STUDIES ON STRENGTH ENHANCEMENT AND POROSITY REDUCTION IN MMCs BY FRICTION STIR WELDING PROCESS

A DISSERTATION

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Abstract

Metal matrix composites are suitable materials for engineering applications encountering surface interactions. Friction stir processing (FSP) is emerging as a promising technique for making surface composites. In this present study by friction stir processing the usage of particulate reinforced metal matrix composite (MMC) is steadily increasing due to its properties such as high specific strength, high specific modulus and good wear resistance. The welding parameters such as welding speed, tool rotational speed and profile of the tool are considered for analysis and the effect of the reinforcement particles on the mechanical properties of the metal matrix composite will be studied. The work piece (AA 7075) of cross-section 120 mm×100 mm and 6.35 mm thickness is prepared and a rectangular groove of depth 2.5mm and width 1.2 mm is prepared on the surface of work piece along the length.

The experiment is carried out with and without incorporating SiC particles along the joint line at different FSP process parameters. Cross-sectional microstructures of the joints are characterized employing optical and scanning electron microscopy (SEM). The results show that the Ultimate tensile strength (UTS) of FSPed specimen with SiC reinforcement is higher than the FSPed specimen without SiC reinforcement. Maximum UTS is obtained at FSP process parameters of rotational speed (N=931rpm) and transverse speed (v=34mm/min) including SiC reinforcement due to formation of good bonding at the interface of Al7075 matrix and SiC reinforcement. The presence of SiC particles in AA 7075 matrix are confirmed by EDX and XRD experiments. Porosity contents are reduced due to formation of strong interfacial bonding between SiC particles and AA7075 matrix at FSP parameters of rotational speed (N=931rpm) and transverse speed (v=34mm/min). Optical microscope and SEM image at FSP parameters of rotational speed (N=931rpm) and transverse speed (v=34mm/min) shows the uniformly distribution of SiC particles and excellent interfacial bonding is achieved at the interface of SiC particles and Al matrix.

Contents **Page No.**

Chapter 1: Introduction

Surface composites tend to show improved properties of composites on surface while keeping every one of the properties of the base material. FSP (Friction stir processing) is one of the procedures to manufacture surface composites and to change microstructural highlights. FSP was referred to by as a headway of FSW (Friction stir welding), a procedure presented at The Welding Institute (TWI), UK in 1991. In beginning stages FSP was utilized to deliver superplastic Al combinations with finest grain measure and of most extreme grain limit misorientations.

1.1 Overview of FSP

Friction stir processing has turned out from the fundamental of friction stir welding and acquainted as a trading off device with change the surface microstructure of metallic sheets and additionally plates. In Friction stir processing, the material surface is enhanced by embeddings a device which is pivoting that has a stick which is little toward the end and dove along a required length in other navigate bearing by applying a heap. So material at the blend zone goes plastic misshaping and sudden recrystallization is begun which prompts refinement of the microstructure.

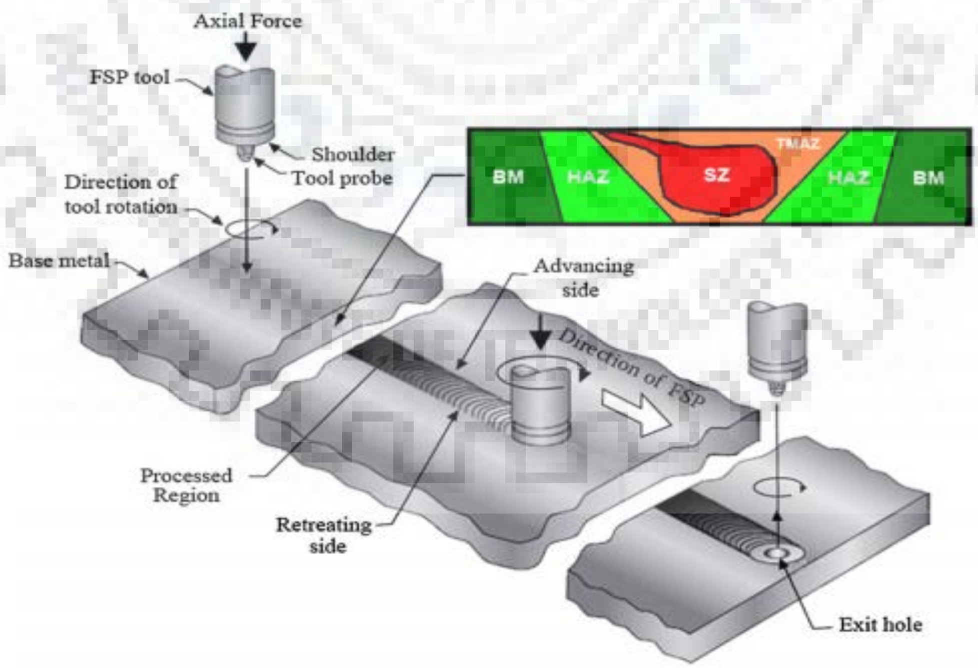


Fig. 1.1: A schematic diagram of FSW/FSP process [14]

1.2 FSW setup

The Friction stir welding set up has-

a. Vertical Milling machine

b. Fixture

c. Backing Plate

d. Tool

e. Specimen

Fig. 1.2: Conventional FSW machine [Reference: WRL Lab, IIT Roorkee]

1.3 Principle of operation

The friction stir welding process has four stages: 1) diving stage, 2) abiding stage, 3) welding stage, and 4) withdraw stage. It begins with the principal stage in which instrument approaches the material, and infiltrates in it to get the underlying warmth. In the second stage we require the working temperature to begin the procedure. It has a consistent weight constrain which is to be in the middle of the apparatus and the material that makes the mechanical vitality as grinding. This proceeds beneath the material's versatile modulus then we apply required weight constrain amongst device and material which brings about the type of drops that is an indication that we have required temperature is come to and we can begin the welding procedure. Presently the welding stage is accomplished through a thermo-mechanical process that has the joined activity of warm warming and also the plastic disfigurement. Getting welding in the grating blend welding forms tends to blend the "sticky" material of the work piece along the coveted joint line. It is given that the temperature accomplished in this sort of warming does not have an entire dispersion, essential materials of both the pieces which are to be joint should be blended mechanically with the apparatus stick. Mechanical work assumes an imperative part in this friction stir welding process since it the two influences the age of warm vitality as grating and also it guarantees the entire blending of base materials in the "sticky" stage with a specific end goal to get a quality and a sound weld joint. In the last (Final) stage, instrument expels from the material totally by the vertical development so the welding cycle is finished.

The friction stir welding strategy has its most extreme use in butt and lap welding, in which to make corner joints is totally conceivable. The required warmth is produced utilizing an extraordinary device which has a body with a bigger measurement as shoulder and a pin.

Fig. 1.3: A typical macrograph with various microstructural zones in FSP AA7075-T651 [5]

1.4 Metal Matrix Composites

Metal matrix composite has a metallic lattice which is strengthened with some another materials, by and large in type of the filaments, particulates, bristles and so forth. MMCs have high particular quality and also high particular modulus and furthermore have the great potential for high break sturdiness and the ecological protection. Thusly these have the ability to supplant metal amalgams in every one of the applications. Metal matrix composites are generally made out of a malleable network with solid fragile strands, hairs or the particles. Consistent filaments might be a few times metallic or artistic. Beryllium (with low thickness and high modulus), steel (with high quality and ease) and tungsten (with high modulus and great hard-headed) are the real metals which are utilized as nonstop fortifications. Nonstop earthenware fortifications have alumina, silicon nitride, silicon carbide, boron carbide and also boron nitride. The Boron and carbon filaments once in a while utilized as nonstop fortification. Irregular fortification typically takes type of the silicon carbide, alumina hairs or the silicon carbide particles.

The most essential Metal matrix composite frameworks, for example, boron/aluminum, carbon/aluminum, alumina/aluminum, silicon carbide/aluminum, alumina/magnesium, and silicon carbide/titanium are those which fortified with the non-metallic strands. The plan and the type of Metal matrix composites have advanced with improvement of the manufacture strategies for both the strengthening materials and the get together of composites. These systems are likewise has an imperative factors in getting the idea of fortification lattice interface, so these are quickly considered.

1.5 Materials selection

1.5.1 Reinforcement selection

A determination criterion for the ceramic reinforcement includes:

(a) Elastic Modulus

(b) Density

(c) Tensile Strength

(d) Thermal Stability

(e) Melting Temperature

(f) Thermal Expansion Coefficient

(g) Shape and Size

(h) Compatibility with Matrix Material

(i) Cost

The auxiliary effectiveness of the intermittently strengthened Metal matrix composite is capacity of thickness, versatile modulus and also the elasticity of fortifying stages. The compound strength and in addition the similarity of fortifications with grid material are so essential for end application as well as in material creation. The warm befuddle strain amongst fortification and the lattice is an essential thought for the composites which will be presented to warm cycling that is a component of contrast between the coefficients of warm extension.

1.5.2 Matrix selection

The generally utilized auxiliary aluminum amalgams (6xxx and additionally 7xxx) can be utilized as frameworks; the utilization of Metal grid composite for the lifted temperature applications requires the nearness of thermodynamically stable scatterings which are extremely vital. This necessity has been got by utilizing a composite dispersed framework in which the natural dissolvability, strong state diffusivity and also the interfacial energies are limited, by limiting coarsening and in addition interfacial responses.

The prerequisites of low thickness with high warm conductivity have made aluminum and magnesium composites the most regularly utilized networks. As for alloying increments, the consequences of studies have demonstrated that the low network alloying augmentations gets in Metal matrix composite with a decent blend of quality, malleability and in addition durability.

1.6 Interfacial Bonding in Metal Matrix Composites

Association of support and the framework was first perceived at a beginning time as one of the basic factor in deciding the properties of the subsequent Metal Matrix Composites. So it is important to have control on the both support framework interfacial holding keeping in mind the end goal to get ideal mechanical properties and dissemination response at the interface so to limit the fiber corruption. The support framework interface in Metal Matrix Composites as in different composites can depend on mechanical holding or some of the time substance holding. The interface which we have amongst framework and artistic fortification is of our advantage in light of the fact that the attributes of the locale decide the heap exchange and the break protection of the Metal Matrix Composites amid misshaping. The properties which we have at interface contribute absolutely to the general working and the conduct of composite. It is watched that heap exchange over the interface is absolutely in charge of quality and the firmness. Flexibility is affected by the unwinding of pinnacle pressure some place close interface and the sturdiness is absolutely reliant on split diversion in interface. In this way, it is fundamental to know the responses at interface while thinking about any Metal Matrix Composites.

On account of Al-SiC (Aluminum-silicon carbide) the essential response at interface is:

$$4Al + 3\ SiC \rightarrow Al_4C_3 + 3Si$$

The Al_4C_3 layer at interface is shaped and Al_4C_3 which is weak in nature is insoluble and subsequently it frames either as withdrew accelerate or the nonstop layer around SiC particles. Be that as it may, silicon enters the aluminum (Al) grid to shape another Al-Si double composite. The Al_4C_3 layer at interface enhances normal counterbalance yield quality of 0.2%, extreme rigidity and work-to crack and also work solidifying rate with a slight lessening in malleability of material.

1.7 Problems identified during fabrication of MMCs

The strengthening material by and large conveys the majority of load and grid material by holding together which empowers stack exchange. The upsides of utilizing materials with metals as lattices incorporate the high elastic and additionally shear moduli, great weakness and the break properties, the warm extension coefficient low esteem, high softening point and high durability, malleability so as high warm and electrical conductivities and also great disintegration as well as erosion protection with great dimensional strength and the great dampness protection. What's more Metal Matrix Composites with aluminum as the lattice advantage from great wear protection, high particular modulus and the particular quality.

It is currently acknowledged that keeping in mind the end goal to amplify the interfacial bond quality in Metal Matrix Composites, it is important to advance the wetting, control compound communications, and the limit oxide arrangement. The communication might be in type of the mechanical locking or the compound holding amongst network and support. The concoction holding amongst fortification and grid must be considered in the conjunction with alternate components. On account of creation systems and difference between physical properties of the earthenware production and the metals, acquiring a well agreeable interface amongst support and the network can speak to a significant issue. Diverse coefficients of the warm development in support and the lattice may bring about the lingering worries in composite because of creation process.

1.8 Fabrication of surface composites using FSP

The Secondary stage particles might be consolidated and appropriated in the metal amid Friction stir processing to manufacture the surface Metal Matrix Composites. Alongside the joining optional stage particles, the grain estimate lessening at surface can be completely accomplished, which is another preferred standpoint with Friction mix handling. Typically restricted notch or a few gaps are delivered on surface of sheet so optional stage particles are completely filled before Friction stir processing is done which is appeared in Fig. 1.4-

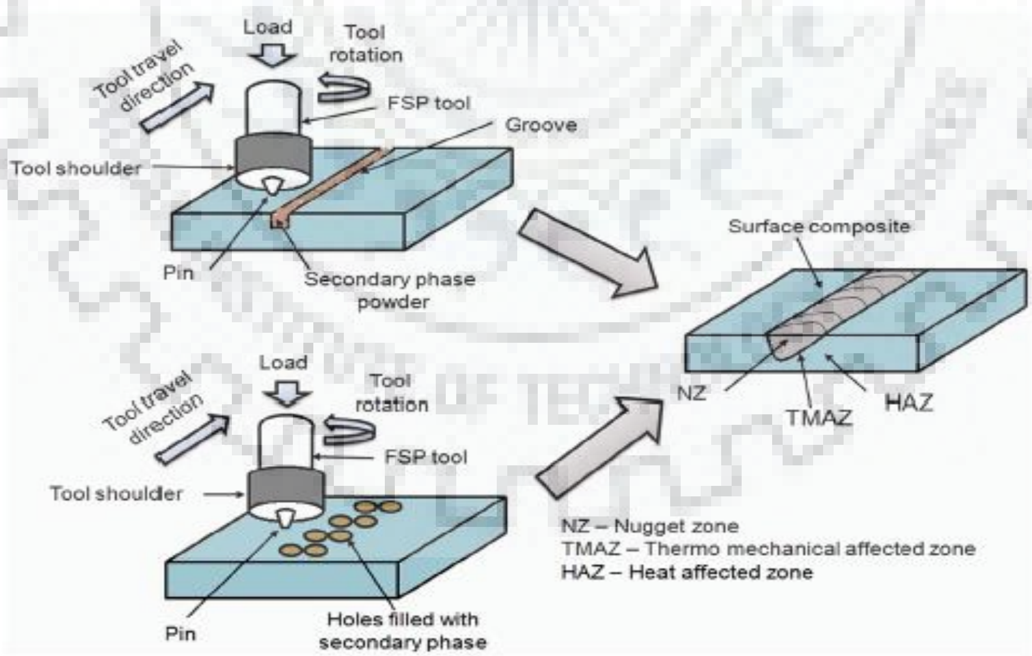


Fig. 1.4: Illustration representation of surface MMCs manufacture by FSP [29]

Portions of the couple of strategies are created to bring auxiliary stage particles into framework material amid Friction stir processing as given beneath:

i) Groove filling technique in which the section is created on surface of work piece and it is loaded with optional stage and Friction stir processing is done totally finished the furrow.

ii) Groove filling and the end technique includes shutting groove with a stick less Friction stir processing device subsequent to filling groove with the optional stage to maintain a strategic distance from escape of auxiliary stage amid Friction stir processing.

iii) Holes filling is likewise another strategy in which the small visually impaired openings are penetrated on surface of the work piece and it is loaded with the optional stage and Friction stir processing is completed.

iv) The gaps filling and the end strategy includes shutting of gaps when they are loaded with the optional stage like notch loading with help of stick less Friction stir processing instrument.

v) Sandwich strategy is the another method for scattering optional stage into lattice material in which auxiliary stage is placed in type of the overlay or a layer between work pieces and the sandwich sort of game plan is made. At the point when Friction stir processing is done, auxiliary stage layer is completely scattered however out mixing zone.

1.9 Effect of process variables

These fall into the three classes as machine variables, tool design variables and the material properties. Mechanical properties of the base materials are definitive in choosing process factors. Many of the process variables are always decided by knowing the mechanical properties of the base material.

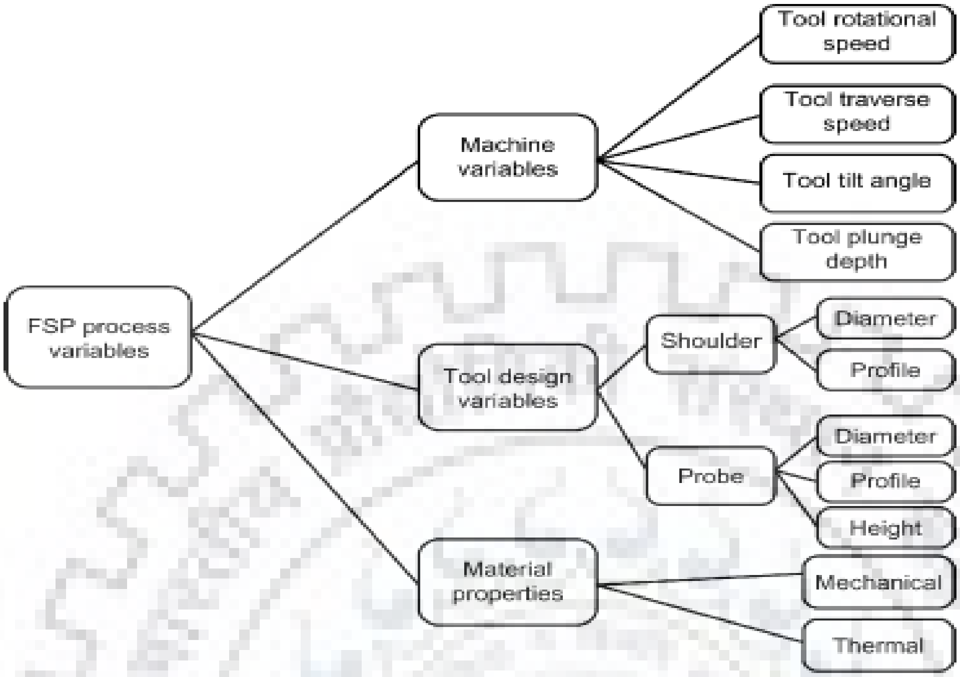


Fig. 1.5: Classification of FSP process Variables [23]

Table 1.1: Summary of major FSW parameters and their effect on the process [16]

Process parameter	**Effect on FSW process**
Rotation speed of tool	Pinnacle temperature rises with expanding rotational speed.
Transverse speed	Pinnacle temperature diminishes with expanding welding speed.
Tool Tilt angle	Reasonable tilt point may enable the device to hold the blended material and exchanged the material effectively from the front to the back.
Vertical weight or inclusion profundity of stick bear	Too high weight prompts overheating, unreasonable glimmer and joint diminishing; while too low weight may cause lacking warming and inward voids or surface furrow.

1.9.1 Machine variables

The Major machine factors are device rotational speed and the apparatus cross speed. The Tool rotational and the transverse velocities decide the measure of the warmth created in work piece. The Tool tilt edge and the infiltration profundity likewise influence arrangement of the SZ, however as a rule these are kept steady. The association of turning instrument with the work-piece produces warm due to erosion and the plastic distortion. Warmth contribution to the SZ impacts the material stream and the microstructure development which has a specifically effect on mechanical and a portion of the tribological properties. The Tool rotational speed and the cross speed decide the measure of warmth contribution to handled zone. Greatest temperature watched for the different aluminium amalgams has been observed to be in scope of 0.6– 0.9 liquefying temperature. The adequate measure of the warmth age in SZ is vital for development of the imperfection free handling zone .So as in Friction blend preparing of alternate composites for instance magnesium, copper and numerous titanium combinations in which warm age in prepared zone is absolutely reliant on the rotational and the cross rates.

1.9.2 Effect of tool speed

The Rotational speed (w) and the welding speed (v) decide measure of warmth contribution to SZ, which influences microstructure and the resultant properties. Lower warm information brings about the more grain refinement and the other way around is additionally valid, however there must be some warmth contribution to plasticize or relax the required material. In the surface composite creation, higher rotational speed (w) is required for the appropriation and separating of groups of the fortification particles. So high rotational speed influences grain refinement because of the high warmth input. Rotational and the cross speed must be advanced to get an imperfection free mix zone and the lessened grain estimate however much as could reasonably be expected for requires application.

1.9.3 Tool geometry

The Tool geometry for the most part comprises of the shoulder measurement, the shoulder highlight, the test shape, the test estimate and the test include. The Flow of plasticized material in the handled zone is completely influenced by the device geometry and in addition the navigate and the rotational movement of hardware. Instrument geometry is likewise an essential part of

Friction stir processingas it straightforwardly influences the warmth age, material stream and in addition resultant microstructure. General device geometry of Friction stir processinghas shoulder of hardware having the sunken moulded profile is utilized as it fills in as escape volume or a repository for uprooted plasticized material from test. The Tilt point is required to keep up material supply underneath device and it empowers trailing edge of shoulder device to expel prepared material. The Tilt edge of 1– 3◦ is utilized for the viable preparing of material. The instrument bear is absolutely in charge of the warmth age. The utilization of expansive width shoulders prompted the high warmth age and the improved material stream though the littler distances across brought about the arrangement of a portion of the imperfections in composites.

1.10 Properties of Aluminium Alloy (AA 7075)

Essentially Aluminum combinations are ordered into the two noteworthy classes as non-warm treatable and the warmth treatable compounds. Non warm treatable compounds don't tend to fortify by warm treatment though the warmth treatable composites tend to reinforce by warm treatment. The improved quality properties in the warmth treatable composites absolutely rely upon knowing marvels of the age-solidifying. In light of quality properties we can state that the warmth treatable composites are arranged into two principle classifications: One of those with the medium quality which are weldable effortlessly and those with the high quality which have an exceptionally restricted weldability. These high quality compounds have been on a very basic level produced for the air ship developments .Aluminum combination 7075 comes into this classification.

It is one of most grounded aluminum amalgams with the high quality to weight proportion. Aside from high quality, these combination has an especially high reaction to the normal age solidifying which settles on it a characteristic decision for the quantity of air ship structure applications, numerous military vehicles, the earth moving gear, numerous scaffolds and in exceedingly focused on safeguard applications It winds up essential in welding of the precipitation hardenable amalgam as 2xxx and 7xxx arrangement aluminum (Al) compounds. Lower warm information brings about the deformities as stick gaps and the passage absconds. With the higher warmth input that fortifying hastens attempt to break up absolutely in grid and we see that bunching of encourages bringing about the poorer mechanical quality of conclusive joint. At numerous spots the device geometry assumes fundamentally an indispensable part in deciding measure of the warmth age amid Friction stir welding.

Table 1.2: Chemical composition of the Aluminum Alloy AA 7075 (in wt. %) [18]

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others	Al
0.4	0.5	1.85	0.3	2.86	0.25	6.0	0.2	0.05	Balance

1.11 Silicon Carbide-Aluminum MMC

The most essential property of the aluminum-silicon carbide with reference to aeronautic trade is absolutely its quality to weight proportion that is three times more than the mellow steel. Likewise we have composites which containing SiC that is strengthening material and AA 7075 that is framework and composites have a high modulus, the quality qualities, the wear protection, the high warm steadiness, so as less weight and the more compelling burden conveying limit when contrasted with a significant number of alternate materials. In this way, it can be seen that these materials offer numerous impressive points of interest to avionic business particularly in the applications that require a decent warm and a decent pliable properties.

1.12 Reactivity of the Metal Matrix and the Reinforcing Material

The properties at interface contribute fundamentally to general working and the conduct of composite. It is seen that heap exchange crosswise over interface is absolutely in charge of the quality and the solidness and we additionally watch that flexibility is affected by the unwinding of pinnacle worry close interface and the sturdiness has reliance on break avoidance in interface. Along these lines, it is basic for contemplating responses at interface while thinking about any Metal network composite.

On account of the Al-SiC essential response at interface is:

$$4Al + 3\ SiC \rightarrow Al_4C_3 + 3Si$$

The Al_4C_3 layer at interface is shaped and Al_4C_3 which is weak in nature is insoluble and frames either as separated encourage or constant layer around SiC particles. By one means or another Si enters aluminum grid for framing an Al-Si paired compound. The Al_4C_3 layer at interface enhances normal balance yield quality very nearly (0.2%), a definitive elasticity, the work-to break and the work solidifying rate with just a little diminishment in malleability of material.

Be that as it may, before investigating purposes behind the adjustment in a portion of the properties, it is extremely basic to consider crack attributes of the two kinds with and without Al_4C_3 layer. At the point when Al_4C_3 is truant break that is split proliferation chiefly occurs through the de attachment at interface. The explanation for this is numerous particles are just in part attached to framework. By one means or another when the Al_4C_3 layer isn't truant, crack spreads basically through the molecule breakage, so proposing the solid interfacial bond. The 'all around fortified' interface affirms more productive load exchange crosswise over interfaces and furthermore it is prevalently in charge of increment in the mechanical properties. The purpose behind the expanded bond quality of that much is expected to the Al_4C_3 layer's capacity of framing introduction connections and the semi-sound interfaces with the both lattice and additionally the particles and furthermore on account of it is 'keyed' into the two surfaces.

1.13 Gaps and opportunities

Compared to unreinforced metals, metal matrix composites reinforced with ceramic phases exhibit high strength, high elastic modulus, improved resistance to wear, creep and fatigue, which make them promising structural materials for aerospace and automobile industries. However, these composites also suffer from a great loss in ductility and toughness due to incorporation of no deformable ceramic reinforcements, which limits their applications to a certain extent. For many applications, the useful life of components often depends on their surface properties such as wear resistance. In these situations, it is desirable that only the surface layer of components is reinforced by ceramic phases while the bulk of components retain the original composition and structure with higher toughness.

In recent years, several surface modification techniques, such as high-energy laser melt treatment, high-energy electron beam irradiation, plasma spraying, cast sinter, and casting have been developed to fabricate surface metal matrix composites. Among these techniques, laser melt treatment (also called laser processing or laser surface engineering (LSE)) is widely used for surface modification.

However, it should be pointed out that the existing processing techniques for forming surface composites are generally based on liquid phase processing at high temperatures. In this case, it is hard to avoid the interfacial reaction between reinforcement and metal matrix and formation of some detrimental phases. Furthermore, critical control of processing parameters is necessary to obtain ideal solidified microstructure in surface layer. Obviously, if processing of surface composite is carried out at temperatures below melting point of substrate, the problems mentioned above can be avoided.

Based on the basic principles of Friction stir welding (FSW), another nonspecific handling method for microstructural adjustment, Friction stir processing (FSP) has been created. FSP has discovered a few applications for microstructural alteration in metallic materials, including microstructural refinement for high strain rate super versatility, manufacture of surface composite on aluminium substrates, and homogenization of microstructure in Nano stage aluminium alloys, metal matrix composites.

Chapter 2: Literature review

Dinaharan et al. [30] conveying aluminium system composites Aluminium lattice composites (AMCs). Aluminium mix AA6082 as the system material and diverse fortifying like SiC, Al_2O_3 and WC, are used as helper atom. AA6082 AMCs are delivered using a game plan of streamlined process parameters. Plate is of size (100× 50 × 10) mm were used for this examination .A despondency of 5 mm significant and 1.2 width is machined along the inside line of the plates. Five such plates were contact mix dealt with by changing aesthetic particles, for instance, SiC (8μm), Al_2O_3 (1μm), TiC (2μm), B4C (4μm) and WC (5μm). The instrument had a shoulder width of 18 mm, stick estimation of 5 mm, stick length of 5.5 mm and a hung stick shape**.**

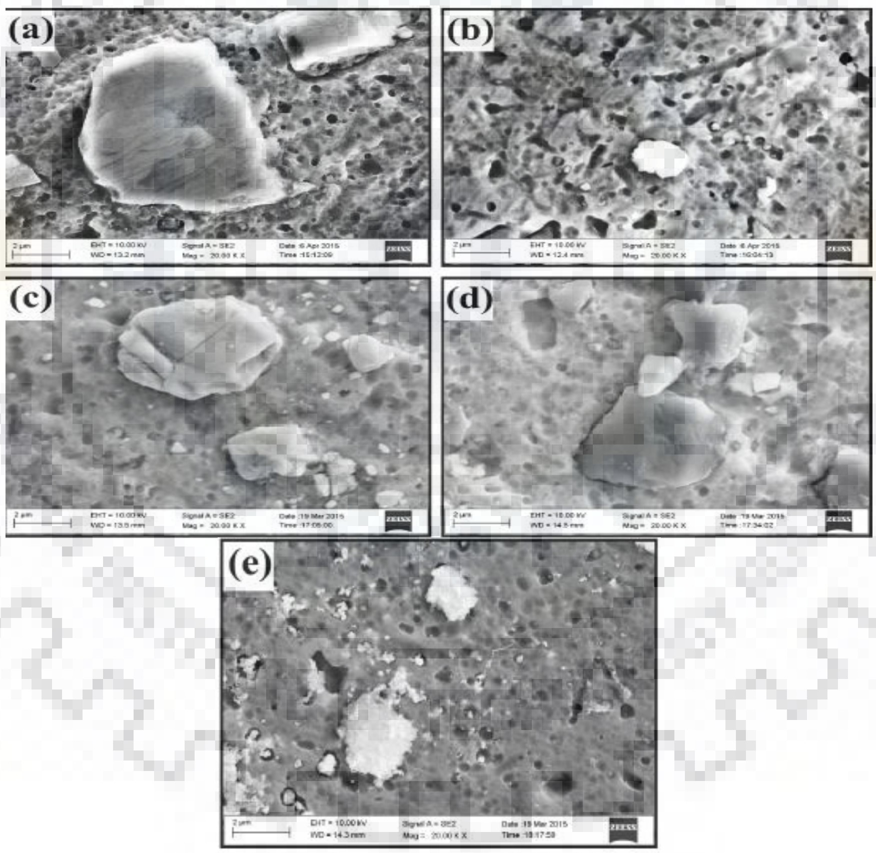


Fig. 2.1: FE-SEM microstructure AA6082 Aluminium matrix composites AMCs reinforced with (a) SiC, (b) Al_2O_3, (c) TiC, (d) B_4C and (e) WC at greater magnification [30]

Where rotational speed of tool is of 1600 rpm, travel speed is of 60 mm/min and vital power is of 10 KN. The scrambling is considered here intragranular in nature and in this way mechanical and tribological properties of Aluminium grid composites (AMCs) are influenced by diffusing. A uniform and furthermore intragranular sprinkling is central to accomplish extraordinary mechanical properties. The dispersing of let go particles is a component of process parameters, for instance, contraption rotational speed and cross speed. They observed no interfacial reaction among aluminium and let go particles and hence incredible interfacial holding. Each and every let go atom updated the UTS of mix AA6082 and break mode moved from pliant to frail.

Abraham et al. [31] shown manages change of AMCs strengthened with (SiO_2) particles using FSP. Scores are made on AA6063 plates and packed with (SiO_2) particles. Aluminium composite AA6063 plates of measurements 100 mm × 50 mm × 10 mm are considered for this investigation. A despondency of 5.5 mm significant is made along the centre line of the plates. The ordinary size of quartz particles used as a piece of this work is 32µm and instrument have a shoulder estimation of 18 mm, stick broadness of 6 mm and stick length of 5.8 mm. The technique parameters used were according to the accompanying: gadget rotational speed = 1600 rpm; explore speed = 60 mm/min, crucial power = 10kN and device tilt point = 0◦.

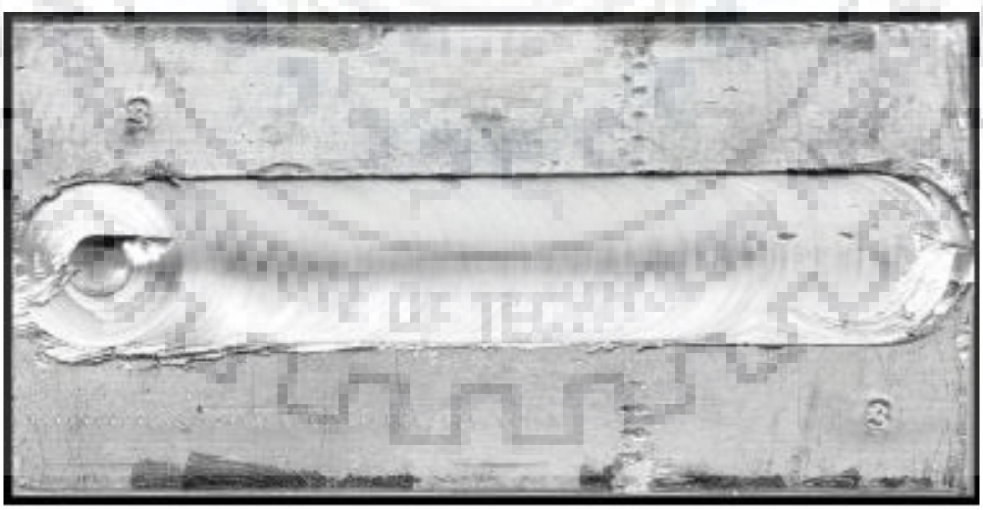


Fig. 2.2: Normal crown appearance of FSPed Aluminium Alloy AA6063 with quartz particles [31]

Top appearance of a blend zone of rubbing blend took care of AA6063 with (SiO_2) particles. The surface of the best is smooth lacking any distresses, voids and dis-coherencies. There are no flaws on the crown. The crown is depicted with bow striations which were made as a result of the rubbing movement of the turning instrument. The quartz particles were passed on reliably in the aluminium structure paying little respect to the zone inside the mix zone. The appropriation of the quartz particles updated the miniaturized scale hardness and wear protection of the AMCs. The part of (SiO_2) particles on the well-used surface and wear trash is depicted. The quartz particles are reliably spread in the composite autonomous of the volume division. The movement was free upon the zone inside the blend zone. The quartz particles experienced changes alive and well on account of high strain rate experienced in the midst of FSP. The interface between the quartz particle and the aluminium network apparently was spotless without the improvement of any kind of intermetallic. The grain size of the composite is refined comprehensively by the mix of extraordinary plastic misshaping and the staying effect of quartz particles. Separations are seen around quartz particles on account of warm befuddle between the aluminium lattice and the quartz atom. Quartz particles extended the micro hardness of the composite.

Bahrami et al. [25] investigated the benefits of SiC particles of Nano sized on mechanical properties and microstructural of the FSPed joint, the test was reiterated while SiC particles have been implanted along the FSP joint line. In the joint, a square stick mechanical assembly was associated in the second go to evaluate the ampleness of trading pin geometry between passes on the already said properties. Microstructure features including grain measure, second stage particles and bolster flow were moreover investigated. The aluminium plate was cut into 120 mm×80 mm strips with a execute shears machine. Therefore, a 0.2 mm wide, 5 mm significant and palatably long profile was made on the faying surfaces of each strip. Improved process parameters are of rotational speed, N=1250 rpm and welding speed, v=40 mm/mn. It was revealed that the extension of SiC nanoparticles improved extraordinary inflexibility and extending by up to 7.2% and 137.7%, independently. Perfect properties were refined in TS case. The replacement of square stay with hung diminished one in the 2^{nd} pass updated extraordinary versatility and extending by up to 7.7% and 4%, independently. SiC fortified illustrations exhibited higher hardness levels concerning without SiC case. Case FSWed without powder is suggested as TW. In like way, TT stays for the illustration FSWed under a comparative getting ready condition while SiC particles were incorporated.

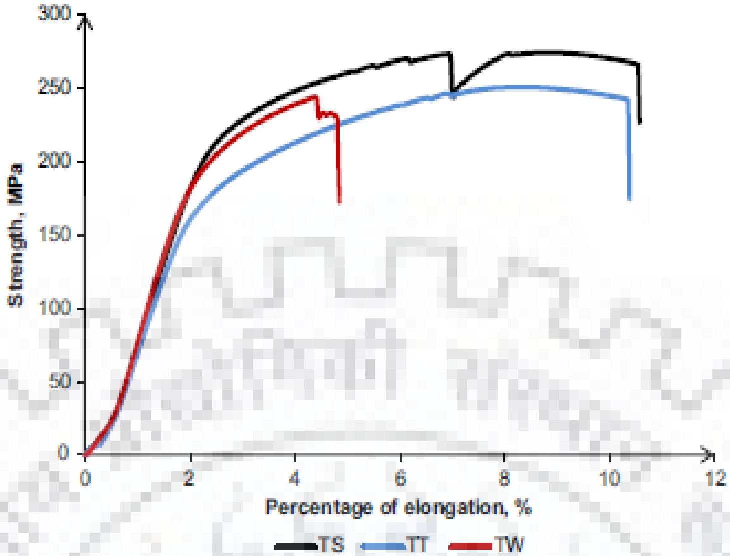


Fig. 2.3: Stress strain graph of FSWed joints [25]

Barmouz et al. [9] used an unadulterated copper plate of measurements (120 mm X 75 mm X 6 mm) .Keeping as a main priority the ultimate objective to make layers of surface composites, 5 lm SiC particles were created in a segment with the estimations of 1mm X 1.2 mm in the midst of the illustrations. By then, the SiC particles were stuffed into the score and upper surface of the segment was closed with a FSP-like gadget without stick to deflect flooding SiC particles. The perfect rotational and explore speeds, realizing a perfect level of powder movement, were 950 rpm and 45 mm/mn, exclusively. Planning gadget was titled by an edge of 2º.Shows the pliant test comes to fruition for unadulterated copper, 1P, 4P and 8P. A complete versatility (UTS) was decreased in situ Cu/SiC composites developed by FSP which was credited to the low wettability of SiC particles. As showed by the results, the UTS is extended subsequent to growing the amount of passes; however 8 Pass which exhibited the most astonishing Ultimate tensile strength among the illustrations containing composite layers is still lower than that of unadulterated Cu.

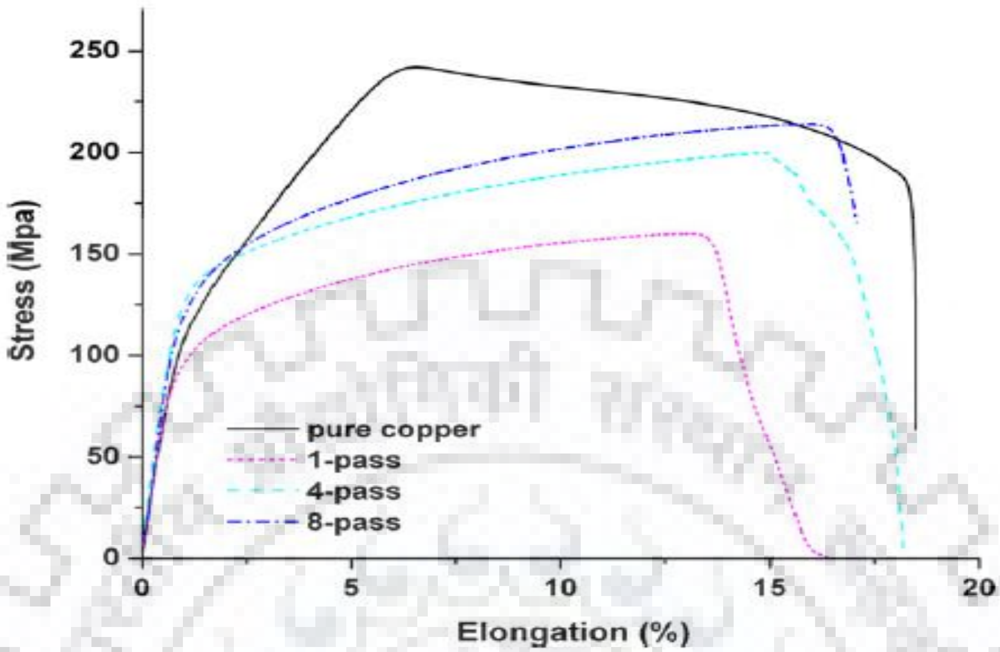


Fig. 2.4: Stress-strain graph for pure Cu and 1-pass, 4-pass and 8-pass, respectively [9]

It can be concluded from their work are as follows:

(1) Multi-pass Friction stir processing(FSP) decreases the SiC particles measure and upgrades the disseminating and parcel of SiC particles in view of lengthier time and genuine blending action in the Stir Zone.

(2) The grains size of the Cu arranges is strikingly diminished by extending FSP passes.

(3) Accurate interfacial holding diminishes the porosity substance.

(4) These recorded essential characteristics watched fate redesign in mechanical properties and electrical resistivity

Akramifard et al. [20] presented examination on unadulterated Cu sheets was strengthened with 25 µm SiC particles to make a layer of surface composite by Friction stir processing (FSP). Remembering the ultimate objective to advance allocation of reinforcing SiC particles, a net of openings were sketched out by enter on the surface of unadulterated Cu sheet. Unadulterated Cu sheets with the estimations of (100 X 70 X 5) mm^3 are used as base mterial. SiC particles (25 µm) used as stronghold. The instrument was tilted 3º from the plate common course.

The enduring rotational and transverse speeds were 1100 rpm and 45 mm/min independently. Wear insurance, Cu/SiC composite were differentiated and unadulterated Cu. Lessening weight in unadulterated Copper is additional than Cu/SiC composite.

Different explanations behind change of wear protection, for example,

1. Orowan strengthening instrument since of fine dispersing of SiC particles.

2. Overhauling micro hardness in perspective of SiC particles, and subsequently change in wear insurance.

3. Reducing direct load contact between Cu/SiC composite and stick in examination with that in unadulterated Cu by virtue of isolating burden between SiC particles and Cu.

XRD instances of SiC powder and Cu/SiC composite. It can be realised that SiC is available in the composite. Since the volume part of Copper is greater than that of SiC, SiC crests in Cu/SiC composite emits an impression of being slight. Vanishing of SiC appearance is an eventual outcome of scattering and lessening of SiC particles survey. Plainly no intermetallic compound has been formed after FSP.Amid hurling of Cu/SiC composite, the implantation of SiC particles to unadulterated Cu acknowledges progression of Cu_3Si intermetallic as exhibited by this response: $Cu + SiC = Cu_3Si + C$. The progression of intermetallic compound can affect properties of composite. Regardless, the temperature of FSP is lower than that of hurling thusly, intermetallic mixes can't be shaped.

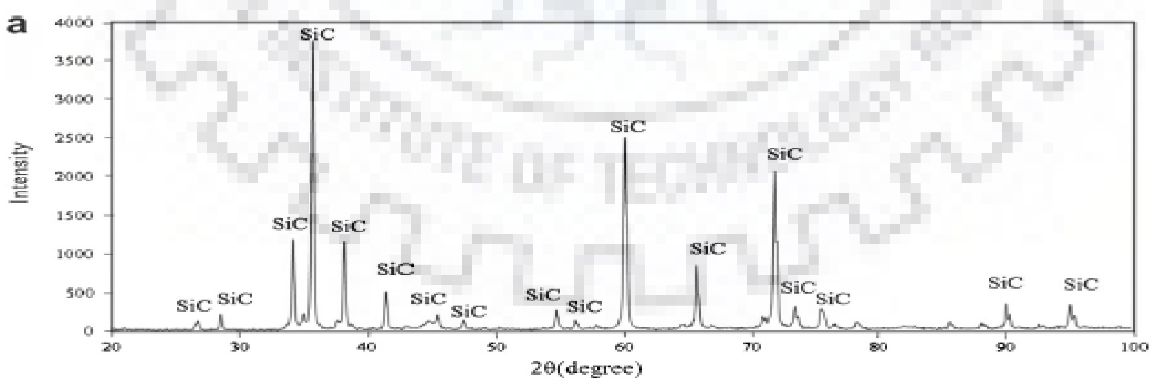


Fig. 2.5: XRD analysis [20]

Rajakumar et al. [32] researched the effect of procedure moreover, instrument factors on flexibility properties of AA7075-T6 joints conveyed by contact blend welding was explored. Square butt joints were made by moving strategy considerations and instrument factors. Quality properties of the FSPed joints were estimated and related with the microstructure, micro-hardness of weld piece. From this examination it is found that the joints fabricated at a gadget rotational speed of 1500 rpm, welding rate of 61 mm/min, critical energy of 9KN, using the instrument with 20 mm bear width 6 mm stick width, 46 HRC gadget hardness yielded higher quality properties appeared differently in relation to different joints.

Results obtained from their work are as follows-

(1) The joint fabricated using the FSW methodology parameters of 1500 rpm (instrument rotational speed), 61 mm/min (welding speed), 9kN (vital power), with the gadget parameters of 20 mm (bear remove over), 6 mm (stick width), 46 HRC (apparatus hardness) yielded higher quality properties contemplated to various joints.

(2) The most outrageous quality properties of 325 MPa yield quality, 383 MPa of inflexibility, 387 MPa of indent tractable quality, 213 HV of hardness and 67% of joint viability exclusively was proficient for the joint made using over the method and mechanical assembly parameters.

(3) Deformity free fine grained microstructure of weld piece and reliably flowed better $MgZn_2$ particles in the weld lump are seen to be the basic segments accountable for the higher inflexibility of the above joint.

Hamdollahzadeh et al. [26] surveyed the ampleness of second pass getting ready on scaled down scale structure and mechanical properties of the FSWed joint, Friction stir welding (FSW) reiterated under a comparable dealing with conditions. Cross-sectional examination offered verification to the soundness of the two joints. Microstructural discernments were coordinated by optical microscope. It was shown that the two-pass took care of case had coarser microstructure than 1-pass set one up. Conclusions In this examination, SiC nanoparticles were consolidated between interfacing strips. FSW was driven with a square stick gadget for one and two passes and the going with results were accomplished:

(1) Particles transport in second-pass arranged cases was better than one-pass took care of example.

(2) Lower UTS of two pass FSWed case to one pass FSWed one was credited to coarsened $MgZn_2$ precipitates in the Heat affected zone.

(3) 2^{nd} pass treatment of Al 7075 blend extended the extent of recrystallized grains and improved joint adaptability because of outstanding weight lessening.

(4) Ductility comes to fruition were endorsed through FESEM micrographs taken from split surfaces of pliant illustrations.

The FSW strategy is measured to occur at great strain rates and allow a high strain to the metal encompassing weld device. In this manner, outstanding plastic turning and frictional warming result in the age of a fine-grain microstructure inside the Stir Zone. This wonder is known as one of a kind recrystallization (DRX). Not simply give nucleation regions amid DRX, bolster particles go about as preventions against grain limit improvements. This event is measured as staying sway**.**

Khorrami et al. [21] studied the impact of SiC nanoparticles on the friction stir preparing of extremely distorted aluminium. (1)Extraordinary grain development happens at the blend zone amid FSP of CGPed aluminium without Nano particles which can demonstrate for in strength of extremely distorted aluminium upon FSP.

(2)Increment in FSP pass number doesn't have noteworthy impact on the blend zone of the example FSPed without nanoparticles; however for tests FSPed with SiC nanoparticles, it can strongly influence the appropriation of nanoparticle sand the microstructural advancements and mechanical properties of the blend zone.

(3)Because of the idea of material stream in the mix zone amid FSP, broad bunches of SiC nanoparticles are framed at their treating side of the mix zone for examples that have undergone 1 and 2 passes of FSP prompting fragile break at these zones nonetheless, amid the third go of FSP the groups of SiC can be smashed and all around appropriated. Accordingly, any wellspring of stress focus isn't shaped at the mix zone and this example is broken from out of the mix zone amid transverse pliable test.

(4) The third go of FSP utilizing SiC nanoparticles can prompt the change of the micro hardness of the blend zone by around 118.8% regarding that of FSPed with no molecule.

(5) From this investigation, it is presumed that applying SiC nanoparticles amid FSP of CGPed aluminium sheets can successfully hinder the grain development at the mix zone, especially for 3 passes FSPed test.

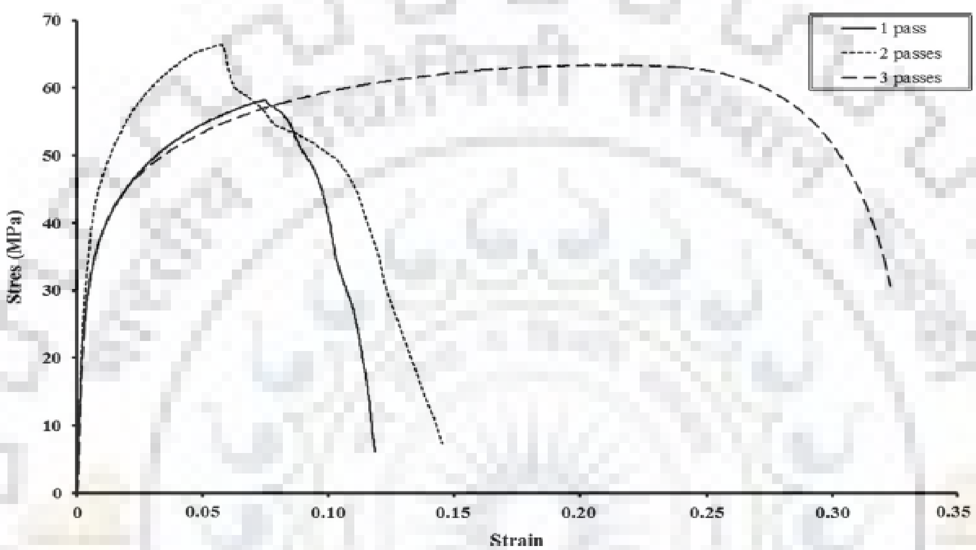


Fig. 2.6: Stress–strain graph of specimens FSPed at different pass numbers with SiC nanoparticles [21]

Bahrami et al. [19] mulled over the piece of SiC nano-particles in upgrading the mechanical properties of friction stir welded (FSWed) Al 7075 composite is looked into. To this end, rubbing mix welding (FSW) was driven at 1200 rpm and 45 mm/min. The trial did with and without uniting SiC nano-particles along the FSP joint line. A 6mm thick aluminium composite of 7075 was picked as the base material. A while later, 100mmX50 mm strips were given using a guillotine shears machine. Impacting a rack to like wrinkle (5mm significant and 0.2 mm wide) on the faying surfaces of each plate allowed SiC strongholds to be combined into the cross section.

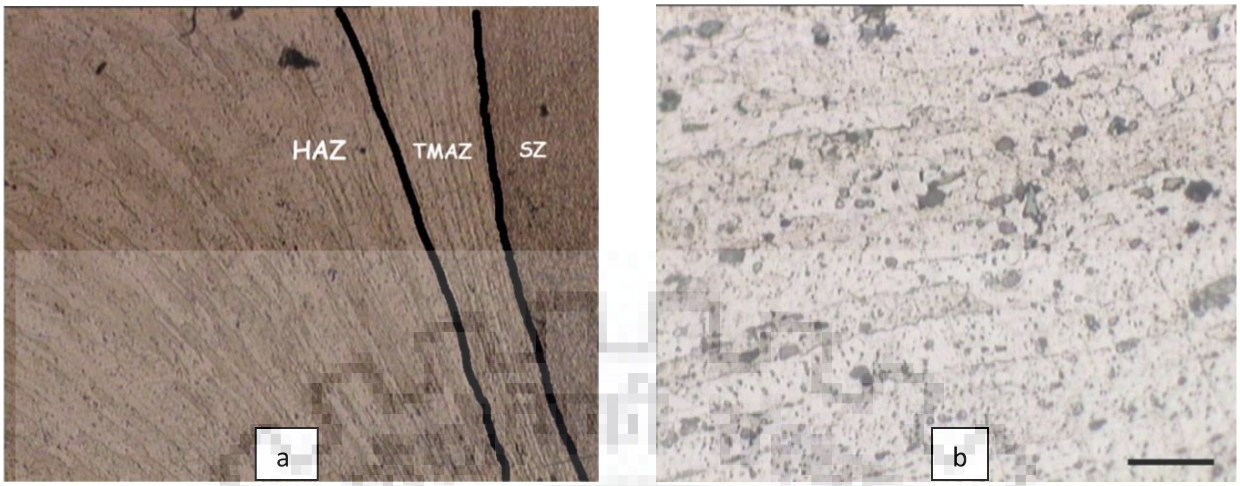


Fig. 2.7: (a) Three main areas in a FSW and (b) BM [19]

Some gave a result which is refining of grain related with Silicon carbide nanoparticles brought about higher exhaustion life. Plus, the weakness test example containing SiC nanoparticle cracked far from the SZ, without SiC example, in any case, broke from SZ. Shows test examples after exhaustion test. This finding unmistakably demonstrates that SiC fortification shad constructive outcome on affect vitality ingestion. As such, sturdiness expanded because of better grain size. Higher sturdiness of the SiC-included example affirms higher UTS and percent stretching of this example as for those of without SiC example.

Wang et al. [7] depicted the SiCp/5A06Al more broad and more significant mass composite was made successfully by using rubbing blend dealing with. Extraordinary interface conditions among reinforcing particles and base material could outline in the midst of this system. The breadth of reinforced territory was varying close by the significance. The transport of made MMCs did not limit to surface composites under device bear or of course agglomerate in nm to 100m degree. The SiCp could stream past the TMAZ under the gadget bear, and it secured the extent of 1.5mm isolated from the edge of the stick at the pushing side. Nevertheless, the width pushed toward getting to be littler in more significant position, and the scattering of MMCs was around 2.5mmat the significance of 2mm, which was in the extent of stick at the moving side. Remembering the ultimate objective to make the SiCp stream in more broad territory, the material should be brought upward relying upon the piece of shoulder. The fortified region accomplishes 5mm×2mm thusly. Likewise, level of SiCp is around 1.5%, which accepted a change part. On the significance of 0.5mm and 1.0mm under surface, the micro hardness was persisting 10% greater than the base metal due to basic scattered SiCp. While on the significance of 1.5×2 mm^2, the micro hardness absent stable strengthened condition, which was extended by regional particularly scattered SiCp. In any case, it impacted the achievability to propel blend to zone fortified as high as base metal.

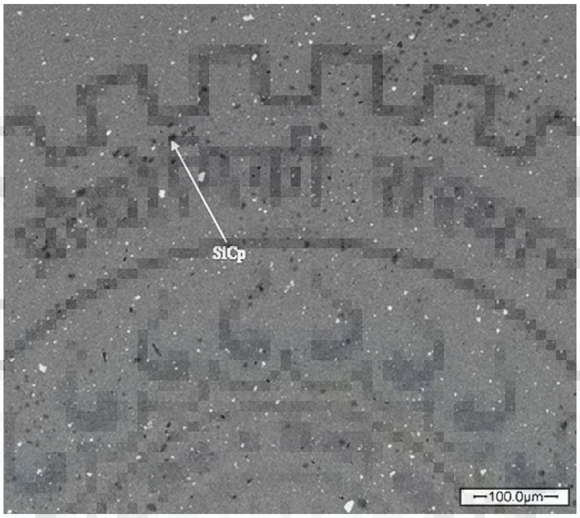


Fig. 2.8: SEM image of the SiCp/5A06 composites [7]

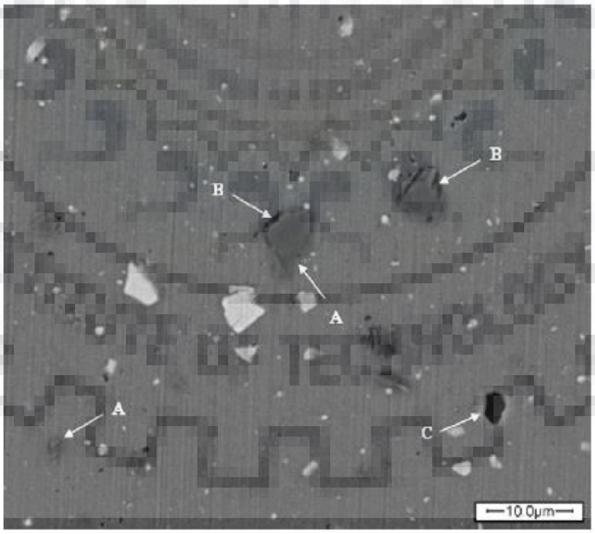


Fig. 2.9: SEM image of interface in SZ [7]

The interface condition of made MMCs was additionally observed by SEM. This result demonstrated that the composites can shape incredible interface holding like location A. Regardless, kiss holding once in a while happens like location B, where around 1μm enormity parts exists between particles moreover, Aluminium base metal. The most detectably dreadful one, as location C, is that particles didn't get bona fide holding with the base metal. By pre-treatment of SiC particles to pure the surface, adding a few materials to enhance wetting property, the interface condition might be made strides.

Devaraju et al. [15] contemplated the effect of strengthening particles, for instance, Silicon carbide (SiC), Graphite (Gr) and rotation speed on mechanical properties of Al amalgam surface half and half composites made by methods for Friction stir processing (FSP) was considered. Taguchi procedure was used to redesign the rotation speed and volume level of help particles for improving the mechanical properties of surface crossover composites. The made surface cross breed composites have been investigated by optical amplifying instrument for diffusing of strengthening particles and revealed that the fortification particles (i.e. SiC and Gr) are reliably scattered in the chunk zone. It is moreover watched that the miniaturized scale hardness at perfect condition is upgraded in view of the proximity and pining effect of hard SiC particles. The wear insurance of the surface half breed composite is enhanced as a result of the mechanically mixed layer created between the composite stick and steel plate surfaces which contained split SiC and Gr. They closed from this examination that the usage of procured perfect condition improves the wear and mechanical properties of surface half breed composites. What's more, the ductile properties at perfect conditions are lesser in little amount as identify with the base material because of presence of support particles which makes the network weak.

Rathee et al. [34] considered that AA6061/SiC surface composites were made and the impact of equipment plunge significance on approach of help particles scattering in metal grid was assessed. Six variable device plunge profundities were picked at unsurprising stages of shoulder remove crosswise over and instrument tilt edge to watch the specific impact of equipment jump assortments. Process considerations decided for the experimentation are rotational speed, welding pace and instrument tilt edge which are taken as 1500 rpm, 45 mm/min, and 2.6 independently. Tremendous scale and the microstructural consider were accomplished utilizing stereo zoom and optical increasing point of convergence freely. Results reflected that lesser plunge significance levels prompt lacking warmth age and gap advancement towards the point of convergence of mix zone. Or maybe, more raised measures of plunge significance result in expulsion of help particles and despite penetrating of material to gadget tolerate. Subsequently, perfect jump significance is needed in working up a defect free surface composites.

Sahraeinejad et al. [24] used a FSP to make MMCs by joining fortress particles in an Al5059 grid. The age framework included relentless contact blend passes on an indent which encased powder strongholds, with various taking care of parameters and gadget geometries used for each pass. A couple of particles of dimensions from 130 nm to 4.3 μm, and changing strategy parameters are concentrated to get a uniform scattering of particles with in a mix zone. Mechanical properties of the Al5059 MMCs fortified with Al_2O_3, SiC, and B_4C with particle sizes of 135, 260, and 35 nm independently are considered. Tractable tests showed 11%, 20%, and 38% climbs in yield quality stood out from a framework amalgam for the composites having nano-scale Al_2O_3, SiC, and B_4C, individually. At the point when 4.3 μm Al_2O_3 particles are used, upper volume segments could be accomplished which achieved a32% rise in a yield quality appeared differently in relation to the base metal.

Miranda et al. [12] depicted the generation of aluminum based FGM composites by rubbing based procedures, in particular FSP and a consumable apparatus approach. A few systems were researched, including the utilization of SiC and alumina fortifications. These systems were actualized and surfaces broke down to assess the impact of affidavit and preparing on molecule conveyance and homogeneity. Three methodologies were contemplated: a square formed score stuffed with support particles, the pre-testimony of a uniform layer of particles before FSP with a non-consumable apparatus, and the last one comprised of a consumable pole in aluminum bored with gaps put in various positions along an outspread line loaded with fortifying particles. Coatings were inspected by optical microscopy, filtering electron microscopy, and in addition, hardness testing. The techniques explored ended up being conceivable in the generation of surface layers fortified with hard materials by FSP in aluminum based amalgams. While the pre-affidavit of fortifications straightforwardly on plate surface empowers the most straightforward way to deal with deliver composites by FSP, the pressing of fortifications in scores can build the composite layer thickness. The consumable pole approach permits keeping composite layers soundly clung to the substrate while maintaining a strategic distance from FSP device wear.

Periyasamy et al. [11] considered that Silicon carbide particles (SiC) fortified cast aluminum (Al) based metal system composites (MMCs) have intensified wide affirmation in the production of light weight assemblies needing high specific quality, high temperature limit and incredible wear security. Friction stir welding (FSW) process considerations accept noteworthy part in picking the execution of weld joints. A complete versatility, indent unbending nature and weld piece hardness of grinding mix butt weld joints of cast Al/SiCp MMCs (AA6061 with 20% (volume divide) of SiCp) were looked into. The associations between the FSW system considerations (rotation speed, transverse speed and center compel) and the responses (extraordinary unbending nature, indent flexibility and welded lump hardness) were set up. The perfect welding considerations to extend the mechanical properties are recognized by using appealing quality method. From this examination, it is found that the joints made with the mechanical assembly rotational speed of 1270 r/min, welding velocity of 89.9 mm/min, and crucial energy of 9.5kN yield the best outrageous flexibility, indent unbending nature and hardness of 255 MPa, 211 MPa and HV104, independently.

Chapter 3: Objectives

- To fabricate the Metal matrix composite (MMCs) on the surface of Aluminium alloy (AA 7075) by making rectangular groove of depth 2.5 mm and width 1.2 mm along the length by using 10 µm Silicon carbide (SiC) particles.
- To determine the optimized process parameters in terms of translational and rotational speeds of tool to maximize the strength of AA 7075/SiC composite joint.
- To study the microstructures of the joint produced by FSP process to establish the structure-property relationship.
- To evaluate the various joint properties by using tensile test of FSPed specimen at various FSP parameters with and without incorporating SiC particles.
- Defects like porosity are to be analysed, based on the results of FESEM and optical microscopy.

Chapter 4: Experimental procedures

4.1 Fabrication of metal matrix composite (MMC)

- The work piece (AA 7075) of cross-section 120 mm×100mm and 6.35mm thickness is prepared from the raw materials.
- A rectangular groove of depth 2.5mm and width 1.2 mm is prepared on the surface of work piece along the length.
- The reinforcement particles SiC of 10 µm are filled in the groove before processing.

Fig. 4.1: Packing of reinforcement in groove

- Next step involves of applying FSP tool without probe (pin) on the rectangular groove. The groove is completely filled with SiC reinforcement in this step.
- In the last step, the rotating tool with pin is applied on the packed groove.

Fig. 4.2: Closing of groove opening by pin less tool

4.2 Selection of tool material and tool profile

The FSP tool is a essential part of this welding procedure. The FSP tool consists of a shoulder and Pin. The pin profile plays an important role in the behaviour of material flow.

- FSP tool is prepared from H13 hot worked steel; heat treated and it is hardened up to 52 HRC.
- It has a square pin profile, shoulder diameter of 18mm, pin length of 5.7mm and pin circumscribed circle diameter of 6mm.

Fig. 4.3: Tools used during FSP

i. Without pin
ii. With pin of square profile

4.3 Selection of process parameters for FSP

Table 4.1: Process parameters selected for FSP

List of Experiments	**Rotational speed (rpm)**	**Welding speed (mm/min)**	**Welding conditions**
1	664	40	Without reinforcement
2	664	40	With reinforcement
3	708	40	Without reinforcement
4	708	40	With reinforcement
5	931	40	Without reinforcement
6	931	40	With reinforcement
7	931	60	Without reinforcement
8	931	60	With reinforcement
9	931	34	Without reinforcement
10	931	34	With reinforcement

Fig. 4.4: Pictorial view of fabricated AA7075/SiC composite by FSP

Chapter 5: Results and Discussions

5.1 Tensile properties

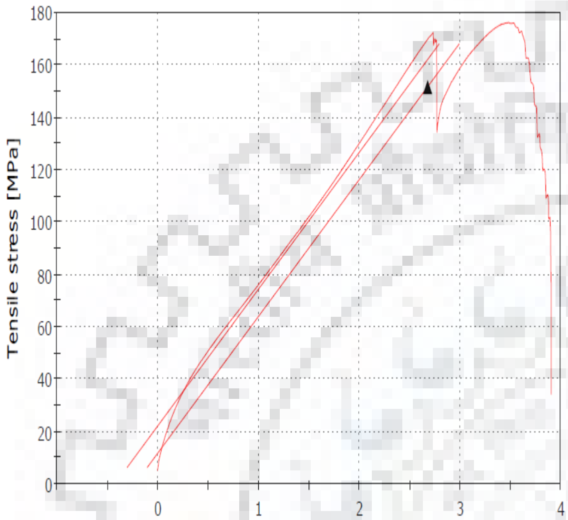
In a large portion of the engineering applications a higher strength and higher flexibility are favoured. Unfortunately, it appears that materials maybe a strong or ductile, but rarely both at once. Interestingly, a refinement of microstructural is reflected as one of the most appropriate approach to attain both a higher tensile strength and toughness for a known metallurgical situation. Ultimate tensile strength (UTS) and percentage elongation of the fabricated FSPed joints are directly depends on the size of grains, distribution arrangement of reinforcement particles and the quality of an interfacial bonding between reinforcement and the metal matrix. The comparative stress-strain diagram of Ultimate tensile strength (UTS) and percent elongation of FSPed specimens are provided with and without incorporation of SiC particles.

The tensile testing is performed by using a universal testing machine (Make: Instron USA; model-5980) of capacity 100 kN at room temperature and at a crosshead speed of 1mm/min.The tensile test specimen is shown in Fig.10.

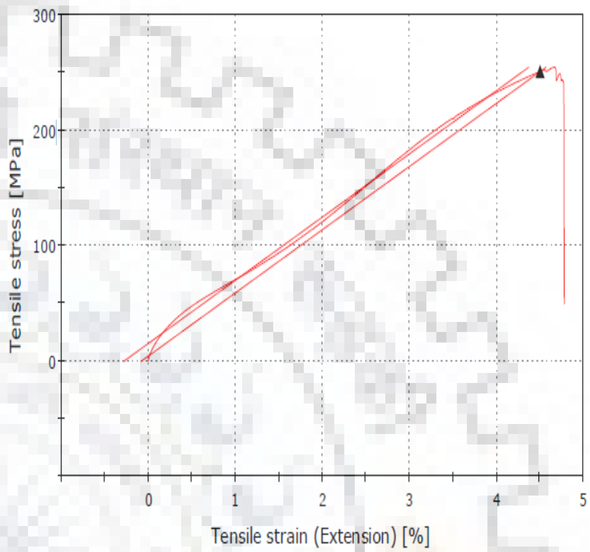
Fig. 5.1: Tensile test specimen

- **Experiment No. 1 and 2**

The engineering stress-strain diagram obtained from tensile test is shown below with and without incorporating of SiC particles at FSP parameters of rotational speed 664 rpm and welding speed 40 mm/min.



(a)



(b)

Fig. 5.2: Engineering stress-strain diagram (a) without SiC particles (b) with SiC particles at 664rpm and 40mm/min

Since, Fig. 5.2 shows that the FSPed specimen with the incorporation of SiC particles have positive results on the enhancement of Ultimate tensile strength (UTS).

Table 5.1: Mechanical property of SiC included and SiC free specimen of experiment no. 1and 2

Property	Without SiC reinforcement	With SiC reinforcement
UTS(MPa)	176.091	254.256
Elongation (%)	3.9	4.77

The results reported in table shows that UTS and percent elongation of FSPed specimen with SiC reinforcement is higher than the specimen without SiC reinforcement.

- **Experiment No. 3 and 4**

The engineering stress-strain diagram obtained from tensile test is shown below with and without incorporating of SiC particles at FSP parameters of rotational speed 708 rpm and welding speed 40 mm/min.

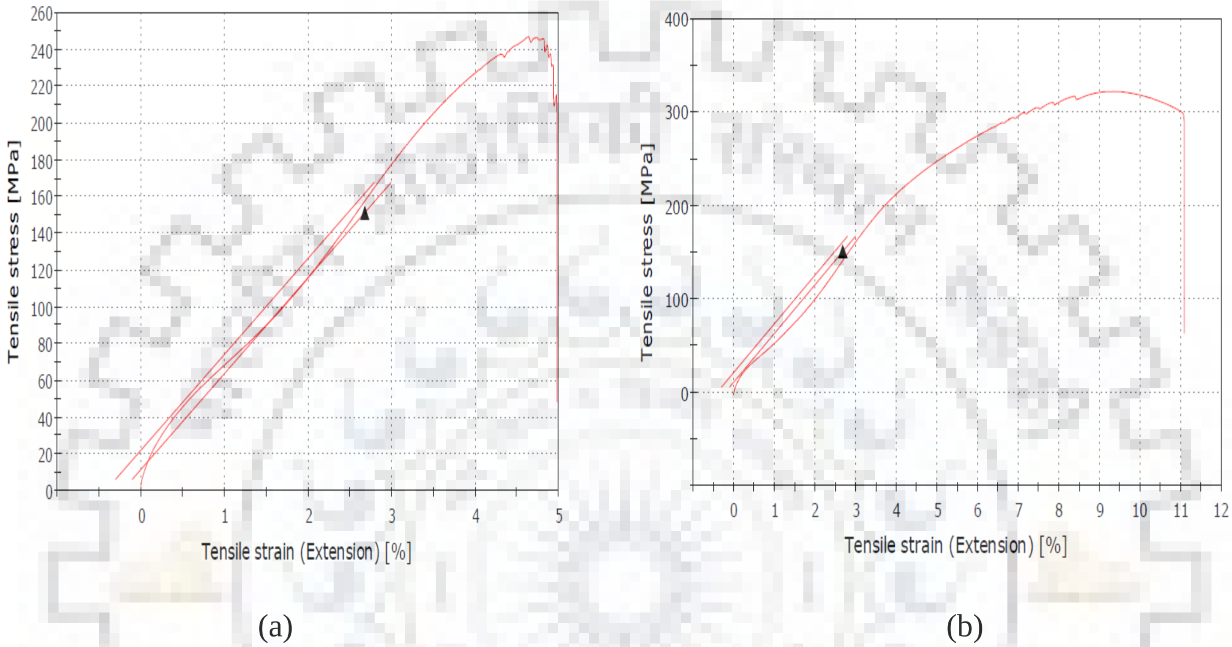


Fig. 5.3: Engineering stress-strain diagram (a) without SiC particles (b) with SiC particles at 708rpm and 40mm/min

Since, Fig. 5.3 shows that the FSPed specimen with the incorporation of SiC particles have positive results on the enhancement of Ultimate tensile strength (UTS).

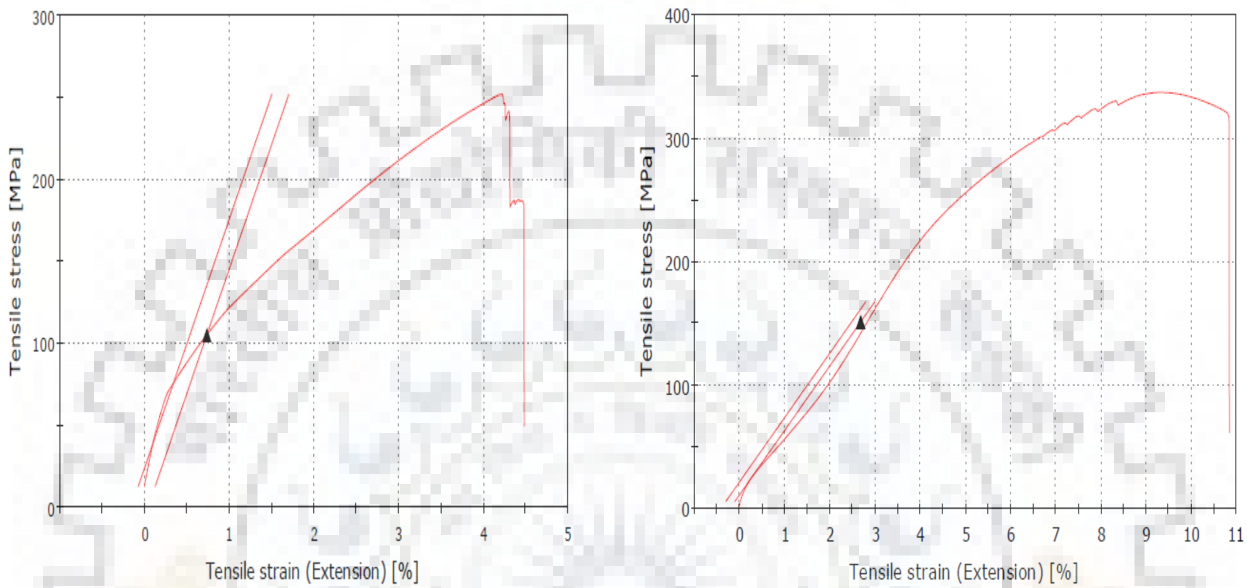
Table 5.2 Mechanical property of SiC included and SiC free specimen of experiment no. 3 and 4

Property	Without SiC reinforcement	With SiC reinforcement
UTS(MPa)	246.894	322.308
Elongation (%)	4.97	11.07

The results reported in table shows that UTS and percent elongation of FSPed specimen with SiC reinforcement is higher than the specimen without SiC reinforcement.

- **Experiment No. 5 and 6**

The engineering stress-strain diagram obtained from tensile test is shown in fig.9with and without incorporating of SiC particles at FSP parameters of rotational speed 931 rpm and welding speed 40 mm/min.



(a) (b)

Fig. 5.4: Engineering stress-strain diagram (a) without SiC particles (b) with SiC particles at 931rpm and 40mm/min

Since, Fig. 5.4 shows that the FSPed specimen with the incorporation of SiC particles have positive results on the enhancement of Ultimate tensile strength (UTS).

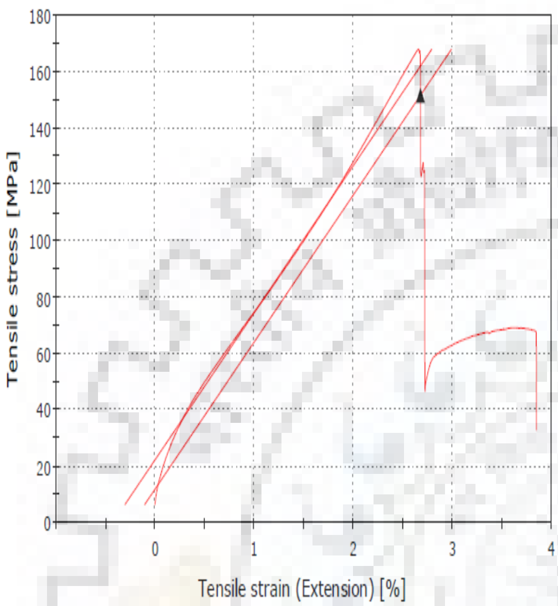
Table 5.3: Mechanical property of SiC included and SiC free specimen of experiment no. 5 and 6

Property	Without SiC reinforcement	With SiC reinforcement
UTS(MPa)	251.887	336.991
Elongation (%)	4.48	10.83

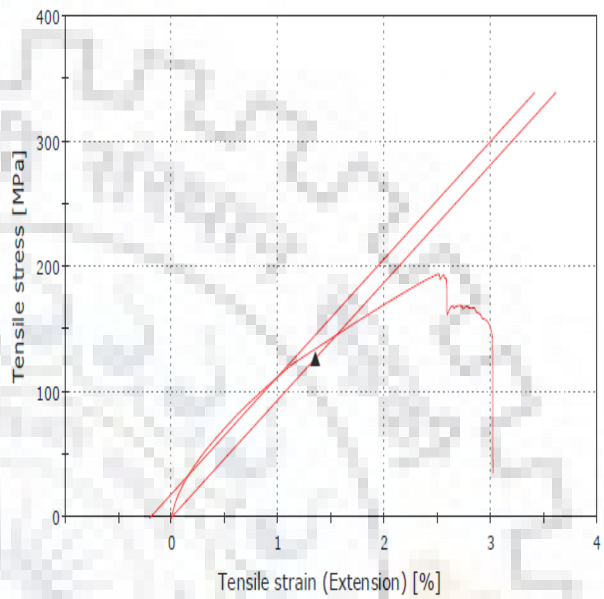
The results reported in table shows that UTS and percent elongation of FSPed specimen with SiC reinforcement is higher than the specimen without SiC reinforcement

➢ **Experiment No. 7 and 8**

The engineering stress-strain diagram obtained from tensile test is shown in fig.9with and without incorporating of SiC particles at FSP parameters of rotational speed 931 rpm and welding speed 60 mm/min.



(a)



(b)

Fig. 5.5: Engineering stress-strain diagram (a) without SiC particles (b) with SiC particles at 931rpm and 60 mm/min

Since, Fig. 5.5 shows that the FSPed specimen with the incorporation of SiC particles have positive results on the enhancement of Ultimate tensile strength (UTS).

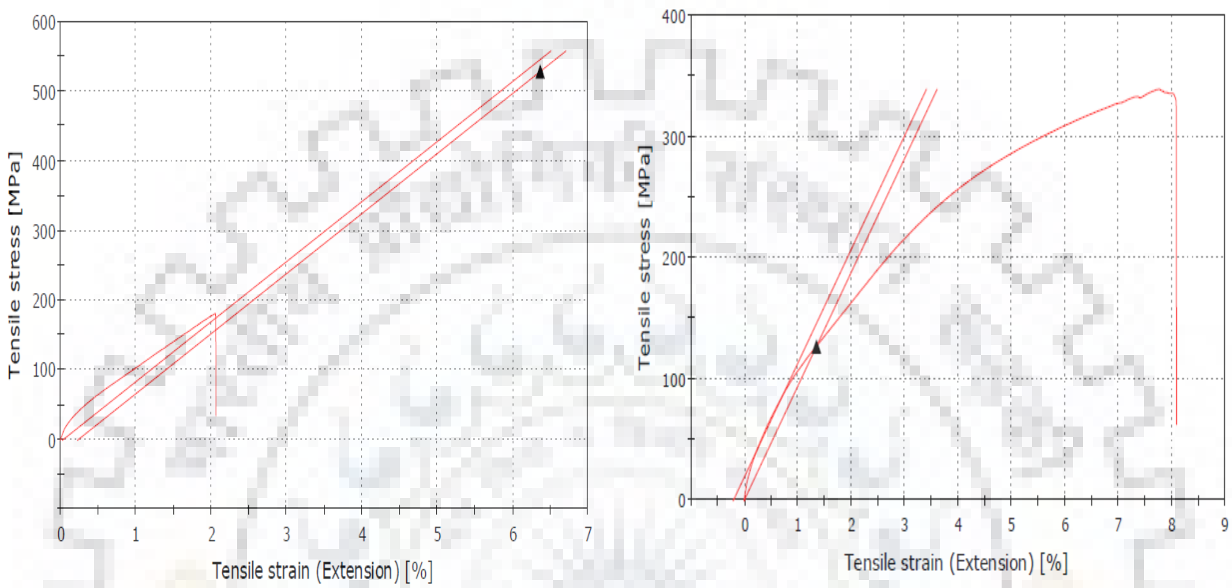
Table 5.4: Mechanical property of SiC included and SiC free specimen of experiment no. 7 and 8

Property	Without SiC reinforcement	With SiC reinforcement
UTS(MPa)	167.836	194.176
Elongation (%)	3.01	3.84

The results reported in table shows that UTS and percent elongation of FSPed specimen with SiC reinforcement is higher than the specimen without SiC reinforcement.

➢ **Experiment No. 9 and 10**

The engineering stress-strain diagram obtained from tensile test is shown in fig.9with and without incorporating of SiC particles at FSP parameters of rotational speed 931 rpm and welding speed 34 mm/min.



(a) (b)

Fig. 5.6: Engineering stress-strain diagram (a) without SiC particles (b) with SiC particles at 931rpm and 34mm/min

Since, Fig. 5.6 shows that the FSPed specimen with the incorporation of SiC particles have positive results on the enhancement of Ultimate tensile strength (UTS).

Table 5.5: Mechanical property of SiC included and SiC free specimen of experiment no. 9and10

Property	Without SiC reinforcement	With SiC reinforcement
UTS(MPa)	181.495	338.935
Elongation (%)	2.06	8.08

The results reported in table shows that UTS and percent elongation of FSPed specimen with SiC reinforcement is higher than the specimen without SiC reinforcement.

The above experiments are carried out with and without incorporation of SiC particles at different FSP parameters. Ultimate Tensile Strength (UTS) of different FSPed specimen obtained from engineering stress-strain curve are given below:-

Table 5.6: UTS of tensile tested specimen at different FSP parameters

Experiment No.	Input parameters		Ultimate tensile strength (MPa)
	Rotational Speed (rpm)	Welding speed (mm/min)	
1.Without reinforcement	664	40	176.091
2.With reinforcement	664	40	254.256
3.Without reinforcement	708	40	246.894
4.With reinforcement	708	40	322.308
5.Without reinforcement	931	40	251.887
6.With reinforcement	931	40	336.991
7.Without reinforcement	931	60	167.836
8.With reinforcement	931	60	194.176
9.Without reinforcement	931	34	181.495
10.With reinforcement	931	34	338.935

The results stated in Table 5.6 shows that the tensile strength of the FSPed specimen with SiC particles is higher than the specimen without SiC particles because:-

(1) Porosity contents are reduced due to strong interfacial bonding between Al 7075 matrix and SiC particles.

(2) Improvement in the interfacial bonding between SiC particles and Al 7075 matrix which leads to removal of interfacial de-bonding and also creation of more cohesive bonding.

(3) Greater level of separation and scattering of SiC particles which declines the possibility of gathering of SiC particles and crack nucleation and also accelerates the grain boundary sliding.

The chances of achieving any strengthening in Metal Matrix Composites (MMCs) depends on the capability to transferal stress from the metal matrix to the stronger reinforcement particles. Thus, in turn it is dependent on accomplishing a strong interfacial bonding between matrix and reinforcement.

As long as the interfacial bonding between metal matrix and reinforcement is weak, the failure will occur at the interface of the metal matrix and the reinforcement before any effective stress transferred to the particle may occur and no strengthening is attained.

5.2 Microstructural observations

FSPed specimens at different FSP parameters are attained by cutting the FSPed plate at its centre normal to the processing direction. Then, these FSPed specimens are polished according to the regular metallographic method and etched for 20 sec with Keller's reagent. The microstructure is viewed by using an optical and scanning electron microscopy (SEM**).**

The optical micrograph of AA7075/SiC AMCs shows the dissemination of SiC particles all over the stir zone (SZ). It is significant to see that the dispersal of the SiC particles is not dependent of the area in the stir zone (SZ). The distinction in the distribution of the SiC particles from the advancing side (AS) to the retreating side (RS) or from the top side to the bottom side is insignificant. The absence of critical variety in dissemination can be identified with sufficient plasticization of aluminium matrix and rotational speed of tool which aids to scatter the SiC particles to all locations of the stir zone.

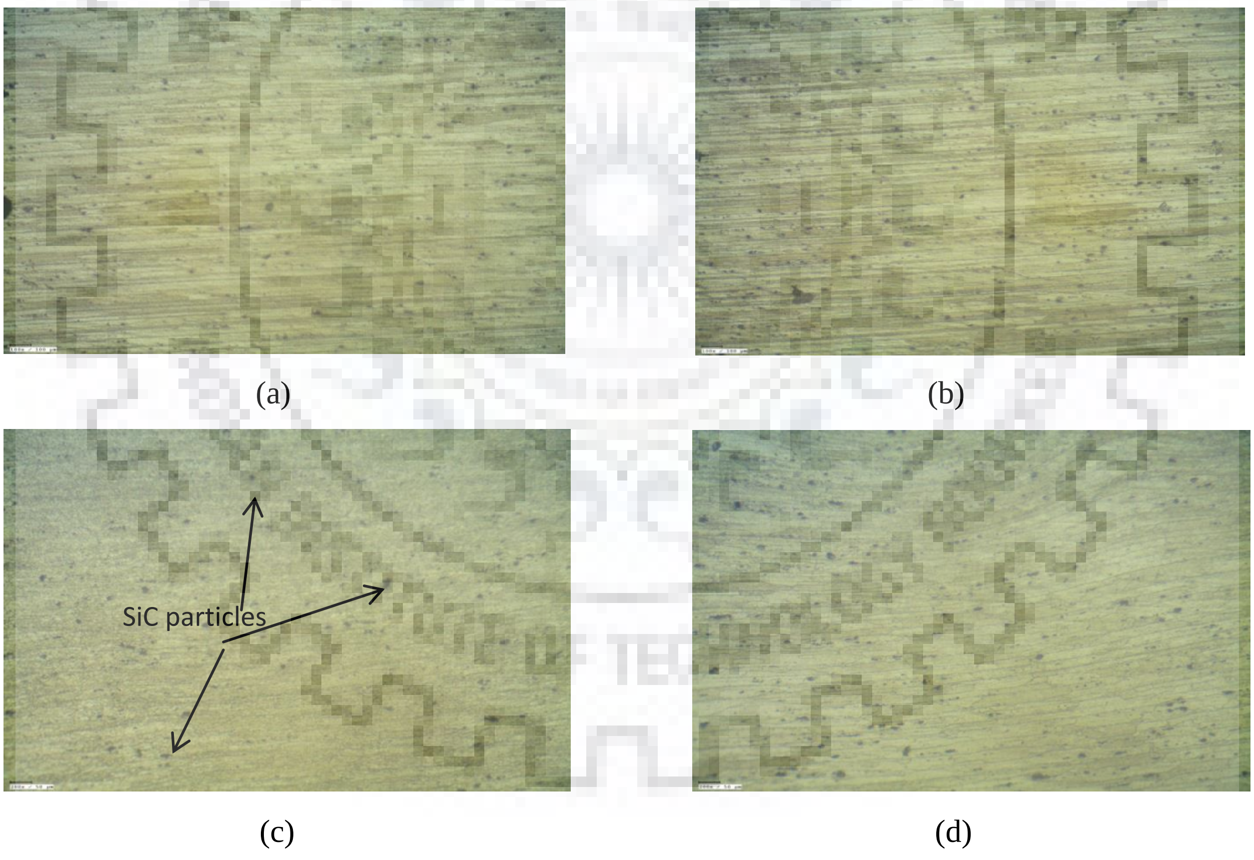
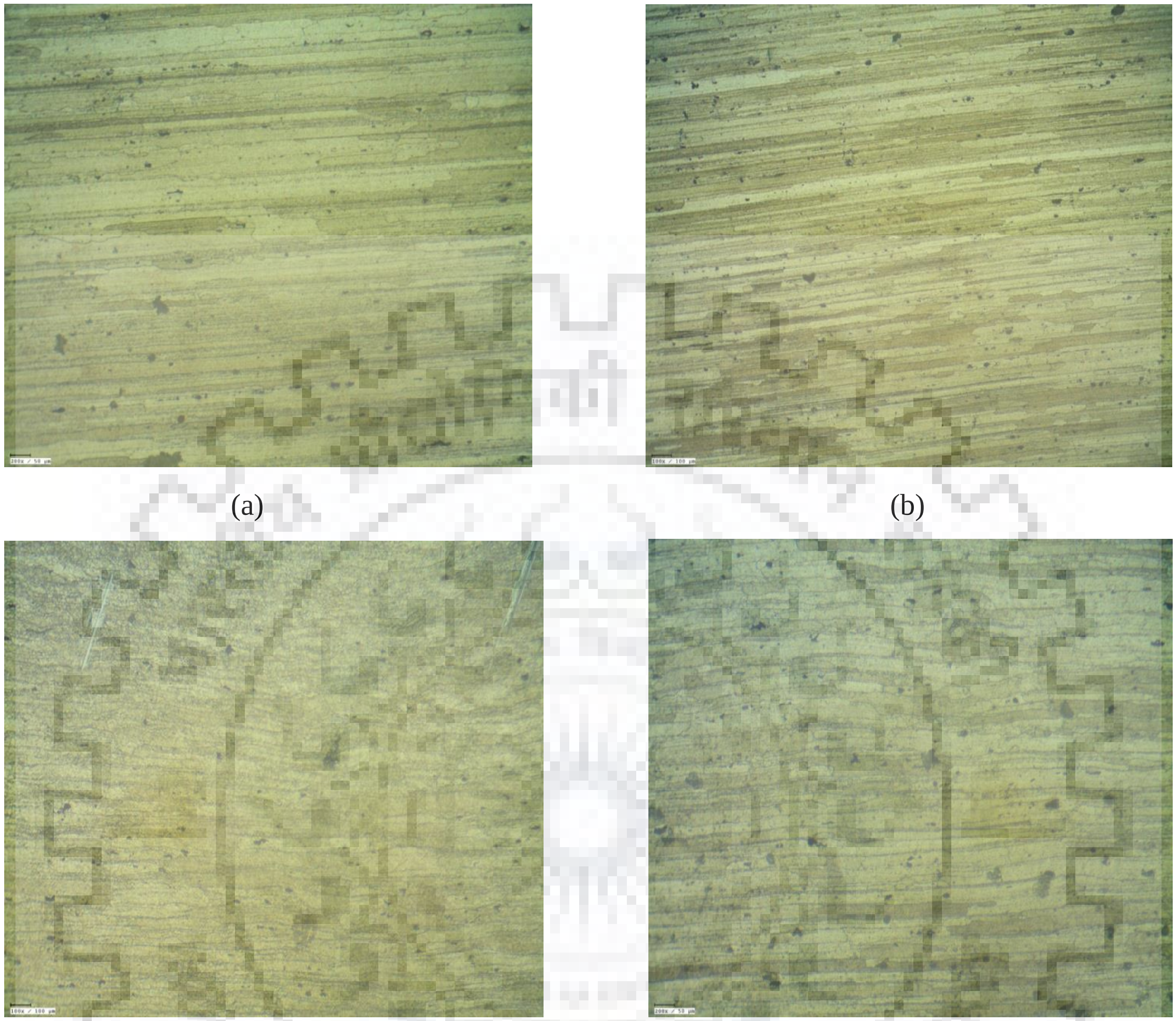


Fig. 5.7: Optical micrograph of AA7075/SiC AMCs observed at different positions within the stir zone SZ; (a) near AS, (b) near RS; (c) center and (d) bottom at FSP parameters 664 rpm and 40 mm/min



(a) (b)

(c) (d)

Fig. 5.8: Optical micrograph of AA7075/SiC AMCs observed at different positions within the stir zone SZ; (a) near AS, (b) near RS (c) center and (d) bottom at FSP parameters 708 rpm and 40 mm/min

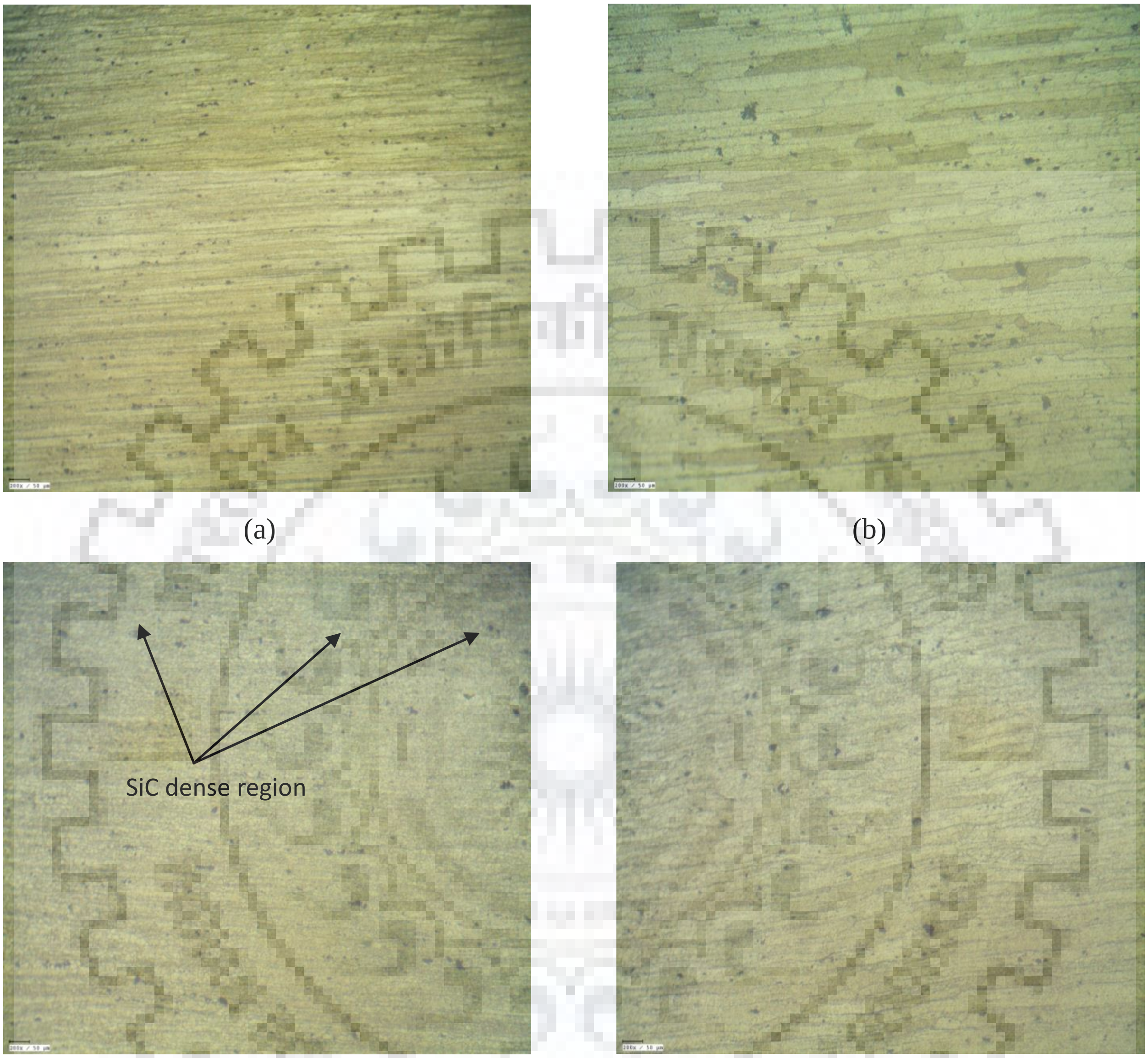


Fig. 5.9: Optical micrograph of AA7075/SiC AMCs observed at different positions within the stir zone SZ; (a) near AS, (b) near RS; (c) center and (d) bottom at FSP parameters 931 rpm and 40 mm/min

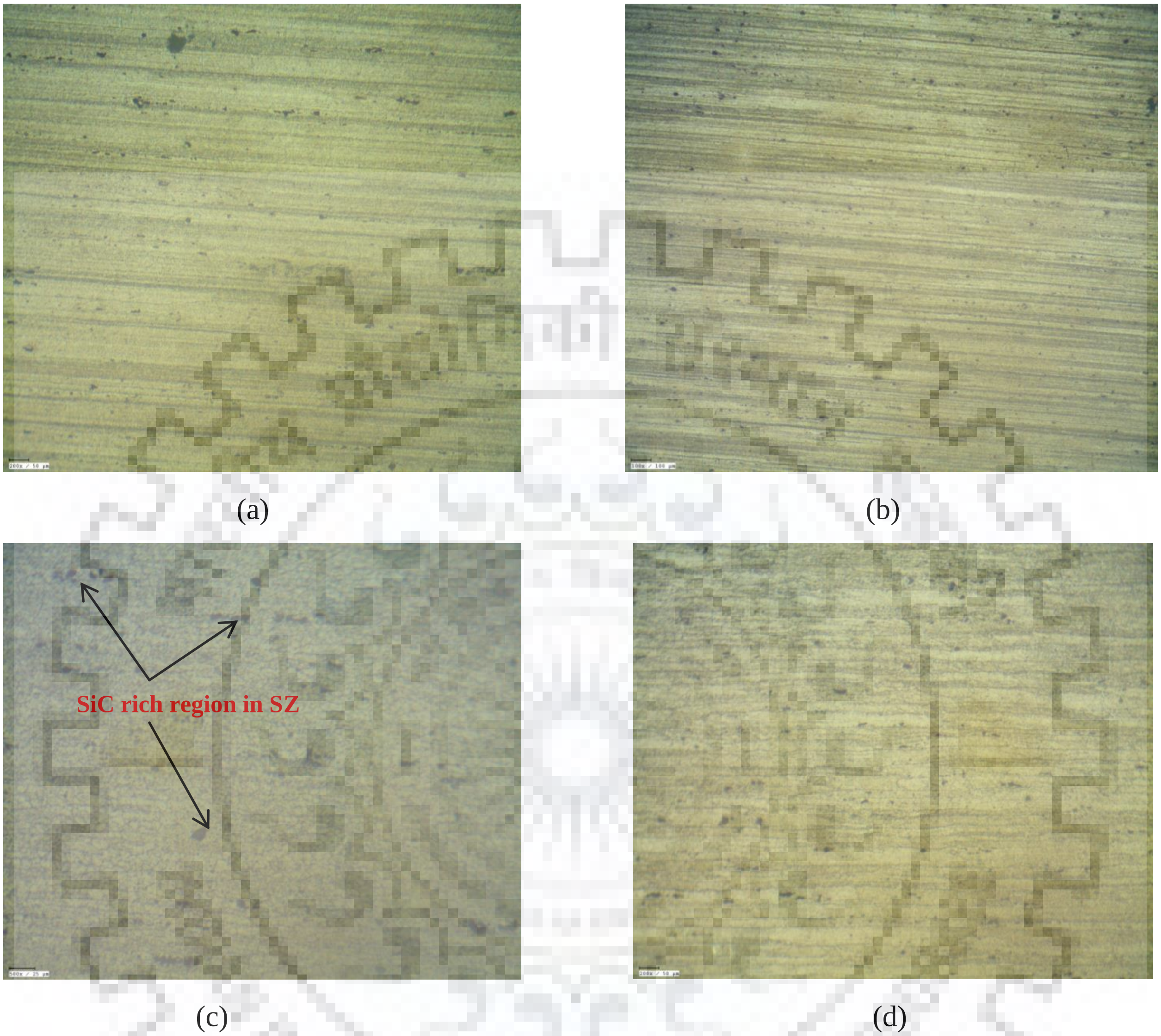
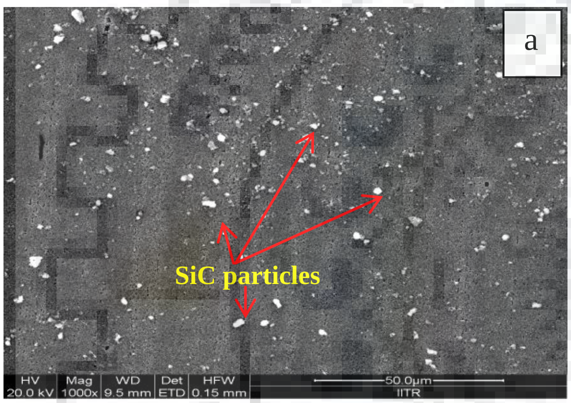


Fig. 5.10: Optical micrograph of AA7075/SiC AMCs observed at different positions within the stir zone SZ; (a) near AS, (b) near RS; (c) center and (d) bottom at FSP parameters 931 rpm and 34 mm/min

Stir zone of the specimens produced by FSP is characterized by fine and equaxied grain structure which is a result of recrystallization caused by concurrent severe plastic deformation and frictional heat.

5.3 FESEM and EDX Observations

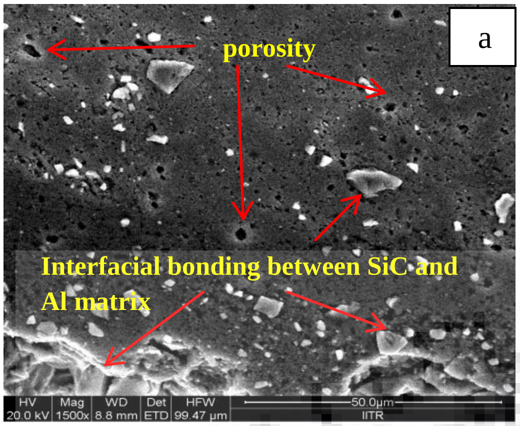
The typical FESEM microstructure of the developed AA7075/SiC AMCs is described below at various FSP parameters and EDX shows the percentage of Si in SiC enrichment region. The SiC particles are dispersed everywhere throughout the AA7075 matrix. The distribution of SiC particles are considered as fairly uniform in the Aluminium matrix composites AMC. The flow of plasticized Al during FSP from advancing side (AS) to retreating side (RS) breakdowns the initial rectangular groove and is forged at the back side of the rotating tool. The dynamic stirring action of the rotating tool mixes the compacted SiC particles in the groove with the plasticized aluminium.



b

Element	Weight %	Atomic %	Net Int.	Error %
C K	12.95	25.04	4.1	23.36
MgK	2.27	2.17	29.76	8.71
AlK	79.87	68.73	979.16	2.23
SiK	4.91	4.06	24.49	13.7

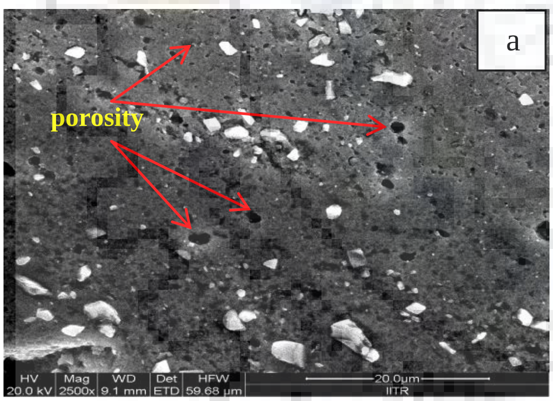
Fig. 5.11: FSPed specimen Shows distribution features of SiCp in stir zone (SZ) at FSP parameters of 664 rpm and 40mm/min (a) SEM image of AA7075/SiCp composite,(b)weight(%) of Si (c)EDX indicates percentage of Si in SiCp enrichment region.



b

Element	Weight %	Atomic %	Net Int.	Error %
C K	10.69	21.71	3.71	25.16
MgK	2.03	2.03	24.78	11.06
AlK	77.02	69.61	948.05	3.1
SiK	5.68	4.94	30.96	12.78
ZnK	4.58	1.71	7.27	27.01

Fig. 5.12: FSPed specimen Shows distribution features of SiCp in stir zone (SZ) at FSP parameters of 708 rpm and 40mm/min (a) SEM image of AA7075/SiCp composite,(b)weight(%) of Si (c) EDX indicates percentage of Si in SiCp enrichment region.

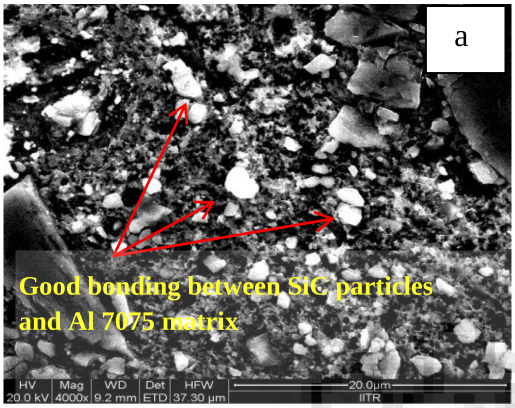


b

Element	Weight %	Atomic %	Net Int.	Error %
C K	14.76	28.91	6.04	18.33
MgK	2.98	2.88	38.1	6.7
AlK	64.81	56.53	853.4	3.56
SiK	11.3	9.47	76.36	8.95
ZnK	6.16	2.22	11.09	6.89

Fig. 5.13: FSPed specimen Shows distribution features of SiCp in stir zone (SZ) at FSP parameters of 931 rpm and 60mm/min (a) SEM image of AA7075/SiCp composite,(b)weight(%) of Si (c) EDX indicates percentage of Si in SiCp enrichment region

a



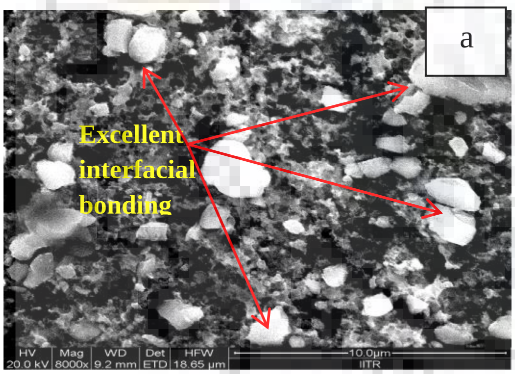
b

Element	Weight %	Atomic %	Net Int.	Error %
C K	18.94	35.23	7.69	18.82
MgK	1.97	1.81	25.45	10.43
AlK	62.08	51.4	826.52	3.25
SiK	12.67	10.07	86.56	9.36
ZnK	4.35	1.49	7.52	25.32

c

Fig. 5.14: FSPed specimen Shows distribution features of SiCp in stir zone (SZ) at FSP parameters of 931 rpm and 40mm/min (a) SEM image of AA7075/SiCp composite,(b)weight(%) of Si (c) EDX indicates percentage of Si in SiCp enrichment region.

a



b

Element	Weight %	Atomic %	Net Int.	Error %
C K	16.41	31.37	6.25	20.43
MgK	1.81	1.71	22.66	12.25
AlK	63.97	54.44	825.69	3.24
SiK	13.34	10.91	86.56	9.44
ZnK	4.46	1.57	7.46	26.95

c

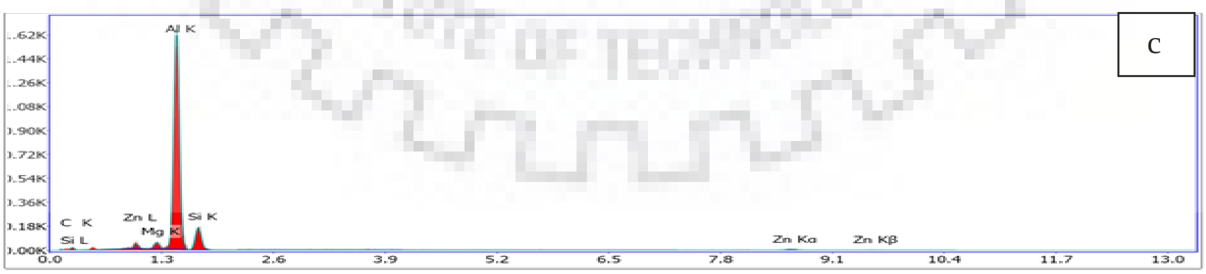


Fig. 5.15: FSPed specimen Shows distribution features of SiCp in stir zone (SZ) at FSP parameters of 931 rpm and 34mm/min (a) SEM image of AA7075/SiCp composite,(b)weight(%) of Si (c) EDX indicates percentage of Si in SiCp enrichment region.

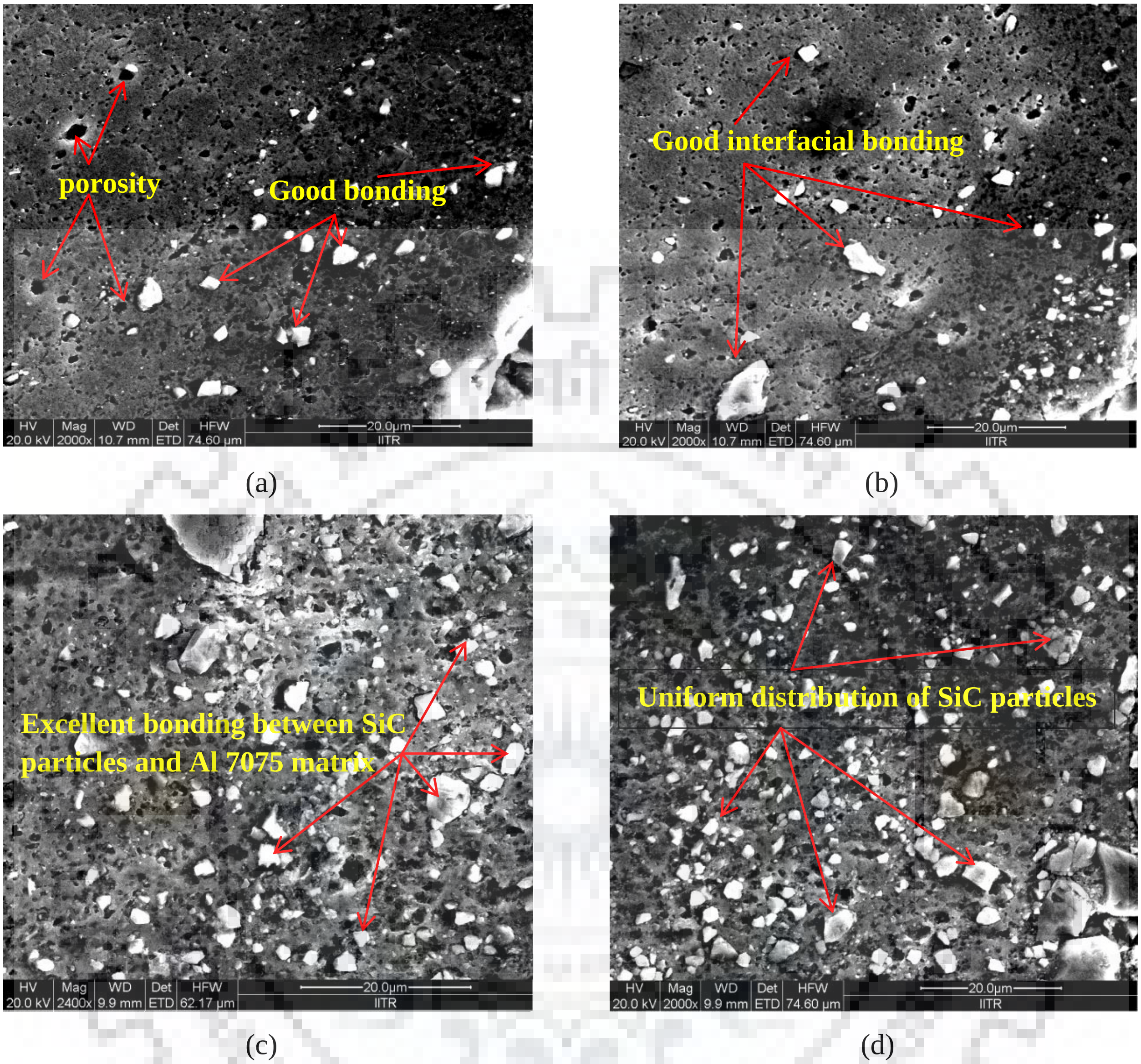


Fig. 5.16: SEM image shows the distribution characteristics of SiC Particles in stir zone

a) Dispersed SiC particles are separated from each other and bonding is not so good due to presence of porosity contents in the stir zone. This SEM image is observed at FSP parameters of 664 rpm and 40mm/min.

b) Porosity contents are reduced due to good interfacial bonding between SiC particles and Al 7075 matrix in the stir zone. This SEM image is observed at FSP parameters of 708 rpm and 40mm/min.

c) Excellent bonding is achieved between SiC reinforcement and Al matrix due to SiC particles are homogeneously distributed in the stir zone. This SEM image is observed at 931 rpm and 40 mm/min.

d) SEM image is carried out at FSP parameters of 931rpm and 34mm/min. Due to uniformly and separately distribution of SiC particles, interfacial bonding is strong at the interface of SiC particles and Al matrix.

The above SEM micrograph images of AA7075/SiC AMC_S at higher magnification are demonstrated. The interface between the AA7075 matrix and the SiC reinforcement is listed in the above figure. The interfacial bonding between Al matrix and SiC reinforcement is clear without the presence of pores or response items. The interfacial bonding assumes a key part in tensile strength and sliding wear to exchange the load productively to the SiC reinforcement. Great interfacial bonding is an essential regardless of uniform dispersion to enhance the properties.

5.4 XRD investigation

Fig shows that XRD pattern of AA7075/SiC AMCs.It can be seen that SiC is present in the AMCs. X-ray diffraction experiment confirmed the existence of SiC particles in AA7075 matrix.

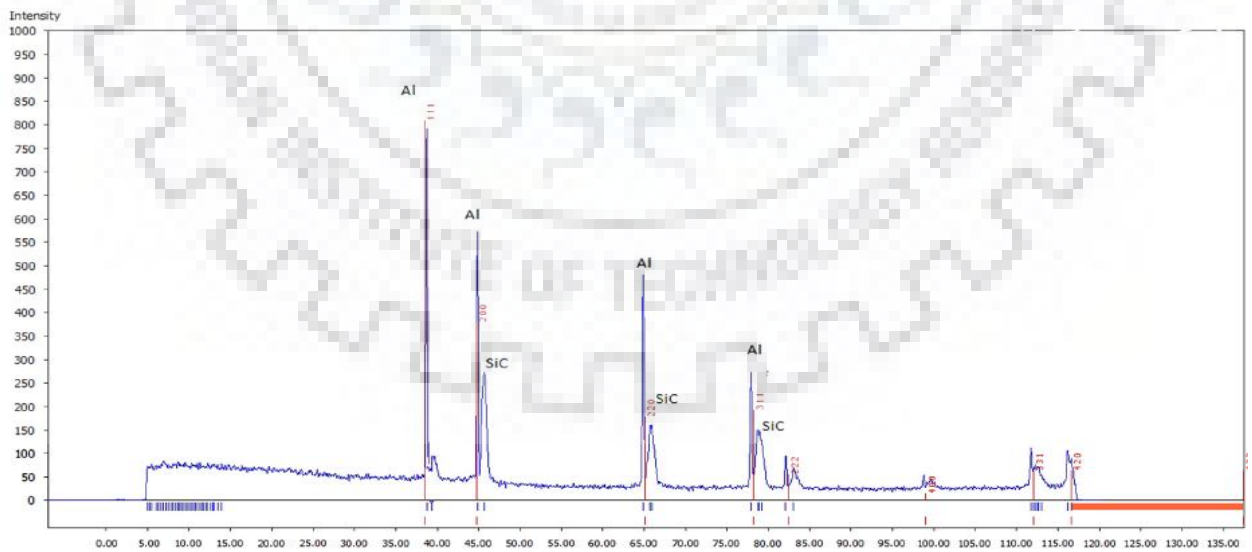


Fig. 5.17: Result of X-ray analysis

Chapter 6: Conclusions

Since, the Metal matrix composite (MMCs) is fabricated on the surface of Aluminium alloy (AA 7075) by making rectangular groove of depth 2.5 mm and width 1.2 mm along the length by compacting 10 µm Silicon carbide (SiC) particles. Then, FSP is carried out at various process parameters in terms of translational and rotational speed with and without reinforcing SiC particles. FSPed specimen is prepared for tensile testing at various FSP process parameters.

The main conclusions can be drawn from the experiments are-

1) The Ultimate tensile strength (UTS) of FSPed specimen with SiC reinforcement is higher than the FSPed specimen without SiC reinforcement at same FSP parameters.
2) As the rotational speed (rpm) of the tool increases, the UTS of the FSPed specimen increases because as the rotational speed increases, the amount of frictional heat generation increases resulting high contact area between shoulder surface and work piece led to sufficient mixing in stir zone.
3) As the transverse speed increases (mm/min), the UTS of FSPed specimen decreases because of insufficient heat input is generated into FSP joint which leads to inadequate stirring action of softened material from AS to RS.
4) Maximum UTS is obtained at FSP process parameters of rotational speed (N=931rpm) and transverse speed (v=34mm/min) including SiC reinforcement due to formation of good bonding at the interface of Al7075 matrix and SiC reinforcement.
5) The presence of SiC particles in AA 7075 matrix are confirmed by EDX and XRD experiments.
6) Porosity contents are reduced due to formation of strong interfacial bonding between SiC particles and AA7075 matrix at FSP parameters of rotational speed (N=931rpm) and transverse speed (v=34mm/min).
7) Optical microscope and SEM image at FSP parameters of rotational speed (N=931rpm) and transverse speed (v=34mm/min) shows the uniformly distribution of SiC particles and excellent interfacial bonding is achieved at the interface of SiC particles and Al matrix.

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