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Enhancing the Friction Welding on Cast\SIC Composites

S.Joe Patrick Gnanaraj, A. Abdul Munaf, P.Ebenezer Sathish Paul, M.Saravana Kumar, R.Prabaharan

Abstract—Investigation and feasibility of continuous drive friction welding of composite materials having different combination (3%, 6% and 9%) of Silicon Carbide was done. The homogeneous distribution between two mating parts and heat affected zone of Fully Deformed Region (FD), Partially Deformed Region (PD), Undeformed Region (UD) was analyzed by using Scanning Electron Microscope. After casting homogeneous distribution analysis was done by optical microscope. Vickers hardness testing was conducted at Welded area and Unwelded area of different combination of Silicon Carbide. Mechanical properties like tensile strength were also measured. It was found that, 9% Silicon Carbide reinforced particle strength and its hardness was increased in Al7075 matrix.

Keywords : : Friction welding, Heat affected zone, Hardness, Microstructure, Tensile strength.

I. INTRODUCTION

Friction welding is a widely used solid state welding process for joining of similar and dissimilar metals.It is used for mass production. The automobile and aerospace industry continuously search for less weight, high stiffness, high strength, high wear resistance, less co-efficient of thermal expansion and high thermal conductivity materials.

Al 7075 is an aluminium alloy with zinc as the primary alloying element. It has high strength compared to many steels. There are still many problems in the joining of discontinuously reinforced aluminium matrix composite.

The friction welding of mild steel and stainless steel are studied and the strength of the joints obtained were found to be good and reasonable **[1,2]**. The feasibility of joining Al_2O_3 reinforced Al alloy composite to SAE 1020 steel by rotational friction welding. The aluminium based MMC material containing 5, 10 & 15% Al_2O_3 particles with average particle sizes of 30 and 60 micron was produced by powder metallurgy technique. The integrity of the joints has been investigated by optical and SEM, while the mechanical properties assessment included micro hardness and shear test. Results indicated that Al/Al_2O_3 composite could be joined to SAE 1020 steel by friction welding. However, it was pointed out that the quality of the joint was affected negatively with the increase in particle size and volume % of the oxide particles in the MMC **[3]**. The heat transfer mechanism initiating the friction welding process was examined and a transient two dimensional heat conduction model for the welding of two dissimilar cylindrical metal bars was introduced. The bar materials consist of copper and steel. To relate the theoretical predictions with the resulting welds, experiments are conducted under different welding conditions by means of which metallurgical and microprobe analysis of the weld cross sections was carried out. This provides visualization of the melted zones and of the diffusion depths. A statistical analysis was carried out for the affecting parameters on the mechanical properties of the resulting welds. The factors affecting the weld include the speed of rotation, the weld duration (burn off time), and the friction load, while the mechanical properties include the tensile strength, the yield strength, the ultimate yield strength and the micro hardness of the weld cross-sections **[4]**. Yield strength, ultimate tensile strength, percentage elongation of the welded joints and hardness variations across the weld interface has been reported. The integrity of the joints has been investigated using optical microscopy and scanning electron microscopy **[5]**. Evaluate the possibility of using the linear friction welding (LFW) technique to produce sound joints on a 2124Al/25 vol% SiC composite. The MMC joints were subjected to micro structural and mechanical characterization, including hardness, tensile and fatigue tests, without any post weld heat treatment. The micro structural analyses showed substantially defect free joints, with a uniform particle distribution in the central zone and a relevant plastic flow of the aluminium matrix alloy. The hardness decrease in the welded zone was approximately 10% in respect to the base material. The joint efficiency was higher than 80%, both in respect to the ultimate tensile strength and fatigue strength at 107 cycles. S-N probability curves were calculated using the maximum likelihood method. Generally the fracture occurred in the Thermo-Mechanically Affected Zone (TMAZ), with a relevant reduction in the elongation to failure **[6]**. Effect of friction pressure on the properties of friction hot rolled MA956 iron-based super alloy plate, produced by mechanical alloying, has been investigated. Optimum friction pressure for this material was determined **[7]**.

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* Correspondence Author
S.Joe Patrick Gnanaraj*, Associate Professor, department of mechanical engineering, department, Francis Xavier Engineering college, Tirunelveli, India.
A.Abdul Munaf, Associate Professor, Department of Mechanical Engineering, Rajalakshmi Institute of Technology, Chennai, India.
P.Ebenezer Sathish Paul, Assistant Professor, Department of Mechanical Engineering, Francis Xavier Engineering college, Tirunelveli, India.
M.Saravana Kumar, Assistant Professor, Department of Mechanical Engineering, Francis Xavier Engineering college, Tirunelveli, India.
R.Prabaharan, Assistant Professor, Department of Mechanical Engineering, Francis Xavier Engineering college, Tirunelveli, India.

Frictions welding of two dissimilar materials, two rods are welded together by holding one of them still while rotating the other under the influence of an axial load which creates Frictional heat in the interface. In this study, mechanical properties of mild steel and aluminium welded rods were evaluated to understand the thermal effects, and an explicit one-dimensional finite difference method was used to approximate the heating and cooling temperature distribution of the joint. The thermal effects of the friction welding were observed to have lowered the welded materials hardness compared to the parent materials. The tensile strength of the welded rods is lower than the parent rods due to incomplete welding. The finite difference method proposed in this work will provide guidance in weld parameter development and will allow better understanding of the friction welding process **[8]**. The micro-structural properties and welding strengths of the joints using austenitic-stainless steel (AISI 304) parts. The experiments were carried out using a designed and constructed experimental friction welding set up, constructed as continuous drive. Under different friction time and friction pressure were carried out to obtain optimum parameters using statistical approach. The strengths of the joints were determined by tension, fatigue and notch-impact tests, and results were compared with strengths of materials. Hardness variations and microstructures in the interfaces of the joints were also obtained and examined. Then, obtained results were compared with those of previous studies **[9]**. An experimental set-up was designed in order to achieve friction welding of plastically deformed austenitic-stainless steels. AISI 304 austenitic-stainless steels having equal and different diameters were welded under different process parameters. Strengths of the joints having equal diameter were determined by using a statistical approach as a result of tension tests. Hardness variations and microstructures using scanning electron microscope (SEM) analysis in the welding zone were obtained and examined. Subsequently, the effect on the welding zone of plastic deformation was analysed. It has been established that plastic deformation of AISI 304 austenitic-stainless steel has neither an effect on the process nor on the strength of the welding joint **[10]**.

In the melting state, the liquid welding pool of composite had a great viscosity with poor flow ability, and it is difficult for composite itself to mix with the filler materials. Consequently, the formation of weld and the quality of welded joint are not satisfactory.

When the molten welding pool was cooled down, the reinforcement phases were rejected by the solidification front, and the normal solidification processes of the welding pool had been broken down, and this would lead to Microsegregation or inhomogeneous distribution of the reinforcement phases. In friction welding, this type of problem does not occur.

In this paper the authors discussed the welding effect on different heat affected zones Partially Deformed Region, Fully Deformed Region, and Undeformed Region.

After Spectrography test, the chemical composition of Aluminium 7075 was depicted in **Table 1**.

Table 1 - Chemical composition of Al7075 Alloy (Mass Fraction, %)

Si	Fe	Cu	Zn	Mg	Cr	Ti	Ni	Mn	Al
0.15	0.17	2.805	4.464	1.917	0.005	0.008	0.203	0.032	Bal

II. MATERIALS AND METHODS

The following equipments / testing machines were used for carrying out the experimental work.

1. Optical Microscope for analysing the macrostructure of the composite.
2. Scanning Electron Microscope for analysing the microstructure of the composite.
3. Universal Testing Machine was used to determine the welding strength of the composite.
4. Vickers Hardness Testing Machine was used to determine the hardness of the composite.

III. EXPERIMENTAL PROCEDURE

In this experiment, Stir casting method was used for the fabrication of Al7075 composite with 3%, 6% and 9% Silicon Carbide particles. First, the Die was designed and fabricated for the required size of 15mm diameter and 85mm length. It was heated to a temperature of 450 ºC. Aluminium alloy was heated in a graphite crucible. The furnace temperature was increased to 1050ºC, and held for 3 to 4 hours until Aluminium alloy gets melted completely. Aluminium dross was then removed from the surface of the molten metal. In the same manner, in another furnace required quantity of Silicon Carbide particles were preheated to 450º and maintained for 3 to 4 hours. The preheated Silicon Carbide particles were added continuously to the molten metal through the side of vortex by mechanical stirring with a stir impeller. The optimum stirring speed of 300 rpm was maintained. After casting, turning and facing of the component to 10mm diameter and 75mm length was done. Friction welding joining process parameter was optimized as mentioned in Table 2. After performing friction welding, the homogeneous distribution of welded area and heat affected zone were identified using Optical Microscope and then with Scanning Electron Microscope. Vickers hardness test was used for hardness measurement. Increase of welding strength due to usage of Silicon Carbide was measured by using Universal testing machine.

Table 2 - Friction Welding Parameters.

Burn off length	1.5 mm
Rotation speed	1450 rpm
Friction time	2.5 sec
Friction pressure	1.5 ton

IV. RESULTS AND DISCUSSION

A. Homogeneous Distribution Analysis

The Optical Microscopic results of Al7075 with 3%, 6% and 9% Silicon Carbide for different microstructures were given below in Fig. 1a, 1b, 1c. From the Optical Microscopic images, the homogeneous distribution of Silicon Carbide particles in Al7075 / SiC composites was observed.

Fig. 1a - 3%Silicon Carbide

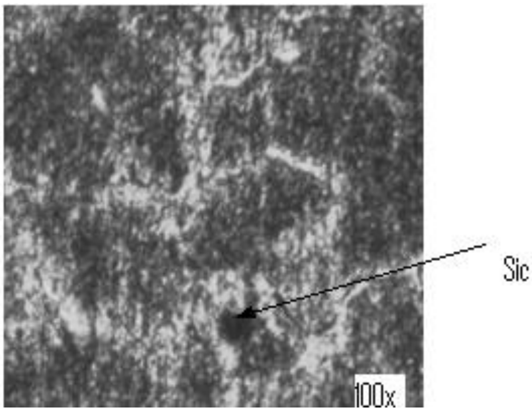


Fig. 1 b - 6% Silicon Carbide

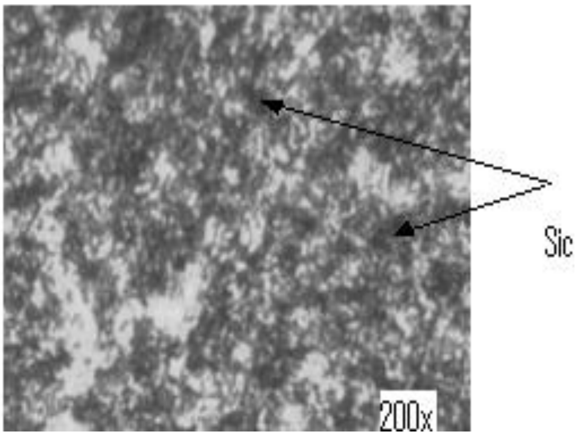


Fig. 1c - 9%silicon Carbide

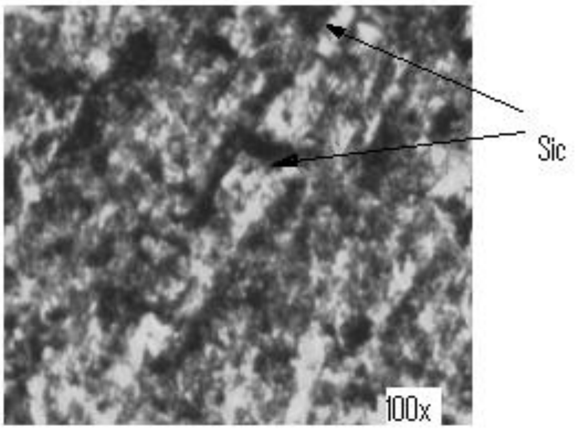


Fig. 1a, 1b, 1c. Shows the homogenous distribution of Al7075 composite with 3%, 6%, & 9% SiC particles.

B. Structure of the heat Affected Zone

The different combination of 3%, 6% and 9% of Silicon Carbide with Aluminium7075 alloy was welded. The friction welding machine was used to weld the composite materials. The friction pressure, rotation speed, burn off length, friction time were kept constant by varying the percentage of Silicon Carbide. The heat affected zone was formed during welding, which reduced the welding efficiency. The welding efficiency could be increased by decreasing the heat affected zone.

Fig. 2a - 3% Silicon Carbide

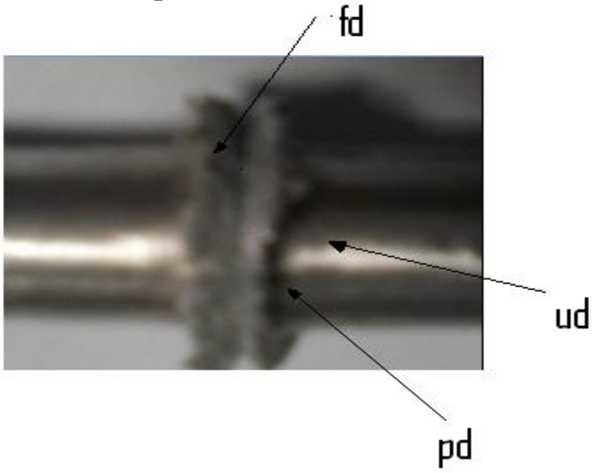


Fig. 2b - 6% Silicon Carbide

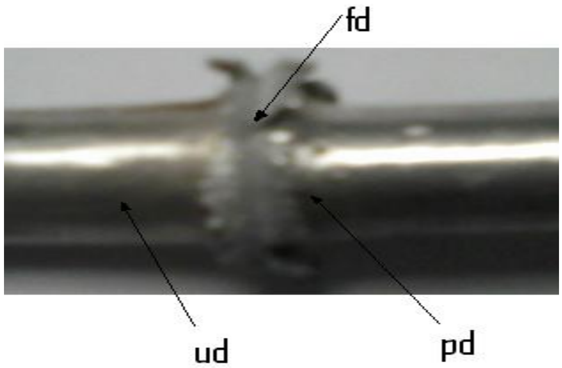


Fig. 2c - 9% Silicon Carbide

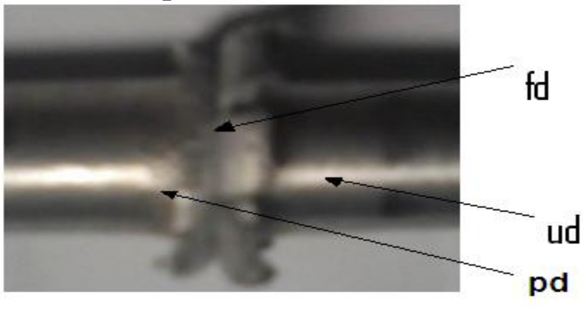


Fig. 2a, 2b & 2c shows the optical microscopic structure of the welded region of Al7075 composite with 3%, 6% & 9% SiC particles.

The images were displayed for different zone of Fully Deformed Region (FD), Partially Deformed Region (PD) and Undeformed Region (UD). After completing the experiment, the scanning electron microscope images of the specimen were taken and shown in Fig 3a, 3b, 3c, 4a, 4b, 4c, 5a, 5b & 5c.

The Scanning Electron Microscope images have shown that the particle size of Silicon Carbide in the Welded Region was smaller than the Unwelded region. The efficiency of the welding increased as the particle size decreases.

Here, welding region Silicon Particle size has reduced and homogeneous distribution of Silicon Carbide between two mating parts was identified. The different welding regions were identified as Fully Deformed Region (FD), Partially Deformed Region (PD), and Undeformed (UD) in the specimen.

Fig. 3 a - 3% Silicon Carbide (Weld Area)

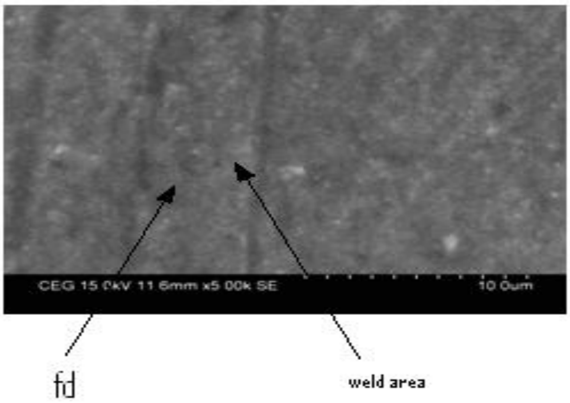


Fig. 3b - 3% Silicon Carbide (Partially Deformed Zone)

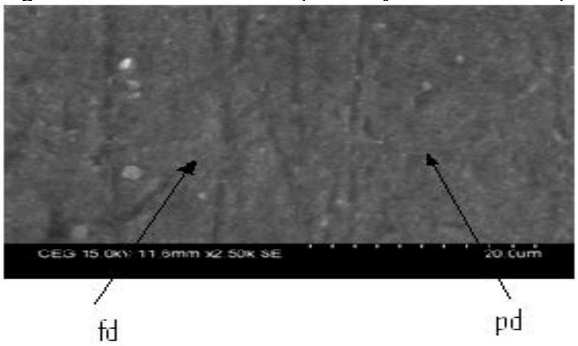


Fig. 3c - 3% Silicon Carbide (Undeformed zone)

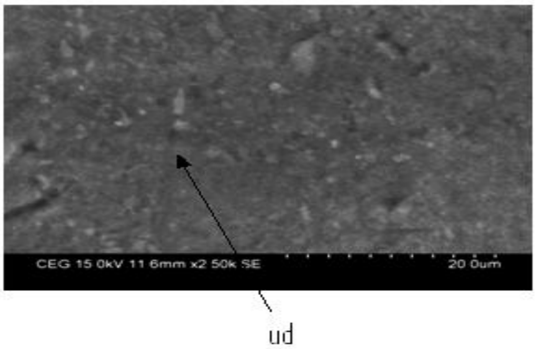


Fig. 3a, 3b & 3c shows the distribution of SiC between two mating parts in fully deformed, partially deformed, undeformed zones when 3% SiC used.

Fig. 4a - 6% Silicon Carbide (Weld zone)

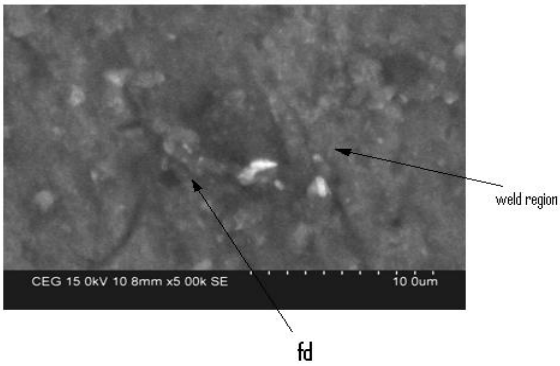


Fig. 4b - 6% Silicon Carbide (Partially Deformed Zone)

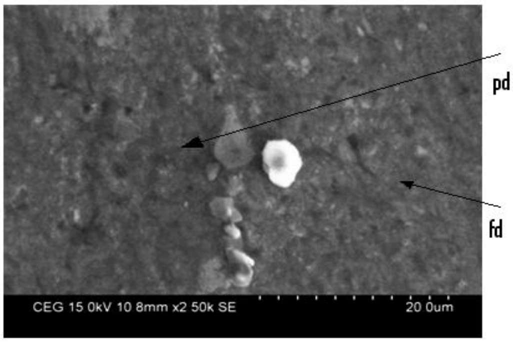


Fig. 4c - 6% Silicon Carbide (Undeformed Zone)

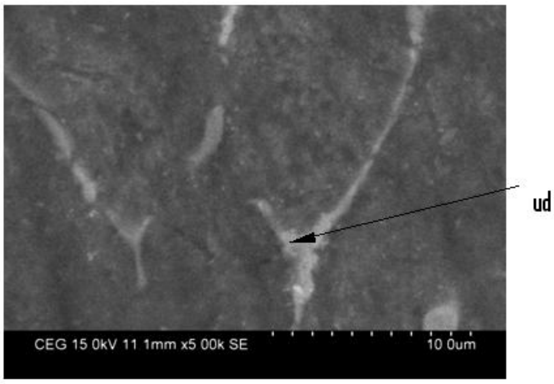


Fig. 4a, 4b & 4c shows the distribution of 6% of SiC between two mating parts in fully deformed, partially deformed, undeformed zones.

Fig. 5a - 9% Silicon Carbide (Weld Zone)

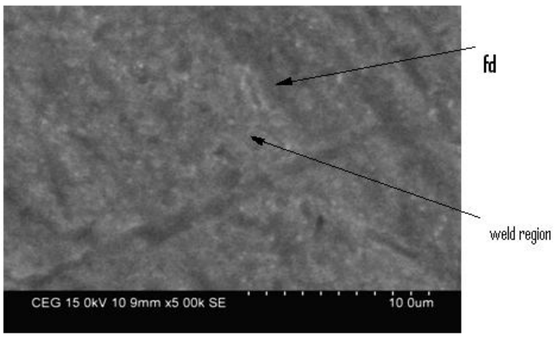


Fig. 5b - 9% Silicon Carbide (Partially Deformed Zone)

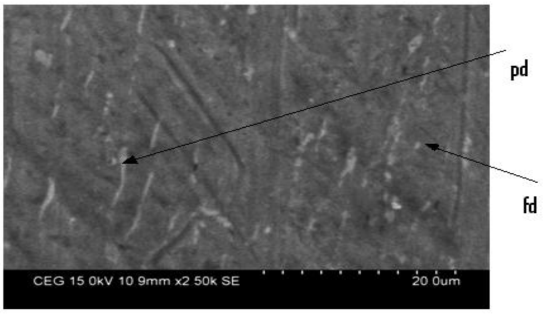


Fig. 5c - 9% silicon Carbide (Undeformed zone)

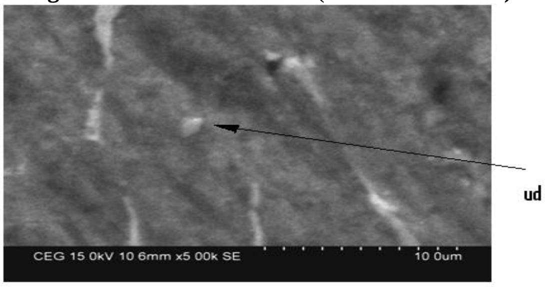


Fig. 5a, 5b & 5c shows the distribution of 9% SiC between two mating parts in Fully Deformed, Partially Deformed, Undeformed zones.

C. Strength Analysis

Welded specimen was tested in Universal Testing Machine UTN 40.SR NO 11/98 -2450. It was found that the tensile strength increased with the increase in Silicon Carbide particles. This means that the Welding Strength has also increased. From the Fig. 6, it was found that welding strength increased with increase in % of SiC.

The welding strength was measured at various levels. When the strength was 56.73 MPa, 3% SiC composite fractured outside the welded region. When MPa was 75.40, 6% SiC composite fractured at the welded region. But the 9% SiC was able to maintain its form upto 142.84 MPa and at this point fracture took place only outside the welded region. The values were tabulated in Table 3 and shown their graphical presentation in Fig 6.

Fig 6 Welding strength vs % of Silicon Carbide

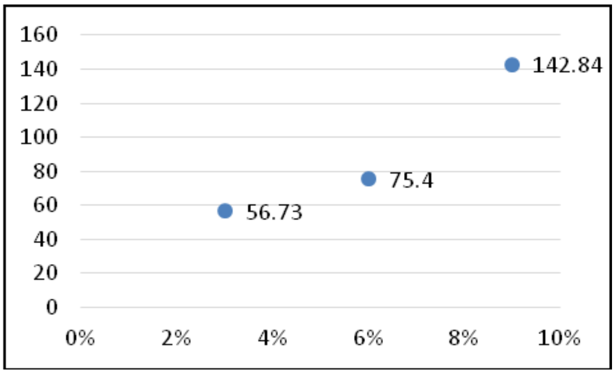


Table 3 Welding Strength

	Mpa	Fracture Location
Al7075+SiC 3%	56.73	Broken outside the welded area
Al7075+SiC 6%	75.40	Broken at the welded area
Al7075+SiC 9%	142.84	Broken outside the welded area

D. Hardness of the Heat Affected Zone

The Vickers Hardness Specimen of the casting samples were tested using Vickers Hardness Testing Machine. Testing was done on the Welded Region, Partially Deformed region and Undeformed region. The results of the samples were presented in the Table 4.

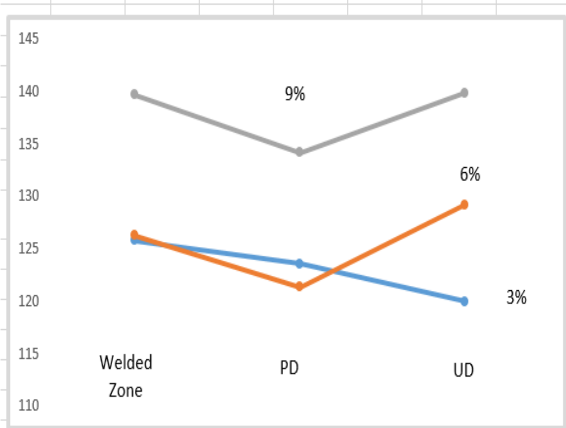
Table 4 - Welding Hardness

	Hardness in HV kg load		
	Welded	Partially Deformed	Undeformed
Al7075+SiC 3%	125.8	123.6	120.0
Al7075+SiC 6%	126.3	121.4	129.2
Al7075+SiC 9%	139.7	134.2	139.9

From the above table, it was observed that

1. With 3 % SiC composite welding hardness was 125.8 at welded region. In the partially deformed and deformed region welding hardness is slightly less than the welded region.
2. With 6 % SiC composite welding hardness was 126.3 in the welded region. The hardness was less in the partially deformed than the welded region but the strength is more in the undeformed region.
3. With 9 % SiC composite welding hardness was 139.7 in the welded region. The hardness was less in the partially deformed than the welded region but the strength is almost same in the undeformed region.

Fig. 7 -Welding Hardness Vs Welding Area



From Fig.7, it was found that the increase in percentage of Silicon Carbide increases the hardness of the composites.

In the Welded Region it was found that the hardness increased from 125.8 to 126.3 (0.396%) when the SiC percentage was increased from 3 to 6%. A sudden increase from 126.3 to 139.7 (10.61%) was found in the hardness when the SiC percentage was increased to 9% from 6%. In the Partially Deformed Region, hardness decreased from 123.6 to 121.4 (1.78%) when the SIC percentage was increased from 3 to 6%. A sudden increase from 121.4 to 134.2 (10.54%) was found in the hardness when the SiC percentage was increased to 9% from 6% In the Undeformed Region, hardness increased from 120 to 129.2 (5.167%) when the SiC percentage was increased from 3 to 6%. A sudden increase from 129.2 to 139.9 (10.856%) was found in the hardness when the SiC Percentage was increased to 9% from 6%.

The hardness variation in percentage of the different zones were tabulated in Table 5.

Table 5 - Hardness Comparison for Samples

S. No.	Increase of SiC, %	% Variation in Hardness (HV)		
		Welded	Deformed	Undeformed
1	3 to 6	0.396 increased	1.78 decreased	5.167 increased
2	6 to 9	10.61 increased	10.54 increased	10.856 increased

V. CONCLUSION

1. The Aluminium 7075/Silicon Carbide composites was casted with 3%, 6%, 9% of SiC and their homogeneous distribution were analyzed. The welding analysis was done in the heat affected zone. It was found that reduction of the heat affected zone increased the welding efficiency.
2. The Scanning Electron Microscopic images of Welding Region, Fully Deformed Region, Undeformed Region and Partially Deformed Region were identified and the result shows that the reduction in particle size increased their welding efficiency.
3. The welding strength of the composites increased due to addition of Silicon Carbide.
4. The welding strength proportionality increased when SiC percentage increased from 6 to 9 %.

List of Symbols

1. Aluminium - Al
2. Silicon Carbide - SiC
3. Vickers Pyramid Numbers - HV

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AUTHORS PROFILE

Dr.S. Joe Patrick Gnanaraj has completed his Under graduation in Mechanical Engineering from Sardar Raja College of Engineering, Tirunelveli, his Post graduation from National Engineering College, Tuticorin and Doctor of Philosophy in desalination. He has more than 11 years of teaching experiences. He had attended more than 15 conference papers and published 12 international journals.

Mr. A. Abdul Munaf, Associate Professor, Department of Mechanical Engineering, Rajalakshmi Institute of Technology, Chennai. Mail id: abdulmunaf.a@ritchennai.edu.in, Completed B. E Mechanical on 2002 at Jayamatha Engg. College, Completed M.E Cad on 2004 at Sathyabama University.

Mr. P. Ebenezer Sathish Paul, Assistant Professor, Francis Xavier Engineering College, Tirunelveli. Completed my Under Graduate in Mechanical Engineering from Karunya Institute of Technology, Coimbatore in the year 2006. Completed my Post Graduate in CAD/CAM from Mepco Schlenk Engineering College, Sivakasi in the year 2008. Work experience is more than 11 years. Presented more than 35 National/International Conferences and published 7 International journals. Life member in Indian Society for Technical Education.

Mr.M.Saravana kumar has completed his under graduation in mechanical engineering from Velammal College of Engineering and Technology in 2012. His Post graduation from regional center, Anna University Madurai in 2014. He has more than 4 years of teaching experience.

Mr.R.Prabaharan has completed his under graduation in mechanical engineering from Prist university in 2009. His Post graduation from Kalasalingam university in 2015. He has more than 4 years of teaching experience.