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# Study on the Effect of Pulsed and Dual Pulsed Mode in GMAW for Aluminium Applications

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**ABSTRACT:** GMAW is one of the most widely used and versatile welding process. To enhance the productivity and quality of GMAW, pulsed and dual pulsed mode welding are introduced. The present investigation aims to contrast the effect of pulsed and dual pulsed mode on ER4043 filler wire in GMAW. The variation of weld bead morphology and primary dendrite arm length of the weld during both pulsed and dual pulsed mode in aluminium welding are examined. Also, the microstructural refinement is also examined between pulsed and dual pulsed mode in aluminium welding. Because of the pulsing current and thermal pulsing in DP-GMAW improves the mechanical and metallurgical properties of the aluminium weld.

**KEYWORDS:** GMAW, ER4043, pulsed and dual pulsed welding, etc

## I. INTRODUCTION

Aluminium welding is considered to be slightly difficult than the steel because of high thermal conductivity, high thermal expansion coefficient and tendency to the formation of aluminium oxide which is refractory in nature. The welding of aluminium alloys also suffer from the problems such as solidification cracking and hydrogen induced porosity, which limits the application of aluminium alloys [3]. However, lightweight engineering alloys especially aluminium alloys serve an important role in aerospace, automotive and naval industries, for energy saving and improved performance. Nowadays, steels are replaced by lightweight engineering alloys in these applications. Among various lightweight engineering alloys, aluminium alloys have attracted attention, due to their exceptional machinability, acceptable strength, and excellent anti-corrosion resistance [1]. For welding of many complicated parts, gas metal arc welding is still used in the industry. The weld quality of Gas Metal Arc Welding (GMAW) welding process can be improved by modifying the current waveform to increase the productivity and also a better process control can be obtained [2]. The main advantage of pulsing waveform is that it will reduce the heat input a compared with conventional Metal Inert Gas (MIG) welding. Unlike conventional GMAW, the pulsed GMAW (P-GMAW) operates by forming one droplet of molten metal at the end of each pulse after that a peak current is applied to detach the molten droplet from the electrode into the weld pool. The parameters included in the P-GMAW are Peak current, Background current or Base current, peak current duration, background current duration, pulsing frequency and load duty cycle. These parameters are additional to the conventional parameters in GMAW such as stick out, wire feed rate, travel speed, etc. Pulsed GMAW, produces a modified spray transfer which is better than that of both short-circuiting and spray transfer [5]. The Dual pulsed GMAW (DP-GMAW) was introduced to improve the weld quality and produce a sound weld as compared with conventional GMAW and P-GMAW. In DP-GMAW, a low frequency current pulse is placed over a high frequency current pulse for better process control as in case of AA5754 aluminium alloy welding [4]. DP-GMAW produces a “stir effect” due to oscillation of arc force and droplet pressure [4], these will not take place in pulsed welding. This “stir effect” improves the quality of DP-GMAW welds as compared with conventional GMAW and P-GMAW welds. In this paper, the variation of the cooling rate, grain refinement and weld bead morphology for aluminium weld ER4043 for SP-GMAW and DP-GMAW was investigated and studied

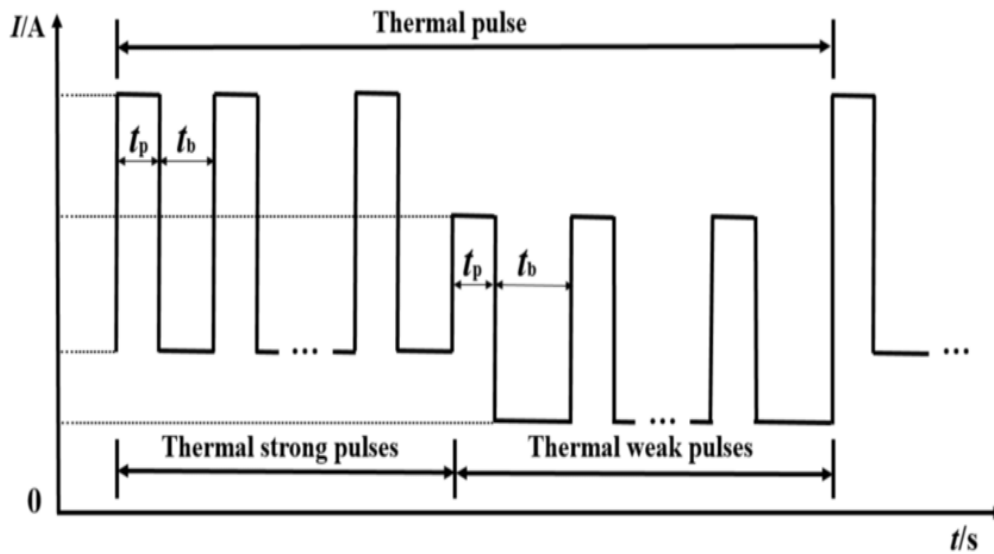


Fig 1: Schematic diagram of current waveform of DP-GMAW with high frequency pulse is superimposed with low frequency pulse (Thermal pulse)

II. MATERIALS AND METHODS

A. Materials and Process parameters:

Aluminium alloys AA1060 was welded using ER4043 filler metal. Table 1 shows the chemical composition of the base metal and filler wire.

Table 1: chemical composition of AA1060 and ER4043

Material	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
AA1060	0.25	0.35	0.05	0.03	-	-	0.05	0.03	Bal
ER4043	5.60	0.80	0.30	0.05	0.05	-	-	0.15	Bal

Bead on plate welding experiments were carried out on the aluminium alloy AA1060 base metal with the dimension 140 X 100 X 6.25 mm using ER4043 filler wire of diameter 1.6mm. The process parameters used for SP-GMAW and DP-GMAW are given in table 2. The stick out used was 10mm and the shielding gas used was 99.99% pure argon having a flow rate of 20 L/min. The welding process was carried out using power source (Kemppi-ProMIG 5200) and a wire feeder unit (Kemppi-ProMIG-530 MXE). The polarity used in the welding is direct current reverse polarity (DCEP). After welding, the aluminium weld was cut in transverse direction to the weld at the center of the plate and the specimen with a dimension of 40 X 10 X 5 mm was extracted. Then the extracted specimen was mounted with bakelite in a hot mounting machine. The specimens are polished with the emery from grade 60 to upto grade 1000 and polished in rough and fine disc polishing machine using alumina powder. The specimens are etched using Keller’s reagent (2ml HF+ 3ml HCl + 5ml HNO<sub>3</sub> + 190 ml H<sub>2</sub>O) with an etching time of 10-15 s. The microstructure and macrostructure image were taken using an optical microscope

The welding parameters given in table 2 are used in SP-GMAW and DP-GMAW to compare the effect of these modes in the grain refinement and weld bead geometry of the aluminium ER4043 weld. It should be noted that the mean current of thermal peak is higher than the mean current of thermal base in case of DP-GMAW, which is not in the case of SP-GMAW.

Table 2: Welding Process parameters

Process parameters	SP-GMAW	DP-GMAW
Mean voltage (V)	21.5	19.4
Mean current (A)	189	150
Welding speed (cm/min)	40	40
Wire feed rate (m/min)	5	5
Wire diameter (mm)	1.6	1.6
Density of wire (kg/m <sup>3</sup> )	2685	2685
Frequency (Hz)	100	2
First phase time (s)	--	0.2
Second phase time (s)	--	0.2

**B. Studies on the weld**

The welded samples were studied for the effect of pulsing between SP-GMAW and DP-GMAW on grain refinement, weld bead morphology such as penetration, bead width, etc. Also, the length of the dendrites were measured using the optical microscope to ensure the grain refinement. The Vickers microhardness were measured on the welded samples along the transverse direction to the weld. The weld morphology were studied using a stereo microscope in which the penetration, bead width and the reinforcement was measured.

**III. RESULT**

After the welding of aluminium plates, the SP-GMAW and DP-GMAW welds are examined. The present section describes the advantages of Dual Pulsed GMAW (DP-GMAW) over the Single Pulsed GMAW (SP-GMAW) in aluminium weld

**A. Macrostructure Examination**

The macrograph of the ER4043 aluminium welds are shown in fig 2 (a) & (b). From the fig, it is evident that the size of the weld pass in DP-GMAW was smaller as compared to the size of the weld pass in SP-GMAW. The DP-GMAW weld pass is smaller than the SP-GMAW weld pass which reduces the residual stress generation of the weld joint. The porosity generation is also reduced in DP-GMAW weld as compared with SP-GMAW weld due to the stir effect that occur in the DP-GMAW.

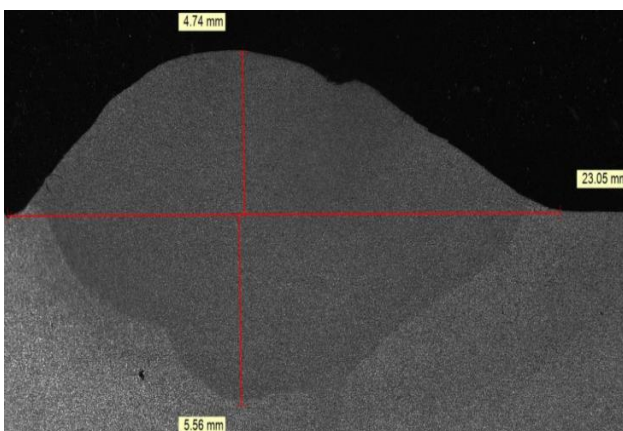


Fig 2 (a): SP-GMAW weld macrograph

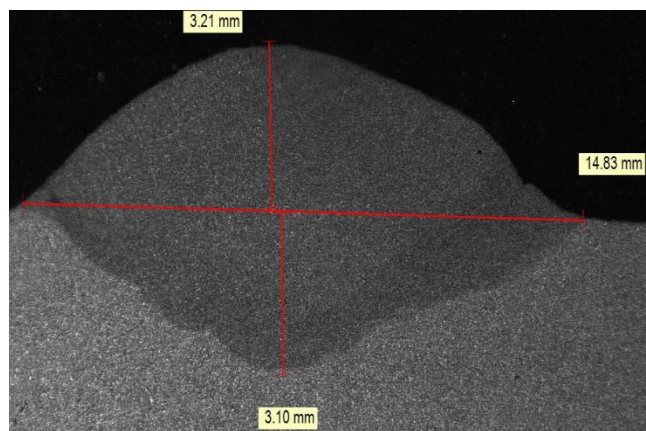


Fig 2 (b): DP-GMAW weld macrograph

**B. Microstructure examination**

The microstructure of the SP-GMAW and DP-GMAW was shown in the fig 3 (a) & (b). From the micrograph, it is evident that the grain size of DP-GMAW weld is smaller as compared to the SP-GMAW weld. This refinement in the grain structure

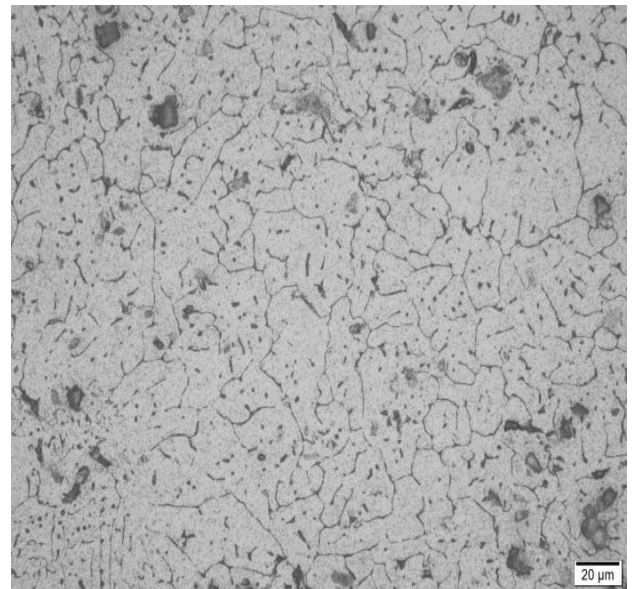
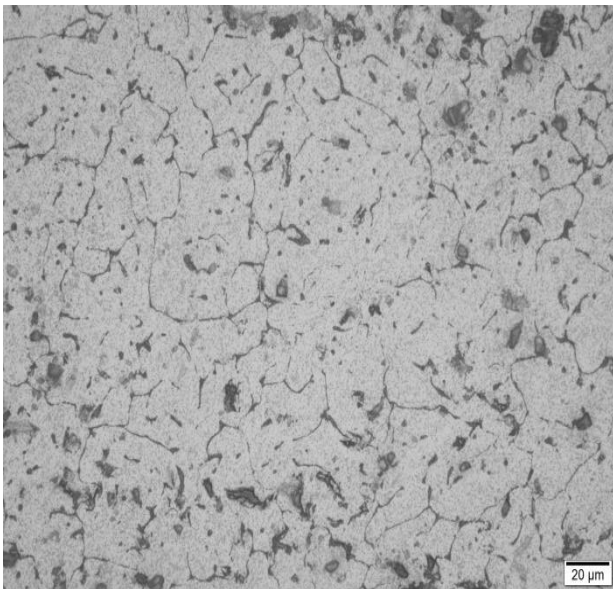
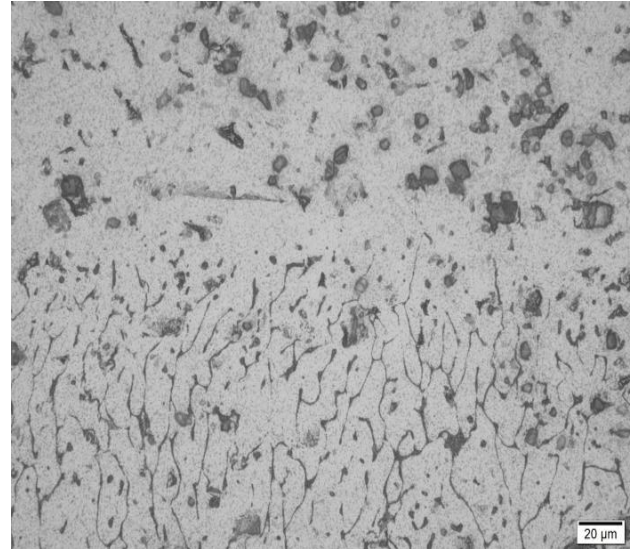
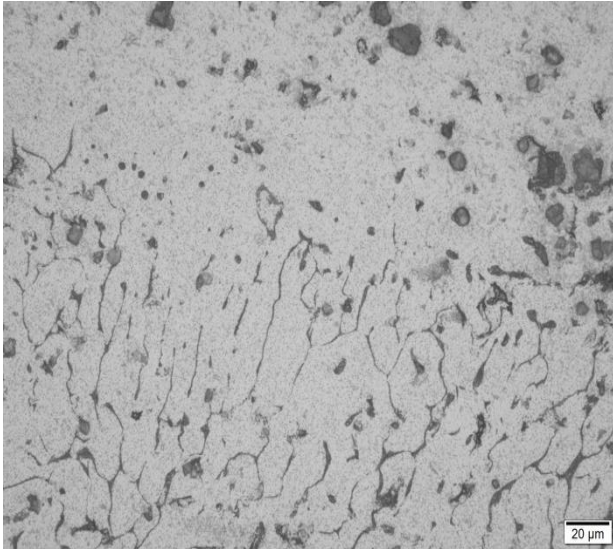


Fig 3(a), (b): microstructure of SP-GMAW weld metal and the weld interface at wire feed speed of 5 m/min at 20µm

Fig 3(c), (d): microstructure of DP-GMAW weld metal and the weld interface at wire feed speed of 5 m/min at 20µm

is due to the change in the heat input between SP-GMAW and DP-GMAW. The microstructure of the weld consists of Al-Si eutectic phase distributed in the  $\alpha$ -Al matrix. From the micrograph, it is evident that cellular structure is observed at the region which are adjacent to the fusion line, whereas dendritic structure are observed at the region which are further away from the fusion line. The fusion zone of the weld has a fine grained dendrites structure consisting of aluminium solid solution,  $\alpha$ -Al, and low melting point segregation phase along the grain boundaries, such as Al-Si eutectics as shown in fig 3(a) & (c). Compared with aluminium solid solution, low melting point segregation phase was etched severely, resulting in a dark consecutive net along grain boundaries. The low melting point phases are formed as a cluster in some areas of the weld and are not uniform throughout the weld. This is due to the solidification behaviour of the weld. During solidification of the molten metal in the weld, grain nucleates on the surface of the unmelted metal



and grew towards the center of the weld. Meanwhile, there will be equiaxed grains formed at the center of the weld. It is also seen that the grain size of weld is well refined in DP-GMAW when compared with SP-GMAW, the finer grain structure will give a better mechanical properties. The refinement in the microstructure of DP-GMAW is due to the increase in cooling rate as compared to the SP-GMAW and also due to the remelting and resolidification phenomenon produces a change in the mean solidification rate. The fine porosity generation in the weld is seen to be more in case of SP-GMAW when compared with DP-GMAW. The DP GMAW welds are almost free from defects such as porosity, lack of fusion and solidification cracking, which provides additional evidence that DP-GMAW is a better process for aluminium welding as compared with conventional and SP-GMAW.

**C. Vickers microhardness**

The microhardness of both weld and the basemetal were taken by vicker’s microhardness. The hardness survey were taken on seven points from weld to basemetal (top to bottom) in a straight line on both pulsed and dual pulsed Aluminium welds. The average microhardness of the weld and base metal are shown in the table 3. The hardness survey of the single and dual pulsed weld samples were shown in the Fig. 4

Table 3: Microhardness of the weld sample.

AVG. MICROHARDNESS (HV)		
Type	Weld metal (HV)	Base metal (HV)
Single pulsed mode	43.66	28.75
Dual pulsed mode	50	28

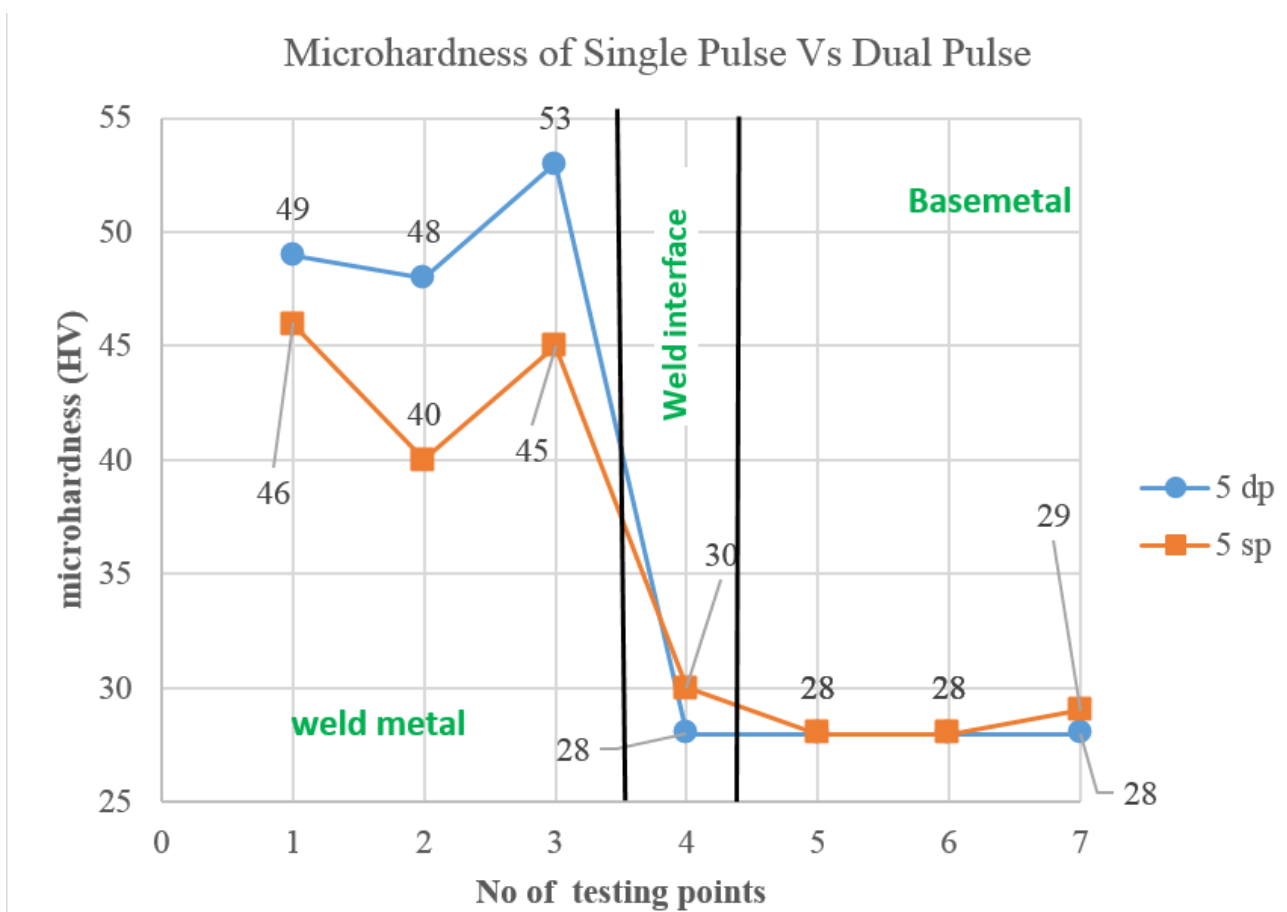


Fig 4: Microhardness of the weld samples

**D. Dendrite arm length in the solidified structure:**

Grain size has a very important effect on the morphology of dendrites. Larger grains consist of elongated dendrites whereas as the grain size decreases, the dendrites also reduce in size, dendritic arms becomes equiaxed and results in

nodular colony of dendrites which are much finer. Hence, reduction in the grain size results in better mechanical properties. To evaluate the grain refinement in the grain structure, the dendrite length was measured and the average was taken. The dendrites are measured with the help of a software using a computerized optical microscope. The dendrite arm measurement is shown in fig 5 and the Average dendrite length of the weld sample are shown in table 4

Table 4: Dendrite arm length

S.No	Type	Avg. Dendrite arm length (µm)
1	Single pulsed weld	106.38
2	Dual pulsed weld	65.55

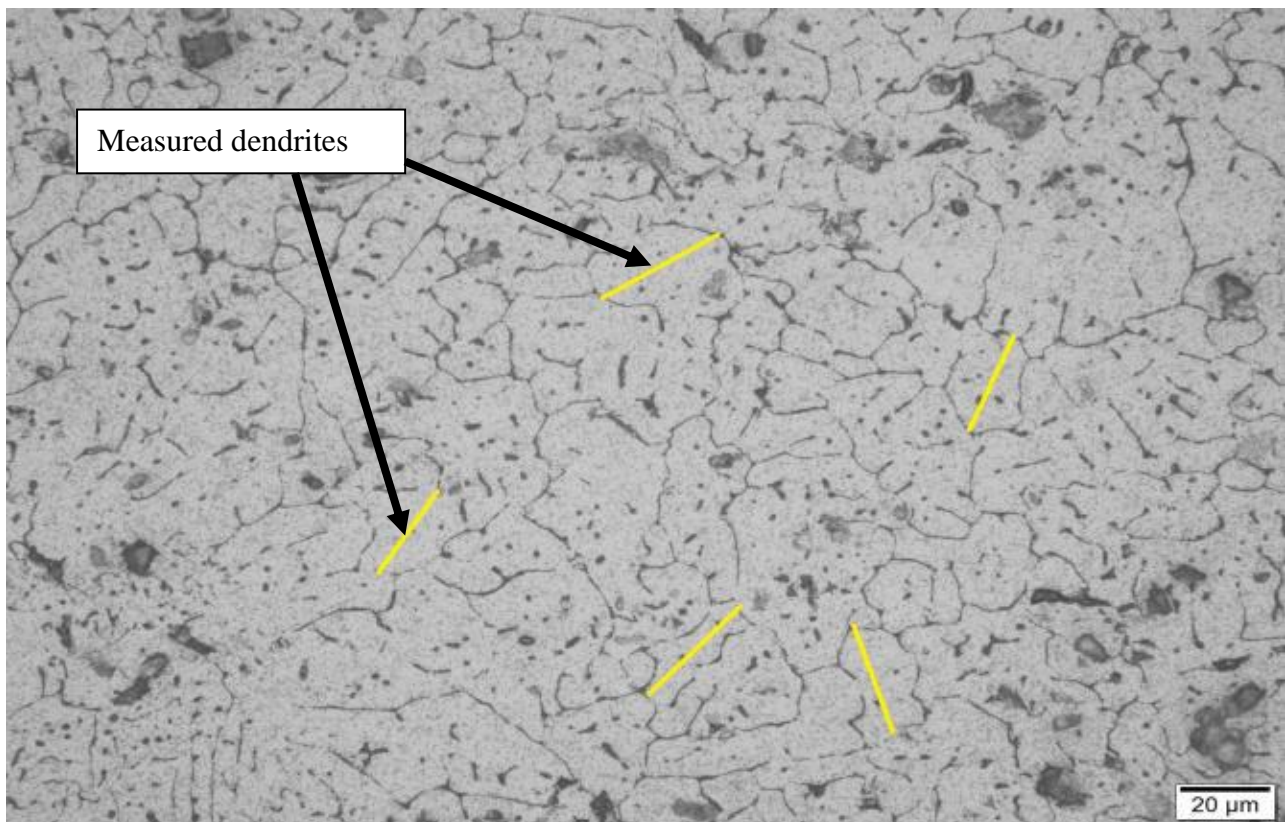


Fig 5: Dendrite arm measurement at 20µm micrograph

#### IV. DISCUSSION

In the view of the results discussed above, it is evident that the DP-GMAW process is used to improve the mechanical and metallurgical properties of the Al weld as compared with the SP-GMAW process. The improvement in the mechanical and metallurgical properties is largely due to the combined effect of pulsed current and thermal pulsation of the process. The weld pass obtained in the DP-GMAW is smaller than the weld pass obtained in SP-GMAW. The porosity generation in the weld is seen to be more in SP-GMAW as compared with DP-GMAW. This is due to arc force of thermal peak is significantly higher than the thermal base. Therefore, an oscillation of the arc force originated from the pulsation in the welding current appears during DP-GMAW. This produces a “stir effect” and it gives time for the escaping of dissolved gas in the weld and reduces porosity in the weld in DP-GMAW. While comparing dual pulsed and single pulsed gas metal arc welding of aluminium, the periodic shrinkage and expansion of the melt pool during dual pulsed welding led to an unusual remelting and resolidification behaviour of the weld metal. Solidification rates and cooling rates were significantly higher for the dual pulsed gas metal arc welding than those for the single pulsed welding and these difference were responsible for the significant refinement of microstructure during dual pulsed welding. The dendrites arm length measurements shows that the in DP-GMAW produces a finer and smaller

dendrites due to the increase in the cooling and increase in the solidification rates. These are the beneficial effect to improve the characteristics of weld joints.

#### V. CONCLUSION

This study gives an outstanding part of DP-GMAW in welding for aluminium applications. Some of the important observation of this study is as follows.

1. The weld bead morphology obtained in DP-GMAW is better than SP-GMAW. The smaller the weld pass, the lesser will be the residual stress generation.
2. A finer grain structure is obtained in DP-GMAW as compared with SP-GMAW, which improves the mechanical properties.
3. The fine pores generation in the weld is reduced in the DP-GMAW due to the combined effect of pulsing current and thermal pulsation (stir effect).
4. The hardness of the DP-GMAW is increased in the weld region due to the refinement in the grains structure than the SP-GMAW.

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