

Study the correlation between Microhardness, Microstructure & In-situ thermal analysis of PCATIG weldedments of Al-SiC composite

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Abstract

Activated TIG welding has been performed on Al – 8% SiC composite 5mm plate with various fluxes such as Al₂O₃, MnO₂, CaO, MgO, SiO₂ & TiO₂. Microstructure, Micro hardness and cooling rate are observed. Correlation between micro hardness, microstructure and cooling rate of Pulsed Current TIG welding and Pulsed Current Activated TIG welding on Al-SiC composite has been studied. Combining the pulsed current TIG and activated TIG welding (PC-A-TIG) on Al-SiC composite showed very fine superior weld microstructure on PCATIG – SiO₂ & PCATIG – TiO₂ which resulted in higher micro hardness values around 70 – 75 Hv. Micro hardness are observed in different locations of weld surface such as 1mm, 2mm & 3mm below the weld surface and it also observed along the weld zone to heat affected zone upto 12mm for the profiling the micro hardness value around the weldment. Microstructure observed in weld centre for observed on weld zone & heat affected zone. Minimum micro hardness value between 63 – 65 Hv found in PCATIG – MnO₂, PCATIG – CaO & PCATIG – MgO due to intermediate micro structure between coarse and fine. PCATIG – Al₂O₃ weld zone & heat affected zone and heat affected zone of PCATIG – MnO₂, PCATIG – CaO & PCATIG – MgO shows coarse microstructure. This resulted in reduced micro hardness around 55 – 60 Hv. Coarse micro structure in weld zone and heat affected zone have least cooling rate. Fine micro structure in weld zone is due to higher cooling rate. Heat affected zone directly depends on temperature gradient between the weld centre and weldment heat affected zone.

1. Introduction

Gas Tungsten Arc Welding (GTAW) also known as Tungsten Inert Gas (TIG) welding showed high quality weld than other arc welding process. Non ferrous metals requires the quality weld with reduced defects and improved mechanical properties of the weld which showed, TIG is more suitable



welding process. However, its shallow weld penetration causes lesser production rate. Increase in weld passes for thick sections lead to higher input in the weld which reduces the weld strength [1] by producing the coarse grain microstructure [2].

To reduce the heat input into weld the Activated TIG welding (ATIG) a new variant was found out. ATIG welding process was developed in early 1960's by the Paton Welding Institute, Ukraine to improve the weld penetration [3, 4]. By improving the weld penetration, number weld passes get reduced by reducing the weld pass the heat input given the weld material is also get reduced [5]. The activated flux TIG welding may have two types of mechanisms that are mostly accepted, first one is based on the reverse Marangoni convection effect[6,7,8], and the other one is based on arc constriction effect [9, 10].

During reverse Marangonic convection, surface tension of weld pool becomes negative to positive by changing temperature co-efficient from positive to negative this lead to transfer heat flow rate in weld pool from weld pool edges to weld pool centre [11, 12]. This increases the heat concentration in weld pool centre and lead to increased weld penetration with decrease in weld width. This theory was proposed by Heiple and Roper [13, 14, 15]. During welding, active flux is dissociated into positive ions and negative ions. Positive ions on base material surface attracts the welding arc and negative ions cover the outer surface of the welding arc & acts as shield to cover welding arc [16, 17, 18]. Due to these arc gets constricted and heat of welding arc concentrated at weld region [19, 20]. This gave increased weld penetration with decreased weld width. This arc constriction theory was proposed by Lucas and Howse.

Pulsed current TIG (PCTIG) welding shows the improved mechanical behaviour than TIG welding. Improved mechanical properties on PCTIG weld is due to fine grain microstructure when compared to constant current TIG welding gave coarse grain structure [21]. During PCTIG welding, peak current gives adequate penetration, base current is responsible to maintain stable arc, pulse frequency & pulse on time gives enough time to transfer heat from the arc to weld material during peak current time, cool down the weld pool during base current time and transfer heat from weld zone to heat affected zone & also to base material region [22].

This reduces the width of the heat affected zone and thermally induced stresses. Due to heat input difference during the PCTIG welding between peak current and base current, weld pool cooled immediately and higher heat concentration on weld pool is reduced [23]. This gave fine grain microstructure on weld zone. Finer the grain size has increased grain boundaries which gave improved mechanical behaviour for PCTIG welded samples. Major Problem in welding of aluminium is hot cracking this can be reduced by reduced heat input and choosing of correct filler material.

Tensile properties, fatigue properties, impact toughness and hardness were increased by achieving fine equiaxed grain microstructure on weld zone by reduced heat input. Due to reduced heat on weld zone, heterogeneous nucleation sites will survive on weld pool which converts columnar denetritic grain into fine equiaxed grain [24]. Liquation cracks in the Heat affected zone acts as the

strong initiation sites for the solidification cracks which occur in weld zone, Healing of liquation cracks through back filling reduce the solidification crack in the weld zone. Pulsed current and Arc oscillation technique gives equiaxed fine grain structure which resist the hot cracking through the increased grain boundaries but in CCTIG have columnar grain structure this will have lesser grain boundaries [25].

Combining the pulsed current TIG and activated TIG welding (PC-A-TIG) on Al-SiC composite showed higher chance getting superior weld microstructure. So investigation of weld strength of Al-SiC composite with ATIG and PCATIG welding shows significance.

2. Experiments

Autogenous welding was performed on Al - 8% SiC composite material with a plate thickness of 5mm using ADOR CHAMPTIG 300AD welding machine. Other welding parameters considered during welding are provided in table 1. Welded samples were shown in figure 1-2.

Table 1: Welding parameter during CCTIG, PCTIG, ATIG and PCATIG welding

Parameter	Condition
Current Type	AC Current
Constant Current TIG	110 A
Electrode Diameter	3.2 mm
Electrode Material	2% Th - Tungsten Electrode
Arc Length	2 mm
Arc Voltage	18V
Welding Speed	2 mm/s
Argon Flow Rate	18 l/min
Active Layer Coating	0.5-1 mg/cm ²
Active fluxes	Al ₂ O ₃ , CaO, MgO, SiO ₂ , TiO ₂ & MnO ₂
Heat Input	990w
Peak Current	160A
Base Current	60A
Pulse On Time	50%
Pulse Frequency	5Hz

During welding, cooling rate at 10mm away weld zone was calculated from time - temperature profile acquired using data acquisition system (DAQ) through LabView software coupled with National Instrument NI cDAQ 9174 kit which employs a temperature acquiring module -NI 9211 with K type thermocouple.

Using standard metallographic procedure the welded samples were prepared for microstructure observation from microscopic image analyzer. Vickers micro hardness of different region such as weld zone, heat affect zone and base material were measured with load of 500g with 10 seconds as indentation time performed using Shimadzu micro hardness tester.



Figure 1: Welded samples of PCTIG, PCATIG- Al_2O_3 , PCATIG- CaO and PCATIG- MgO

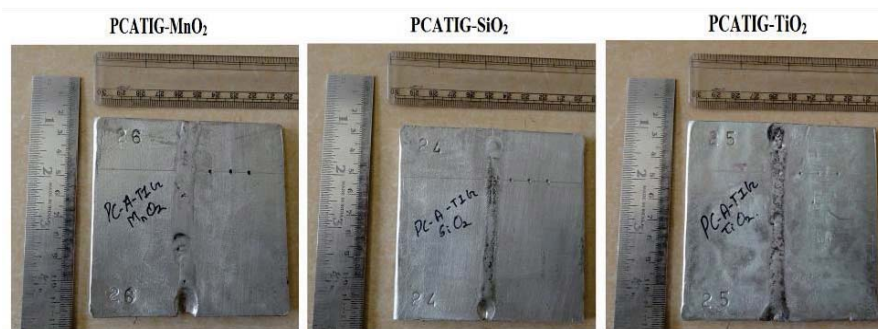


Figure 2: Welded samples of PCATIG- TiO_2 , PCATIG- SiO_2 and PCATIG- MnO_2

3. Results & Discussion

3.1 Micro hardness – PCTIG & PCATIG welded samples

Table 2: PCTIG & PCATIG welded samples micro hardness

Welding conditions	Weld centre (HV)		3mm away from weld centre (HV)		7mm away from weld centre (HV)	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
PCTIG	66.64	4.42	60.12	2.32	56.03	2.64
PCATIG- Al_2O_3	63.51	3.07	59.53	2.28	56.53	1.50
PCATIG- CaO	58.69	1.23	55.38	1.79	52.07	1.47
PCATIG- MgO	64.91	1.80	61.20	2.13	56.93	1.77
PCATIG- SiO_2	71.72	3.64	65.92	2.57	61.92	0.85
PCATIG- TiO_2	67.10	2.50	61.38	2.94	56.27	1.92
PCATIG- MnO_2	63.78	2.16	58.71	2.61	55.02	1.98

Table 2 shows the average micro hardness value of CCTIG & PCATIG weldment on weld centre, 3mm away from weld centre & 7mm away from weld centre. Standard deviation is also tabulated. Figure 3, shows the micro hardness 1mm below the weld surface. Figure 4 shows the micro

hardness value 2mm below the weld surface. Figure 5 shows the micro hardness values of 3mm below weld surface. Here micro hardness values are observed in different locations from weld centre to 12mm away from the weld centre. Micro hardness value did not have much change after 10mm away from the weld centre which is more or less equal to the base material micro hardness.

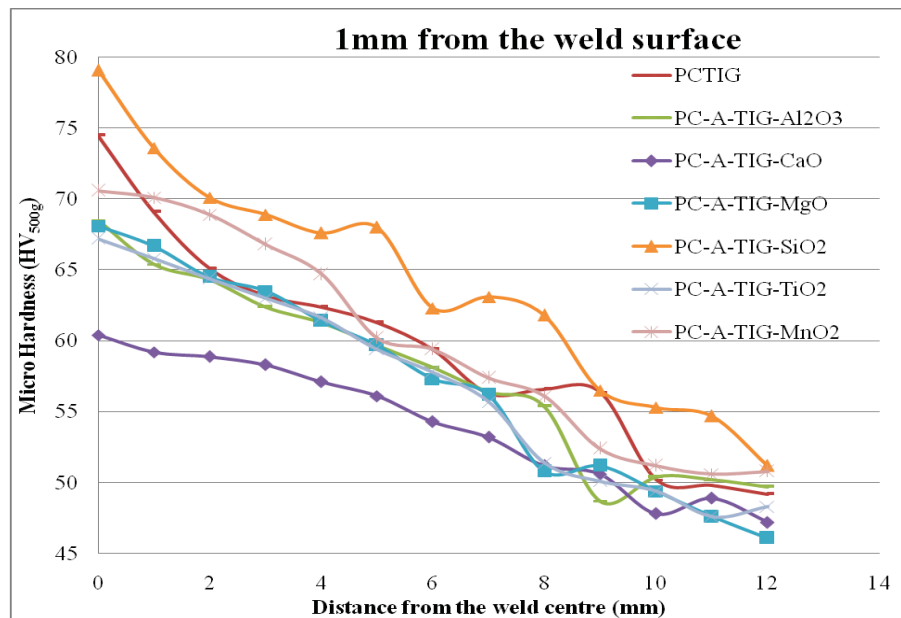


Figure 3: Micro hardness of PCTIG & PCATIG welded samples 1mm below the weld surface

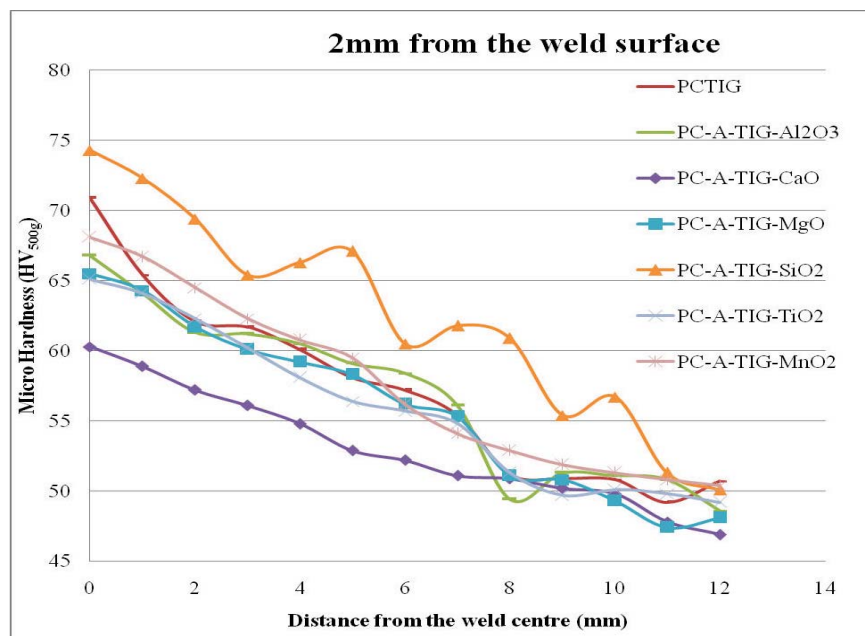


Figure 4: Micro hardness of PCTIG & PCATIG welded samples 2mm below the weld surface

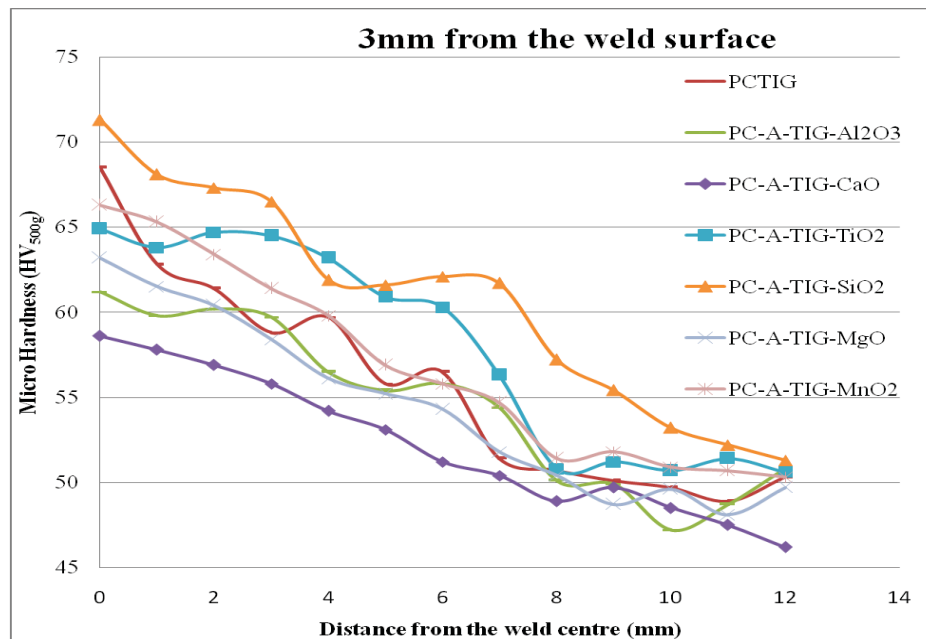


Figure 5: Micro hardness of PCTIG & PCATIG welded samples 3mm below the weld surface

3.2 Microstructure – Base material, PCTIG and PCATIG welded samples

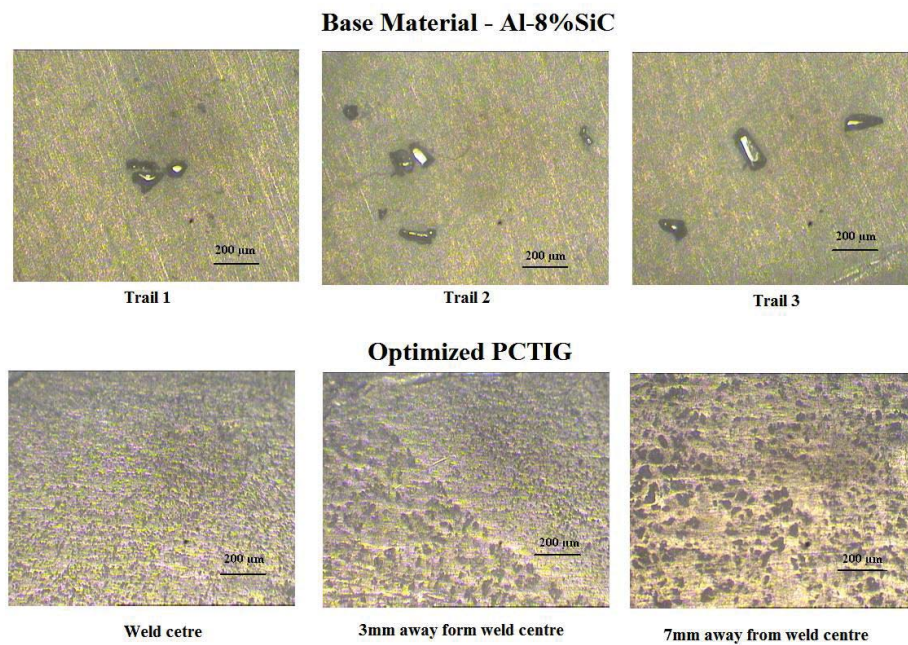


Figure 6: Microstructure of base material (Al – 8% SiC composite), PCTIG welded samples

Figure 6, shows the micro structure of base material, PCTIG welded samples. Figure 7, shows PCATIG – Al_2O_3 , PCATIG – CaO & PCATIG – MgO micro structure of weld zone, 3mm away from weld zone & 7mm away from the weld zone otherwise called as heat affected zone.

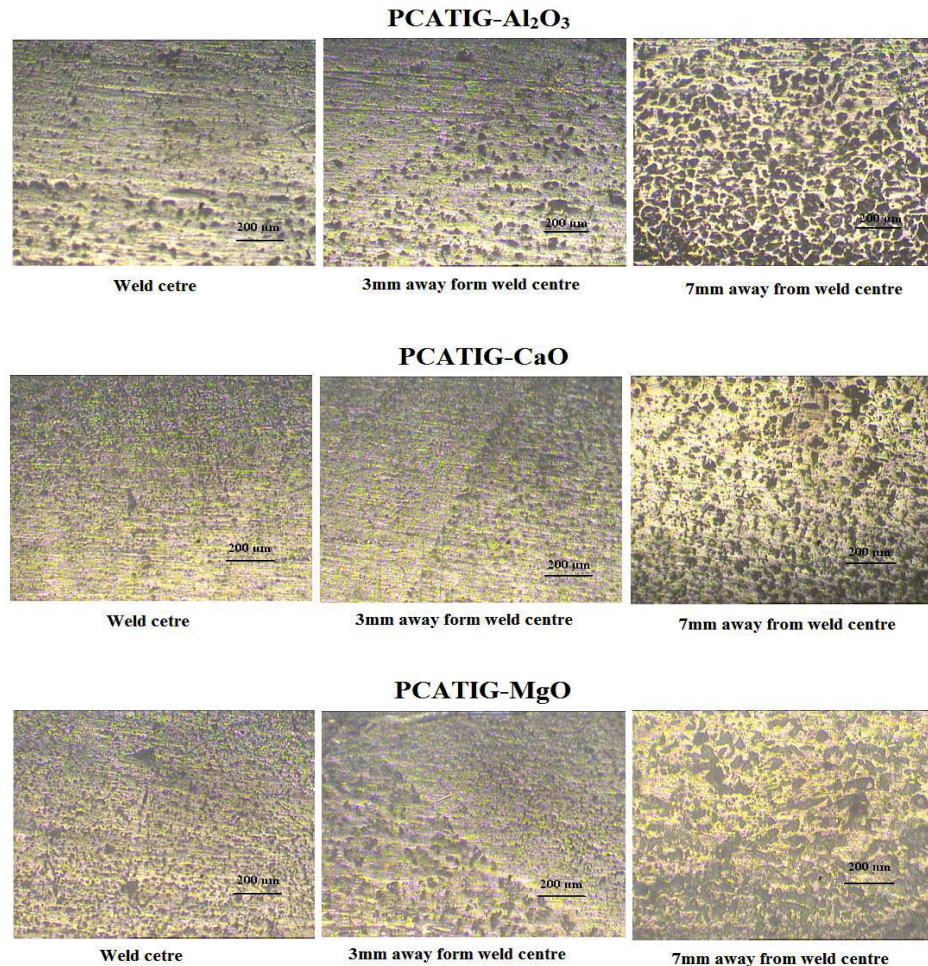


Figure 7: Microstructure of PCATIG welded samples with active fluxes such as Al_2O_3 , CaO & MgO

Figure 8 shows the micro structure of PCATIG – MnO_2 , PCATIG – SiO_2 & PCATIG – TiO_2 weldments. From Figure-6, the following results are observed, very fine grain microstructure is observed in base material and fine grain size microstructure in weld zone and in HAZ. Figure 7 shows PCATIG – CaO & PCATIG – MgO is also showed coarse grain structure which is similar to PCTIG welded microstructure. Intermediate size between fine and coarse microstructure is found in heat affected zone in PCATIG – MnO_2 & PCATIG – Al_2O_3 . Figure-8 shows PCATIG – SiO_2 & PCATIG – TiO_2 is having very fine grain microstructure in both weld zone and fine grain microstructure heat affected zone. Base material showed very fine grain microstructure.

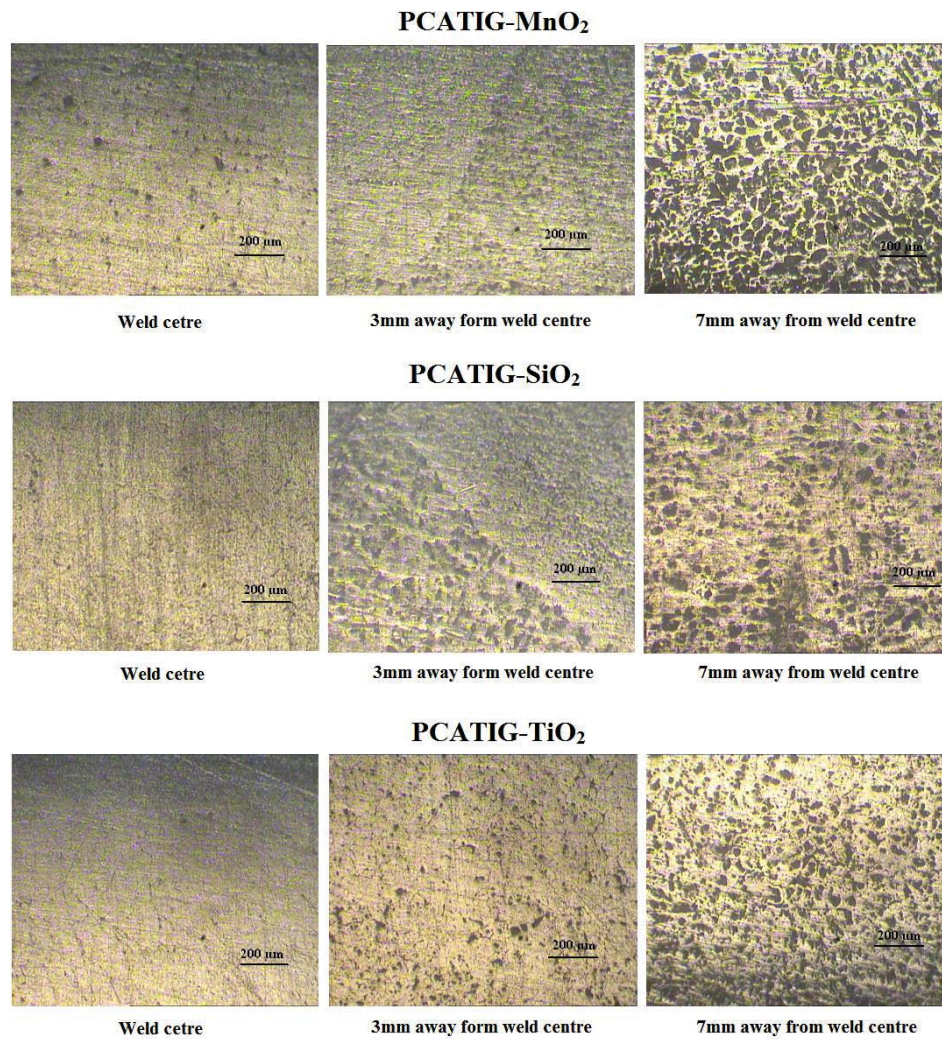


Figure 8: Microstructure of PCATIG welded samples with active fluxes such as TiO₂, SiO₂ & MnO₂

3.3 Cooling rate – PCTIG & PCATIG welded samples

Table 3: PCTIG & PCATIG welded samples cooling rate

PCTIG welding condition	PCTIG	PCATIG - Al ₂ O ₃	PCATIG - CaO	PCATIG - MgO	PCATIG - SiO ₂	PCATIG - TiO ₂	PCATIG - MnO ₂
Rate of cooling (K/s)	291	286	289	288	295	294	288

Table 3 shows the cooling rate CCTIG & ATIG weldments of various active fluxes are recorded and tabulated. Highest cooling rate is observed in PCATIG-SiO₂ followed by PCATIG – TiO₂ of 295K/s & 294K/s. Lowest cooling rate is observed in PCATIG – CaO & PCATIG – Al₂O₃ of 289K/s & 286K/s. Higher cooling rate produces the fine grain microstructure and lower cooling rate

produces the coarse grain microstructure in weld zone and heat affected zone. This is due to the temperature gradient observed in weld zone and between weld zone & heat affected zone.

4. Conclusion

Correlation between micro hardness, microstructure and cooling rate of Pulsed Current TIG welding and Pulsed Current Activated TIG welding on Al-SiC composite has been studied. Combining the pulsed current TIG and activated TIG welding (PC-A-TIG) on Al-SiC composite showed very fine superior weld microstructure on PCATIG – SiO₂ & PCATIG – TiO₂ which resulted in higher micro hardness. Micro hardness are observed in different locations of weld surface such as 1mm, 2mm & 3mm below the weld surface and it also observed along the weld zone to heat affected zone upto 12mm for the profiling the micro hardness value around the weldment. Microstructure observed in weld centre for observed on the weld zone. 3mm away from the weld centre line shows interaction of weld zone & heat affected zone. 7mm away from the weld centre line shows the heat affected zone. Minimum micro hardness value of found in PCATIG – MnO₂, PCATIG – CaO & PCATIG – MgO due to intermediate micro structure between coarse and fine. PCATIG – Al₂O₃ weld zone & heat affected zone and heat affected zone of PCATIG – MnO₂, PCATIG – CaO & PCATIG – MgO shows coarse microstructure. This resulted in reduced micro hardness. Cooling rate for the different PCTIG & PCATIG welding are recorded and correlation between the micro structures are studied. Coarse micro structure in weld zone and heat affected zone have least cooling rate. Fine micro structure in weld zone should have higher cooling rate. Heat affected zone directly depends on temperature gradient between the weld centre and weldment heat affected zone.

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