iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 3 **Issue:** IV **Month of publication:** April 2015

DOI:

Volume 3 Issue IV, April 2015
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Fabrication and Performance Evaluation of Al-2014 Based Metal Matrix Composites Reinforced with SiC Particulates & Fly-Ash

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Abstract*— With continuing quest for new generation of materials which of improved properties over conventionally available materials, vigorous research activities were pursued in this desired direction to develop a new class of materials having light weight, higher strength and lower cost. A Metal Matrix Composite (MMC) is a composite material with atleast two constituent parts, one being a metal and the other being different metal or other materials. MMC's are increasingly becoming attractive materials for advanced aerospace applications because their properties can be tailored through addition of selected reinforcement. Present work is focused on the study of behaviour of Al cast-alloy(2014) with SiC particulates and Fly-Ash by stir-casting techniques. Different weight % of SiC particulates and Fly-Ash is used as reinforcement phase in this MMC. Various mechanical tests like Tensile-Test, Impact-Test are performed on the samples of MMC to evaluate the mechanical properties of this AL based MMC.

***Keywords*— Metal matrix, Tensile Strength, Impact Strength, Fly Ash, Aluminium alloy**

I. INTRODUCTION

The aim involved in designing metal matrix composite materials is to combine the desirable attributes of metal and ceramics. The addition of high strength, high modulus refractory particles to a ductile metal matrix produce a material whose mechanical properties and intermediate between the matrix alloy and the ceramic reinforcement. Aluminium is the most abundant metal in the Earth's crust, and the third most abundant element, after oxygen and silicon. It make up about 8% by weight of the Earth's solid surface. Due to easy availability, High strength to weight ratio, easy machinability, durable, ductile and malleability Aluminium is the most widely used non-ferrous metal in 2005 was 3.19million tonnes.

A. Aluminium Alloys

Selecting the right alloy for a given application entails considerations of its tensile strength, density, ductility, formability, workability, weld ability and corrosion resistance. Aluminium alloys are alloys in which aluminium (Al) is the predominant metal. The typical alloying element are copper, magnesium, manganese, silicon, and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminium is used for wrought products for example rolled plate foils and extrusions. Cast aluminium alloys yield cost effective products due to its low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is Al-Si, where the high levels of silicon (4.0% to 13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required. Wrought aluminium alloys are used in the shaping process: rolling, forging, extrusion, pressing, stamping. Cast aluminium alloys are comes after sand casting, permanent mould casting, die casting, investing casting, centrifugal casting, squeeze casting and continuous casting. Aluminium alloys are classified in figure 1.1

Fig 1.1: Classification of Aluminium Alloy

1) Cast Aluminium Alloys: Aluminium and its alloys are used in variety of cast and wrought form and conditions of heat treatment. Forging, sections, extrusions, sheets, plate, strip, foils and wire are some of the examples of wrought form while castings are available as sand, pressure and gravity die-casting e.g. Al-Si and Al-Mg alloys. The designation of Cast Aluminium alloy is shown in Table 1.1

Table 1.1: Designation of Cast Aluminium alloys

Alloy Designation	Details
1XXX	99% Pure Aluminium
2XXX	Cu containing alloy
3XXX	Si, Cu/Mg containing alloy
4XXX	Si containing alloy
5XXX	Mg containing alloy
6XXX	Zn containing alloy

2) *Wrought Aluminium Alloys:* To meet various requirements, aluminium is alloyed with copper, manganese, magnesium, zinc and silicon as major alloying elements. The designation of wrought aluminium alloy is shown in Table 1.2

Table 1.2: Designation of Wrought Aluminium alloys

Alloy Designation	Details
1XXX	99% Pure Aluminium
2XXX	Cu containing alloy
3XXX	Si, Cu/Mg containing alloy
4XXX	Si containing alloy
5XXX	Mg containing alloy
6XXX	Mg and Si containing alloy
7XXX	Zn containing alloy
8XXX	Other alloy

B. Designation of Aluminium Alloys

The aluminium association of America has classified the wrought aluminium alloys according to four-digit system. The classification is adopted by the International Alloy Development System (IADS). Table 1.3 gives the basis of designation of wrought and cast aluminium alloys in the four-digit system. The first digit identifies the alloy type the second digit shows the alloy modification. The last two digits indicates the specific aluminium. Aluminium alloy in present Work is shown in Table1.3

Table 1.3: Alloys conforms to British Standards 2014 Cast Aluminium

Chemical Composition	*Weight Percentage*
Chromium	*0.1% max*
Copper	*3.9%-5%*
Iron	*0.7% max*
Magnesium	*0.2%-0.8%*
Manganese	*0.4%-1.2%*
Silicon	*0.5%-1.2%*
Titanium	*0.15% max*
Zinc	*0.25% max*

C. Introduction to Composite Materials

Composites are materials in which two phases are combined, usually with strong interfaces between them. They usually consist of a continuous phases called the matrix and discontinuous phase in the form of fibres, whiskers or particles called

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ISSN: 2321-9653

reinforcement. Considerable interest in composite has been generated in the past because many of their properties can be described by a combination of individual properties of the consistent phases and the volume fraction in the mixture. Composite materials are gaining wide spread acceptance due to their characteristics of behaviour with their high strength to weight ratio. The interest in metal matrix composites (MMCs) is due to the relation of structure to properties such as specific stiffness or specific strength. Like all composites, aluminium matrix composites are not a single material but a family of materials whose stiffness, density, thermal and electrical properties can be tailored. Composite materials are high stiffness and high strength, low density, high temperature stability, high electrical and thermal conductivity, adjustable coefficient of thermal expansion, corrosion resistance, improved wear resistance etc. the matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material.

D. Silicon Carbide (Sic) As Reinforcement

Silicon Carbide is the only chemical compound of carbon and silicon. It was originally produced by a high temperature electro-chemical reaction of sand and carbon. Silicon Carbide is an excellent abrasive and has been produced and made into grinding wheels and other abrasive products for over one hundred years. Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties.

It is used in abrasives, refractoriness, ceramics, and numerous high-performance applications. The material can also be made an electrical conductor and has applications in resistance heating, flame igniters and electronic components. Silicon carbide is composed of tetrahedral of carbon and silicon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. Silicon particles are shown in Fig 1.16.

Fig.1.2: Silicon carbide as reinforcement

E. Properties of Silicon Carbide

1) Low density
2) High strength
3) Low thermal expansion
4) High thermal conductivity
5) High hardness
6) High elastic modulus
7) Excellent thermal shock resistance
8) Superior chemical inertness

Detailed properties of SiC are shown in Table 1.4

Properties	Value	Properties
Melting Point (^{0}C)	2200-2700	Linear coefficient of expansion(10^{-6}K)
LIMIT OF APPLICATION (^{0}C)	1400-1700	Fracture toughness (MPa-m$^{1/2}$)
Moh's Hardness	9	Crystal structure
Density (g/cm^3)	3.2	Linear coefficient of expansion (10^{-6}K)

F. Fly-Ash As Reinforcement

The incineration of lignite results in waste products, mainly fly ash and additional bottom ash and slag. Every year 150 million tons of fly ash is produced worldwide . Fly ash is used in cement and construction industry. Unused fly ash is disposed into landfills or settling ponds . The disposal of ash results in significant environmental problems, therefore ash and fly ash is classified as a products can be enriched with Cr, Ni and F . Higher amounts of F are attributed to apatite, which can have contents up to 5.5 % of F.

Fig.1.3: Fly-Ash as reinforcement

Chemical proportions of LIGNITE ash are shown in Table 1.5

Component	Lignite
SiO_2 (%)	15-45
Al_2O_3 (%)	20-25
Fe_2O_3 (%)	4-10
CaO (%)	5-30
MgO (%)	1-10

II. LITERATURE REVIEW

This chapter presents a review of the literature data available on the effect of various reinforcement types, their size and volume fabrication, ageing behaviour with Al based MMC's. Metal matrix composites are a combination of two phases, matrix and the reinforcement. Matrices can be selected from a number of Aluminium alloy e.g. A 2000, 6000, 7000, 2014, 6061 and many reinforcement types SiC, B_4C, Al_2O_3, and C etc. are available in different sizes morphologies(particulates short fibres long fibres and platelets) and volume fractions. These reinforcements can be combined with the different matrices, resulting in large composite systems. Furthermore, several different processing routes, such as powder metallurgy, stir casting, squeeze casting, hot extrusion etc.

N.Chawla, J.J.Williams, G.Piotrowski, and R.Saha [2003]

Authors investigated the tensile strength processes in discontinuously reinforced aluminium (DRA). In this experiment author varies the average particle size (6-23 micro meter), Heat treatment is also given. Conclusion of this paper is that as particle size increases Tensile strength decreases. Heat treatment increases the tensile strength.

Manoj Singla, D.Deepak Dwivedi, Lakhvir Singh, Vikas Chawla [2009]

In this author studied to develop aluminium based silicon carbide particulate MMCs with an objective to develop a conventional low cost method of producing MMCs and to obtain homogenous dispersion of ceramic material. To achieve these objectives two method of stir casting technique has been adopted and subsequent property analysis has been made. Aluminium (98.41% C.P) and SiC (320-grit) has been chosen as matrix and reinforcement material respectively. Experiments have been conducted varying weight fraction of SiC (5%,10%,15%,20%,25%) while keeping all other parameters constant. An increasing trend of hardness and impact strength with increase in weight percentage of SiC has been observed. The best results (maximum hardness 45.5 BHN & maximum impact strength of 36 N-m) have been obtained at 25% weight fraction of SiC.

I.A.Ibrahim, F.A.Mohamed, E.J.Lavernia [2001]

In this review author studied the mechanical properties that can be obtained with metal matrix composited by varying reinforcement percentage by 0,10,15,20% and taking different alloy AA6061, AA2014, AA356. Conclusion of this paper is by increasing reinforcement % age yield strength, ultimate strength is increasing.

D.J.Lloyd [1994]

This review has primarily been concerned with the factors influencing the micro structural, mechanical properties relationship of composites shows the effect of different reinforcement. In this author study different reinforcement effect on different alloy are considered. Conclusions of this paper are elongation of composites increases as increases percentage of reinforcement and tensile strength are increases.

Vivekanandan have fabricated the aluminium fly ash composite by stir casting process. The addition of fly ash acts as a barrier to the movement of dislocations and there by increases the hardness of the composite. And also by adding fly ash to the aluminium in molten state increases the abrasive wear resistance. This strengthening of the composite is because of the solid solution strengthening, dispersion strengthening and particle reinforcement.

A. GAPS Found From Literature

The extensive review of literature carried out for the present study reveals that a lot of work has been reported to enhance the properties of Aluminium metal matrix composites through stir casting or by any other process. The work carried out by different researchers can be categorized in to the following broad classes: Very limited amount of work has been reported which explains the factors affecting mechanical properties like Tensile strength and Impact strength and Aluminium matrix composites. Very limited work on combined effect of Silicon Carbide and Fly-Ash on Aluminium metal matrix composited properties have done.

III. PROBLEM FORMULATION

A. Objectives Of Present Work

The problem is to study the tensile strength behavior of Al-SiC/FA metal matrix composite (MMC) of aluminium alloy of grade 2014 with addition of varying percentage composition of SiC particles and Alumina made by stir casting technique. The tensile strength and Toughness like mechanical properties will also be taken into consideration. For the achievement of the above, an experimental set up is prepared where all the necessary inputs were made. The aim of the experiment is to study the effect of variation of the percentage composition by stir casting technique. The present work emphasizes the literature review of Al-Si alloy and its composites. There are many manufacturing processes to form composites commercially. But the technique and still under progress for its commercialization in developing countries like India. The objectives of present proposal are as follows:

1) To prepare the cost-effective MMC material by taking Al-Si alloy with matrix ceramic particulate like silicon carbide as reinforced phase using stir casting technique.
2) Tensile strength & Impact strength of the prepared MMCs.

IV. EXPERIMENTAL WORK

A. Experimental Set Up Used In Stir Casting Operation

Equipments used to perform the Stir Casting operation and testing of composited is shown in Table 4.1

Table 4.1: List of Equipment used for Stir Casting Operation

S.No	Equipments Used		S.No	Equipments Used
1	Muffle Furnace		5	Die
2	Radial drilling machine		6	Power Hacksaw
3	Graphite Cruicible		7	Universal Testing Machine
4	Graphite Stirrer		8	Impact Toughness Machine

The equipments used during experimental work are shown in Figure.

1) *Muffle Furnace:* Muffle Furnace was used to heat the material to desired temperatures by conduction, convection or blackbody radiation from electrical resistance heating elements. A muffle furnace(sometimes retort furnace) in historical usages is a furnace in which the subject material is isolated from the fuel and all of the products of combustion including gases and flying ash. In our furnace which is shown in Figure maximum temperature of 1100°C was achieved.

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Fig.4.1: Muffle Furnace

2) *Radial Drilling Machine:* This machine was used for rotating stirrer at different speeds.

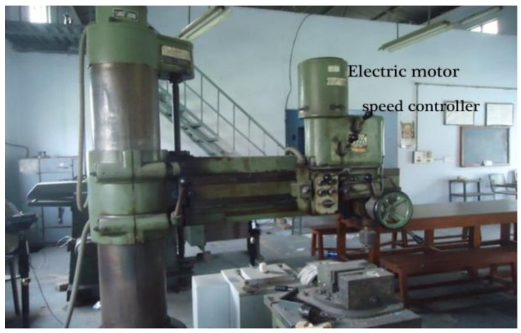

Fig.4.2: Radial Drilling Machine

3) *Graphite Crucible:* A crucible is a refractory container used for metal, glass, and pigment production as well as a number of modern laboratory processes, which can withstand temperatures high enough to melt or otherwise alter its contents. Historically, they have usually been made of clay, but they can be made of any material with a higher temperature resistance than the substances they are designed to hold. Graphite crucible is shown in Fig.4.3

Fig.4.3: Graphite crucible used to keep molten metal in Muffle furnace

4) *Die:* Die is used to give a desired shape to the final specimens which is designed on the CNC(Computer Numerical Control) machine.

Fig.4.4: CNC used for preparing die

Fig.4.5: Die made up of Mild Steel

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5) *Power Hacksaw:* A power hacksaw (or electric hacksaw) was a type of hacksaw that was powered either by its own electric motor. A hacksaw is a fine-tooth saw with a blade under tension in a frame, used for cutting materials such as Aluminum alloy into small pieces so is to keep the alloy into crucible. Power hacksaw is shown in Fig.

Fig.4.6: Power Hack Saw

V. RESULTS AND DISCUSSION

A. *Tensile strength test*

Tensile tests were used to assess the mechanical behavior of the composites and matrix alloy. The composite and matrix alloy rods were machined to tensile specimens with a diameter of 14.75mm and gauge length of 75mm. Ultimate tensile strength (UTS), often shortened to tensile strength(TS) or ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before necking, which is when the specimen's cross-section starts to significantly contracts.

Fig.5.1: Tensile Strength Specimens of different composition

Table 5.1: Strength Results

PROPORTIONS	TENSILE STRENGTH (N/mm^2)	LOAD AT PEAK(KN)	YIELD STRESS (N/mm^2)	LOAD AT YIELD(KN)	ELONGATION (%)
Al 2014	101.830	17.4	80.762	13.8	1.21
Al+5%SiC	109.850	18.3	89.65	15.318	1.36
Al+10%SiC	128.516	21.96	102.357	17.49	1.55
Al+5%FA	131.131	22.26	103.305	17.82	1.27
Ai+10%FA	135.540	27.82	107.634	18.391	1.58

1) *Yield Strength Comparison:*

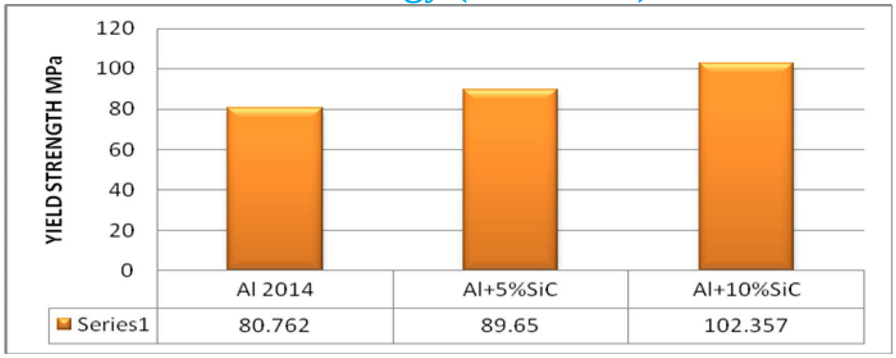

Fig.5.2: Comparison of Yield Strength with wt.% variation of SiC

Fig.5.3: Comparison of Yield Strength with wt.% variation of Fly-Ash

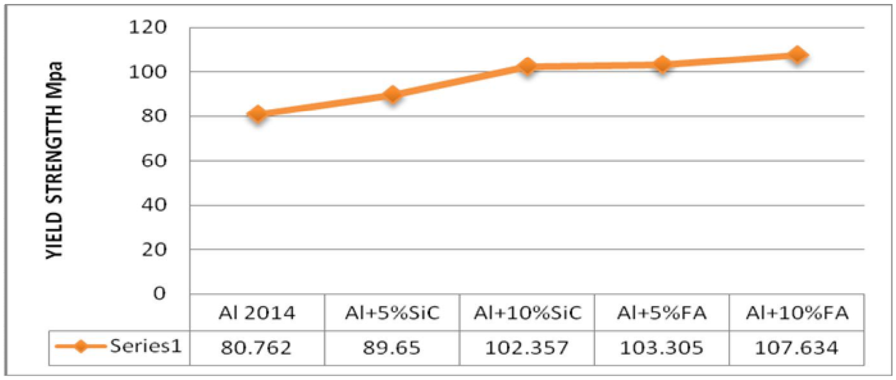

Fig.5.4: Comparison of Yield Strength with wt.% variation of SiC and Fly-Ash

2) Ultimate Strength Comparison:

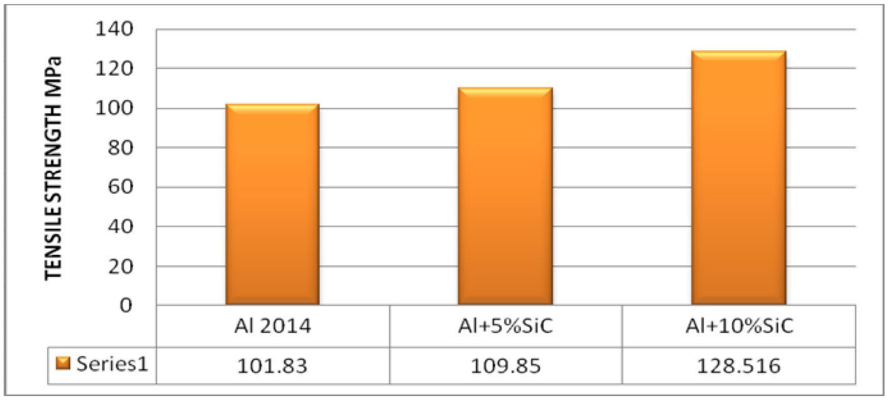

Fig.5.5: Comparison of Tensile Strength with wt.% variation of SiC

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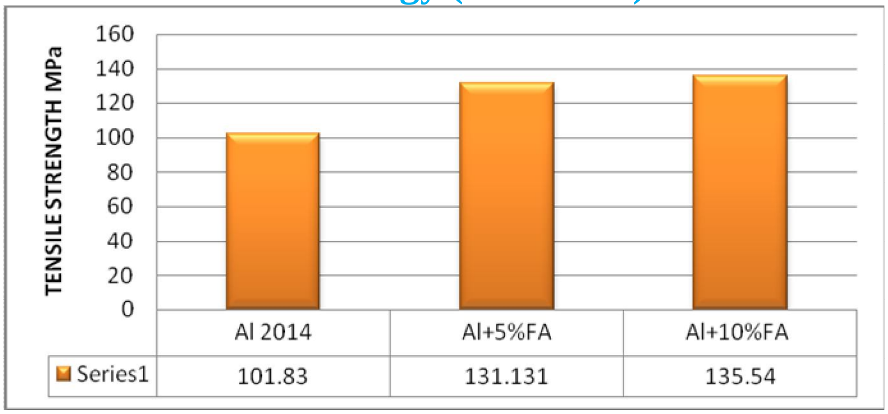

Fig.5.6: Comparison of Tensile Strength with wt.% variation of Fly-Ash

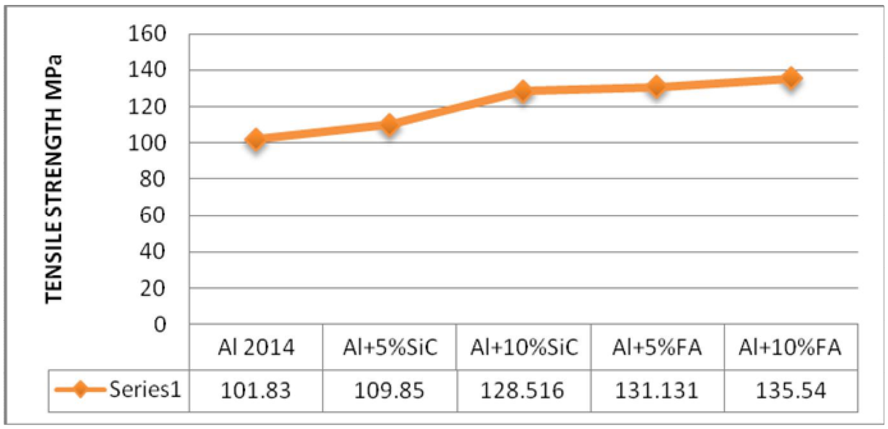

Fig.5.7 : Comparison of Tensile Strength with wt.% variation of SiC and Fly-Ash

3) Stress vs. Strain Curves: During tensile testing of a material sample, the stress-strain curve is a graphical representation of the relationship between stress, derived from measuring the load applied on the sample, and strain, derived from measuring the deformation of the sample, i.e.elongation, compression or distortion. The slope of stress-strain curve at any point is called the tangent modulus; the slope of the elastic (linear) portion of the curve is a property used to characterize materials and is known as the Young's modulus. The area under the elastic portion of the curve is known as the modulus of resilience.

Stress v/s Strain curves for Al2014 Alloy with wt.% variation of SiC and Fly-Ash

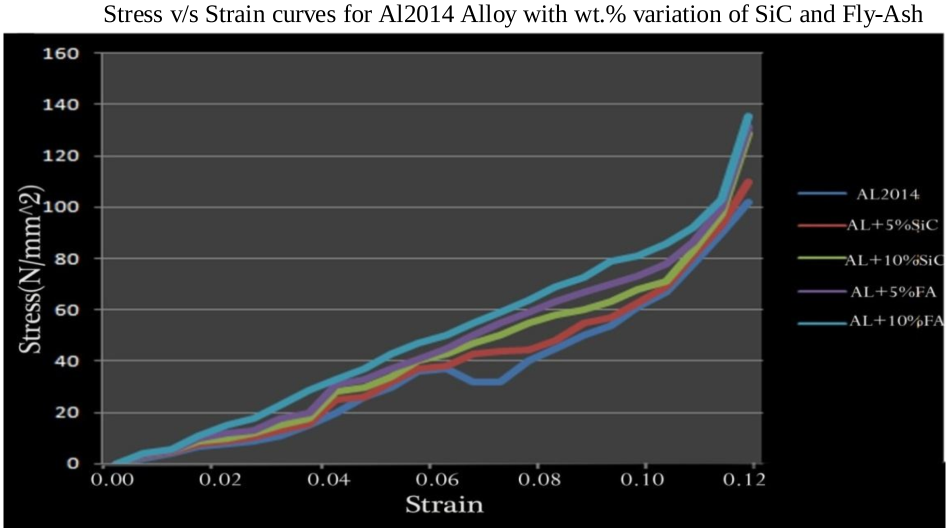

Fig.5.8: Stress vs. Strain curves for Al2014 Alloy with wt.% variation of SiC & Fly-Ash

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It exhibits a very linear stress-strain relationship up to a well defined yield point. The linear portion of the curve is the elastic region and the slope is the modulus of elasticity or Young's Modulus. As deformation continues, the stress increases on account of strain hardening until it reaches the ultimate strength. Until this point, the cross- sectional area decreases uniformly because of Poisson contractions. The actual rupture point is in the same vertical line as the visual rupture point. The work hardening rate increases with increasing volume fraction of reinforcement (and decreasing matrix volume). The higher ductility can be attributed to the earlier onset of void nucleation with increasing amount of reinforcement.

B. Impact test results

1) *Determined with a Charpy or Izod test:* Impact properties are not directly used in fracture mechanics calculations, but the economical impact tests continue to be used as a quality control method to notch sensitivity and for comparing the relative toughness of engineering materials. For both tests, the specimen is broken by a single overload event due to the impact of the pendulum. A stop pointer is used to record how far the pendulum swings back up after fracturing the specimen. The impact toughness of a metal is determined by measuring the energy absorbed in the fracture of the specimen.

Fig.5.9: Impact Strength specimens with wt.% variation of SiC and Fly-Ash

Table 5.2: Results of Impact Test

S.No	Composites	Impact Energy Nm
1	Al 2014	5.93
2	Al + 5% SiC	6.38
3	Al + 10% SiC	7.03
4	Al + 5% FA	6.63
5	Al + 10% FA	7.48

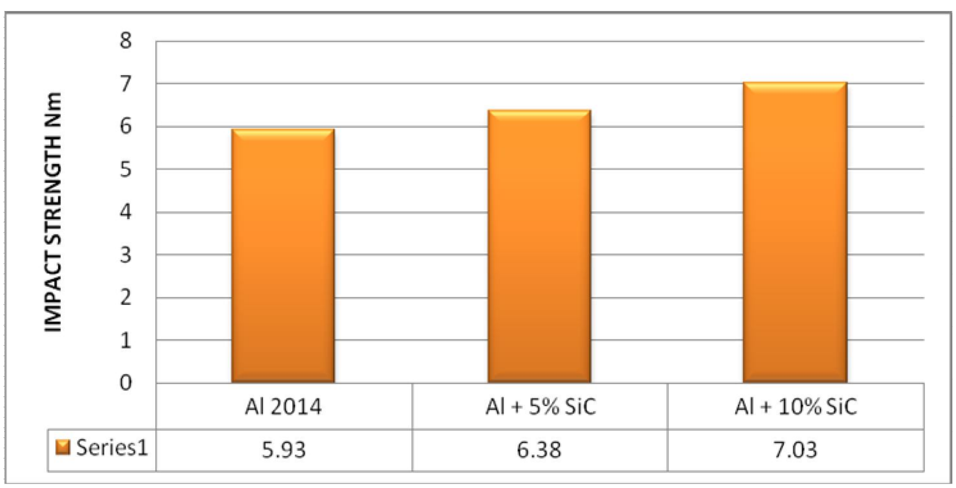

Fig.5.10: Comparison of Impact Strength with wt.% variation of SiC

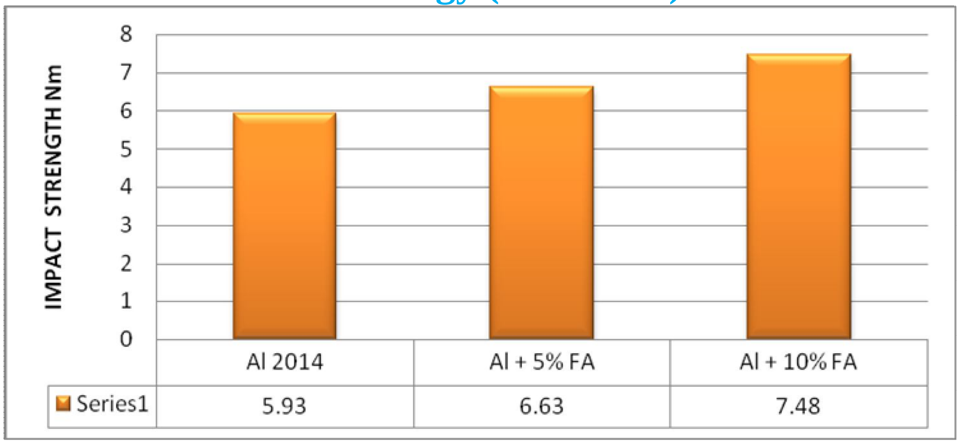

Fig.5.11: Comparison of Impact Strength with wt.% variation of Fly-Ash

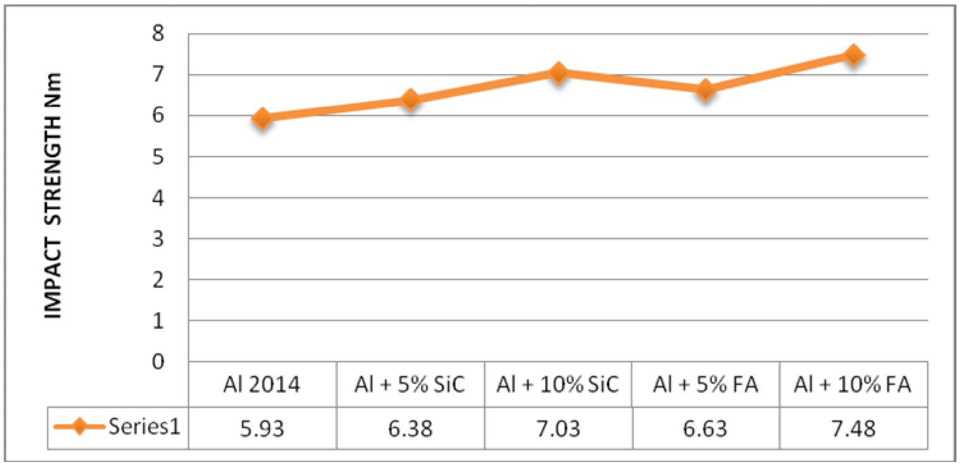

Fig.5.12: Comparison of Impact Strength with wt.% variation of SiC and Fly-Ash

VI. CONCLUSIONS

The conclusions drawn from the present investigations are as follows.

A. Aluminium matrix composites have been successfully fabricated by stir casting technique with fairly uniform distribution of SiC & Fly-Ash particles.

B. The results confirmed that stir formed Al alloy 2014 with SiC/FA reinforced composites is clearly superior to base Al alloy 2014 in the comparison of Tensile strength as well as Impact strength.

C. It is found that elongation tends to increase with increasing particles wt. % which confirms that silicon carbide and fly-ash increases ductility.

D. It appears from this study that UTS and Yield strength starts increases with increase in weight percentage of SiC and Fly-Ash in the matrix.

E. Impact strength is increase by adding SiC & Fly-Ash.

F. From the results, it is also confirmed that Fly-Ash reinforced composites gives more Tensile & Impact Strength comparing to SiC reinforced composites.

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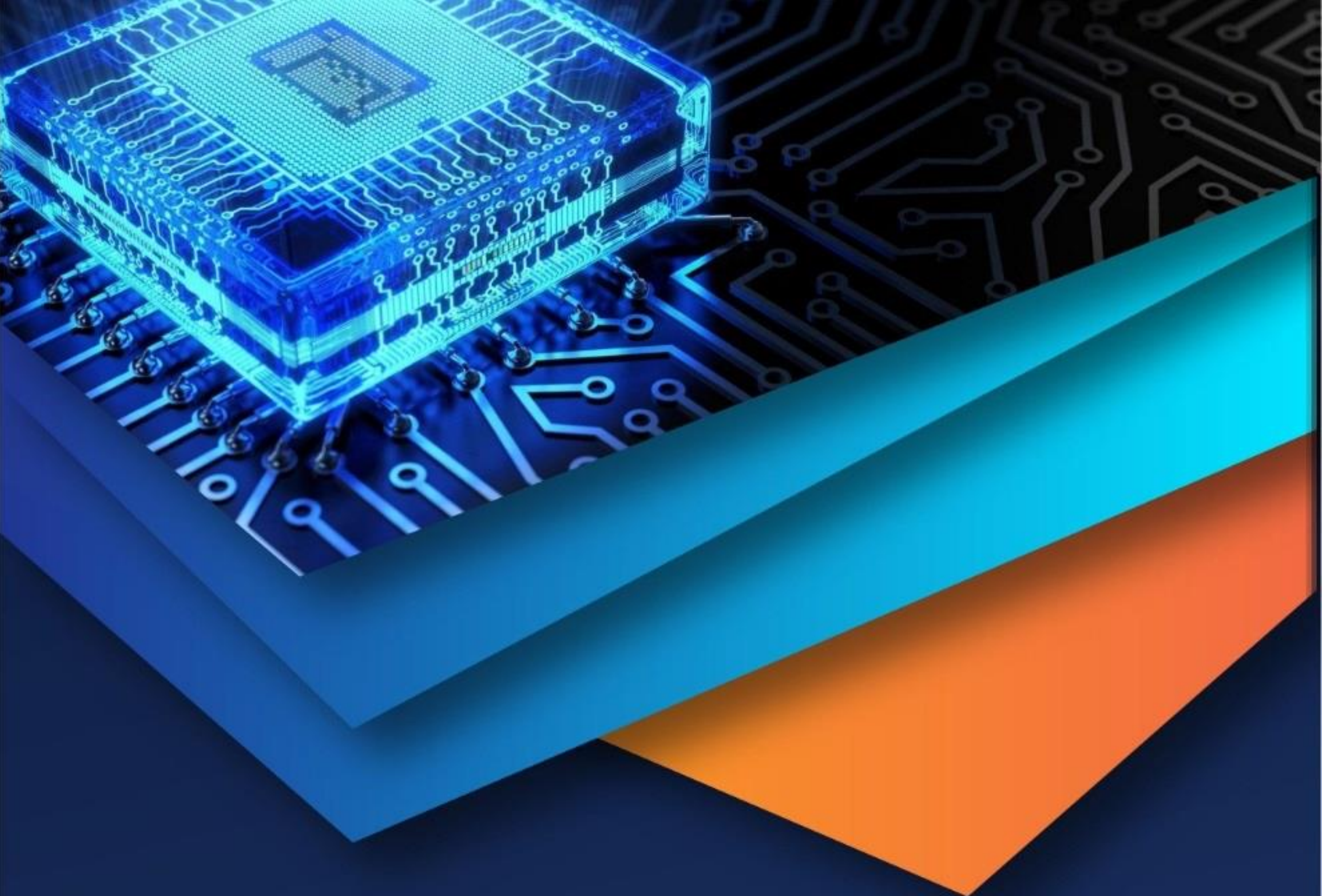

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