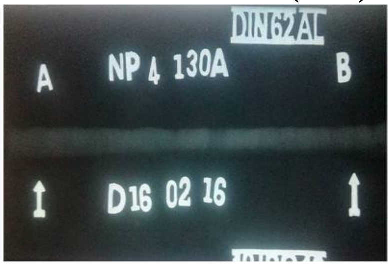

FIG. 24
NON-PULSED CURRENT (130)

Images of tensile strength test work pieces

FIG. 25 WORK PIECES BEFORE TEST

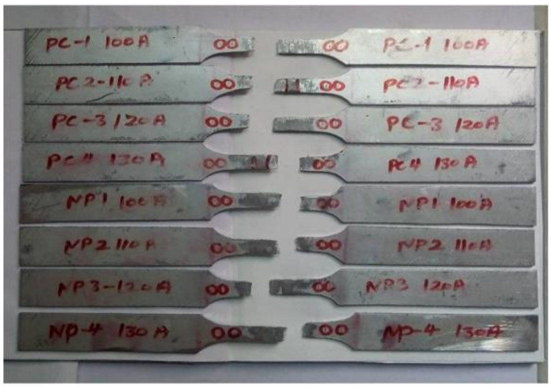

FIG. 26 WORK PIECES AFTER TEST

TABLE 10
TENSILE STRENGTH TEST RESULTS OF AA6061

S.no.	Process	Frequency (HZ)	Thickness	Ultimate Tensile Strength (MPa)	0.2% Proof stress (MPa)
1	Pulsed 100 A	6	3	152.290	149.893
2	Non-Pulsed 100 A	-	3	158.300	137.848
3	Pulsed 110 A	6	3	167.341	114.440
4	Non-Pulsed 110 A	-	3	158.470	106.256
5	Pulsed 120 A	6	3	170.370	127.671
6	Non-Pulsed 120 A	-	3	158.912	121.251
7	Pulsed 130 A	6	3	158.983	136.989
8	Non-pulsed 130 A	-	3	154.915	94.150

Images of welded samples used for hardness test and microstructure test

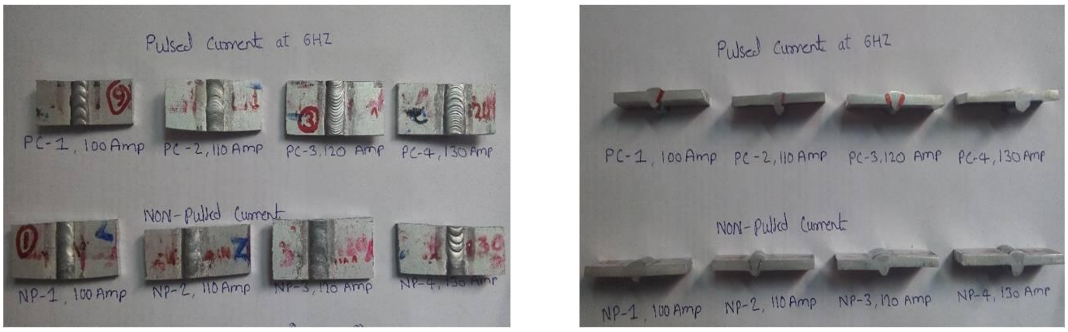

FIG. 27 SAMPLES USED FOR HARDNESS TEST AND MICROSTRUCTURE

TABLE 11
OBSERVED HARDNESS RESULTS FOR WELDMENT WELDED WITH PULSED CURRENT 100A

S.no.	Location	Observed values in HV			
		Impression 1	Impression 2	Impression 3	Average
1	WELD ZONE	70.8	70.4	71.2	70.80
2	HAZ	72.0	72.4	72.0	72.13
3	FUSION ZONE	76.1	76.3	77.0	76.47
4	BASE METAL	67.0	67.5	67.2	67.23

TABLE 12
OBSERVED HARDNESS RESULTS FOR WELDMENT WELDED WITH PULSED CURRENT 110A

S.no.	Location	Observed values in HV			
		Impression 1	Impression 2	Impression 3	Average
1	WELD ZONE	70.4	70.8	71.2	70.80
2	HAZ	71.6	71.2	71.6	71.47
3	FUSION ZONE	76.9	77.1	76.9	76.97
4	BASE METAL	67.2	67.4	67.0	67.2

TABLE 13
OBSERVED HARDNESS RESULTS FOR WELDMENT WELDED WITH PULSED CURRENT 120A

S.no.	Location	Observed values in HV			
		Impression 1	Impression 2	Impression 3	Average
1	WELD ZONE	72.0	72.8	71.6	72.13
2	HAZ	73.2	73.6	74.0	73.60
3	FUSION ZONE	74.4	75.3	75.7	75.13
4	BASE METAL	67.5	67.2	67.1	67.26

TABLE 14
OBSERVED HARDNESS RESULTS FOR WELDMENT WELDED WITH PULSED CURRENT 130A

S.no.	Location	Observed values in HV			
		Impression 1	Impression 2	Impression 3	Average
1	WELD ZONE	69.2	68.8	69.2	69.07
2	HAZ	71.2	70.8	71.2	71.07
3	FUSION ZONE	71.6	71.6	71.2	71.47
4	BASE METAL	67.0	67.7	67.0	67.23

TABLE 15
OBSERVED HARDNESS RESULTS FOR WELDMENT WELDED WITH NON-PULSED CURRENT 100A

S.no.	Location	Observed values in HV			
		Impression 1	Impression 2	Impression 3	Average
1	WELD ZONE	70.4	70.0	69.6	70.00
2	HAZ	71.6	70.4	70.8	70.93
3	FUSION ZONE	72.4	72.0	72.8	72.40
4	BASE METAL	67.2	67.2	67.3	67.23

TABLE 16
OBSERVED HARDNESS RESULTS FOR WELDMENT WELDED WITH NON-PULSED CURRENT 110A

S.no.	Location	Observed values in HV			
		Impression 1	Impression 2	Impression 3	Average
1	WELD ZONE	70.8	70.0	70.4	70.49
2	HAZ	70.8	71.2	70.4	70.80
3	FUSION ZONE	71.2	72.8	72.0	72.00
4	BASE METAL	67.1	67.4	67.2	67.23

TABLE 17
OBSERVED HARDNESS RESULTS FOR WELDMENT WELDED WITH NON-PULSED CURRENT 120A

S.no.	Location	Observed values in HV			
		Impression 1	Impression 2	Impression 3	Average
1	WELD ZONE	71.6	71.2	70.8	71.20
2	HAZ	71.6	71.6	71.8	71.67
3	FUSION ZONE	73.2	74.0	73.2	73.47
4	BASE METAL	67.1	67.3	67.4	67.26

TABLE 18
OBSERVED HARDNESS RESULTS FOR WELDMENT WELDED WITH NON-PULSED CURRENT 130A

S.no.	Location	Observed values in HV			
		Impression 1	Impression 2	Impression 3	Average
1	WELD ZONE	66.6	66.0	67.4	66.57
2	HAZ	71.2	70.8	70.4	70.80
3	FUSION ZONE	71.6	71.2	70.8	71.20
4	BASE METAL	67.0	67.7	67.0	67.23

Images of microstructure at Heat Affected Zone (HAZ)

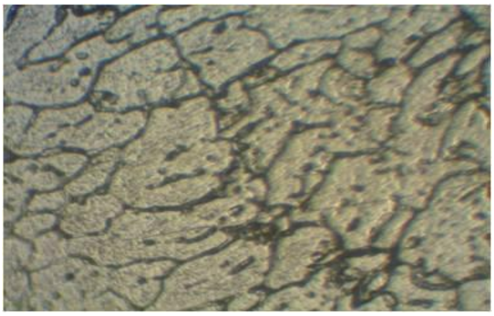

FIG. 28 PULSED 100A (HAZ)

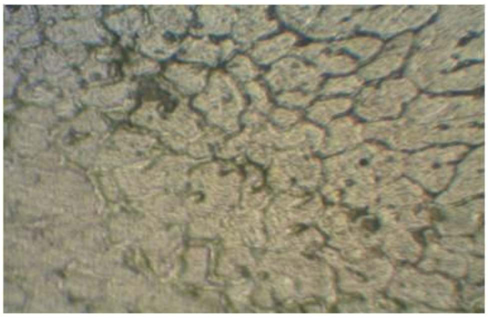

FIG. 29 PULSED 110A (HAZ)

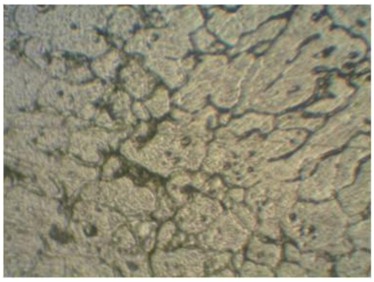

FIG. 30 PULSED 120A (HAZ)

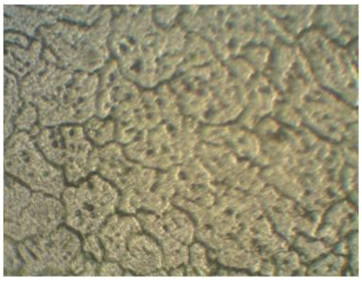

FIG. 31 PULSED 130A (HAZ)

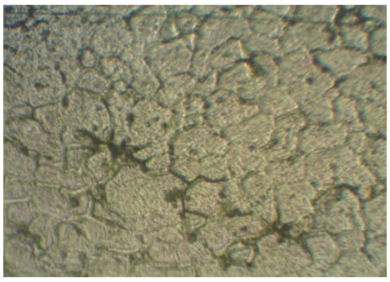

FIG.32 NON-PULSED 100A (HAZ)

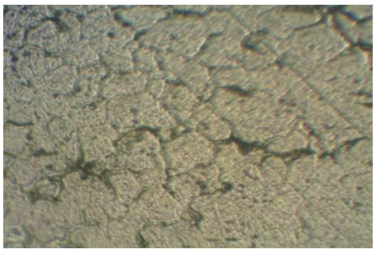

FIG. 33 NON-PULSED 110A (HAZ)

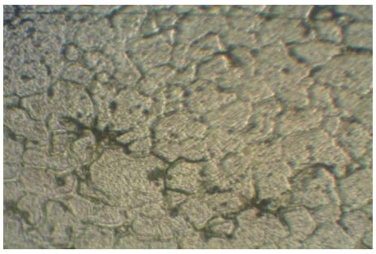

FIG. 34 NON-PULSED 120A (HAZ)

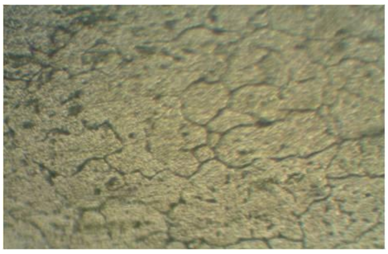

FIG. 35 NON-PULSED 130A (HAZ)

1. Liquid penetrant tests were conducted upon these weldments to know the effect of Pulsed current and Non-pulsed current on the welding characteristics of these metal alloys. No defect was observed during liquid penetrant test.
2. Radiography tests were conducted on these weldments, no significant defects were found on weldments. No porocity was observed in pulsed current and non-pulsed current welded weldments.
3. Tests were conducted on all the weldments and observed more Tensile strength values in all Pulsed current weldments done at (100A, 110A, 120A, 130A) compared to Non-pulsed current weldments done at (100A, 110A, 120A, 130A). Among all pulsed current weldments, observed more tensile strength i.e. "170.370 MPa" in weldment done at 120Amp.
4. A load of 5kgs was applied to obtain Vickers hardness HV. Tables 11-18 lists the Vickers hardness values for all weldments at weld zone, heat affected zone, base metal and fusion zone for pulsed and non-pulsed current. It was observed that the values of hardness are less in the Non-pulsed current joints compared with the Pulsed current ones in all the locations. The reason for the decrease in the hardness can be attributed to the variation in the temperatures attained and also the pulsing of current in the joint fabricated by the pulsed current. Hence the higher hardness is attributed to the joints fabricated by pulsed current.
5. The strength of the weld metal is characterized by the grain size and the phase present in the microstructure. The phase formation and grain growth are highly influenced by the thermal cycle of the welding process. The interesting region of would be the weld metal and the interface zones because at the weld metal the temperature goes to the peak and cools rapidly thus formation of finer grain sizes. The welded specimen was prepared using the standard metallographic procedure, and the polished surfaces were itched with aqua-reagent to get the clear microscopic view of the weldments. The results of the microstructure of all weldments at the heat affected zone (HAZ) are presented in fig.28-35.

IV. CONCLUSION

The main conclusions of the present study can be summarized as follows,

1) The pulsed current welding technique records lower peak temperatures and lower magnitude of residual stresses compared with non-pulsed current welding, which is highly preferable for thin sheet welding.

2) The tungsten inert gas or gas tungsten arc welded aluminium alloy joint fabricated by pulsed current welding technique exhibits superior tensile properties compared with non-pulsed current welding technique.

3) The formation of finer grains caused by pulsed current is the main reason for enhanced tensile and hardness properties of the joints.

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