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Effect of SiC Reinforcement on Fatigue Characteristics of Al-SiC Metal Matrix Composite

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ABSTRACT

Aluminum silicon carbide metal matrix composites are utilized in various fields like aviation, airplanes, submerged, automobiles and so on. Various assembling procedures are accessible for the manufacturing of aluminum silicon carbide metal matrix composites (Al-SiC MMC). In the different techniques, stir casting course is basic and more affordable just as utilized for large scale manufacturing. The fundamental constraints of stir cast Al-SiC MMC are inappropriate distribution of SiC reinforcement in matrix and less wettablity of SiC reinforcement molecule with liquid Aluminum. This paper highlight that different properties of stir cast Al-SiC MMC relies on fabrication strategy, volume portion, shape, size of particles and distribution and properties of constituents. A variety of preparing ways have been set up for the manufacturing of particle/whisker/short fibre fiber reinforced composites. The present work is study on effect of fatigue characteristics of Aluminium (Al6061) based metal matrix composite with varying weight percentage (0%, 3%, 6% and 9%) of reinforcement of particulate silicon carbide particles size of 40-50µm.

Keyword: ***- Aluminium metal matrix composite, SiC, Reinforcement, Stir casting, Fatigue strength***

1. INTRODUCTION

According to matrix constituent composites are classified into ceramic-matrix composites, metal matrix composites and organic-matrix composites. Among these composites, MMCs provide significantly improved properties such as higher strength, specific modulus, damping capacity, stiffness, good wear resistance and weight savings. The main drawback of MMC generally lies in the relatively high cost of fabrication and of the reinforcement materials. In terms of shape, the reinforcement material may be sub-divided into four major categories Continuous fibres, Short fibres, Whiskers and Particles. between various reinforcements, particles are the most common and cheapest reinforcement. While continuous fiber reinforcement MMCs provide the most effectual strengthening, particle reinforced MMCs are widely use due to their cost-effectiveness, isotropic properties. Between various matrix materials aluminium alloy matrix materials possess good corrosion resistance and high tensile strength. likewise among various reinforcements silicon carbide reinforcements are economical; improve tensile strength and elastic modulus at little expense of ductility. Silicon carbide as such, because of its high hardness, has got a number of applications such as in automobile parts, electronic circuits, structural materials, nuclear fuel particles, etc.. The Al-SiC MMC possess wide range of physical and mechanical properties such as high strength, stiffness, low density, high corrosion, wear resistance, low thermal shock, high electrical and thermal conductivity, good thermal properties and good damping ability. Aluminium SiC Metal matrix composites are used in various fields like automobile, aerospace, fuselage skins of high performance aircrafts, underwater etc.

2. OBJECTIVE

In the view of the large scope available for investigation, the present work is taken up to study the influence of SiC reinforcement particulates in Al6061 matrix alloy, on the mechanical and fatigue characteristics of the composites. The objective of present work is following

- Fabrication of Al-SiC_p Metal Matrix Composite using stir casting method with 0% 3%, 6% and 9% SiC particulates.
- Mechanical characterization Aluminium Silicon carbide Metal Matrix Composite
- Fatigue characterization of Aluminium Silicon carbide Metal Matrix Composite

3. FABRICATION OF AL-SIC_P MMC USING STIR CASTING TECHNIQUE

Work Material Details

The details of the material selected for present investigation are as discussed below. Aluminium (AL6061) based metal matrix composite with varying volume fraction (0%, 3%, 6% and 9%) of reinforcement of particulate silicon carbide particles of 40-50µm size has been selected for the present investigation.

AL6061:

Among several series of aluminium alloys, AL6061 is one of the most extensively used alloys for its excellent properties. Basically AL6061 is an alloy of Aluminium, Magnesium and Silicon, which is highly resistant to corrosion, has excellent extrudability and exhibit moderate strength.

Table-1: Mechanical properties of A6061

Properties	Elastic Modulus (Gpa)	Density (g/cm^3)	Poisson's Ratio	Tensile Strength in Mpa	Melting Temperature in ^{0}C
Values	68.9	2.70	0.33	200-280	600

Table-2: Chemical composition of A6061

Al	Mg	Si	Fe	Cu	Cr	Zn	Ti	Mn	Remainder
95.85 - 95.56	0.8 - 1.2	0.40 - 0.80	0.0 - 0.7	0.15 - 0.40	0.0 - 0.25	0.0 – 0.25	0.0 – 0.25	0.0 – 0.15	0.05 each, 0.15 total

Silicon Carbide:

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. SiC is an excellent abrasive which is used in grinding wheels and other abrasive products. We used Silicon Carbide reinforcement particulates of about 40-50 microns size. Some of the properties of SiC are represented in Table.

Table-3: Mechanical properties of SiC

Properties	Elastic Modulus (Gpa)	Density (g/cm^3)	Poisson's Ratio	Tensile Strength in Mpa	Melting Temperature in ^{0}C
Values	410	3.22	0.14	160	3100

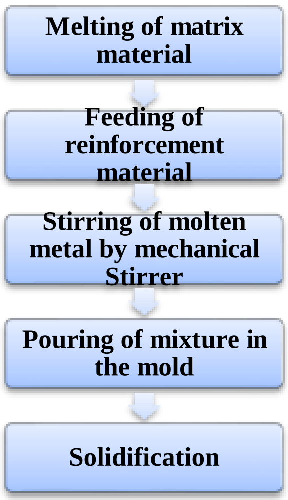
Fig-1: Al 6061

Fig-2: Silicon Carbide powder

Table- 4: Percentage composition of Al-SiC for Stir Casting technique

Sample	Aluminium 6061		Silicon Carbide reinforcement	
	Weight (gm)	% by Weight	Wight (gm)	% by Weight(gm)
A	2780	97%	86	3%
B	2840	94%	182	6%
C	2800	91%	277	9%

Process of Stir Casting:



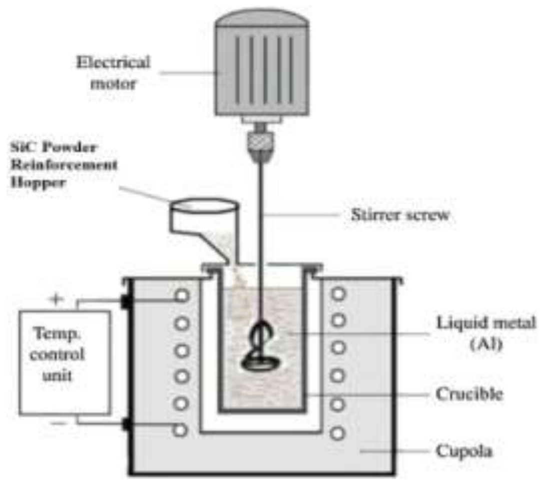


Fig-3: Schimatic Diagram of Stir Casting

Fabrication of Al-SiC$_p$ Metal Matrix Composites:


Step-1: Molten metal


step-2: Stirring of molten metal


step-3: Sand Mold


Step-4: pouring of mixture in the mold


step-.5: Casting Samples

4. MECHANICAL CHARACTERIZATION

Rockwell Hardness Number

It can be observed from the results that there is an increasing trend in the hardness values of the composites. The increase in hardness can be attributed to the uniform distribution of SiC particulate reinforcement in AL6061 matrix, forming strong interfacial bond between the matrix and the reinforcement.

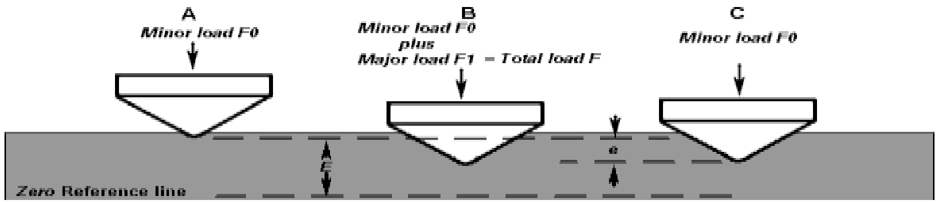


Fig-4: Rockwell Principle

Table-5: RHN of as cast composites

A6061+ 0%SiC$_p$	A6061+ 3%SiC$_p$	A6061+ 6%SiC$_p$	A6061+9%SiC$_p$
60	70	73	78

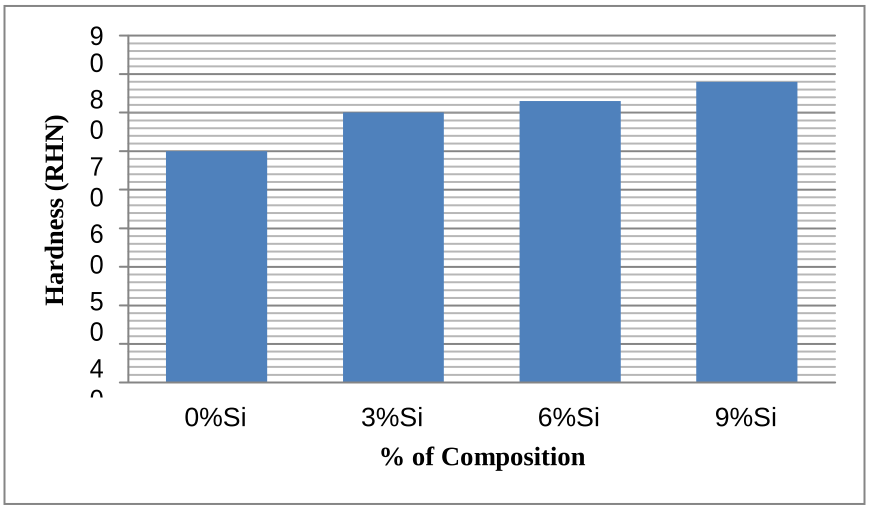


Chart-1: RHN of Base alloy and Composites

Tensile Strength

The tensile test is the most commonly performed and is the simplest among of all the mechanical tests. In this experiment, a specimen is subjected to a gradually increasing uniaxial load until failure occurs

Stress is a measure of the intensity of an internal force. Stress is defined as the force P per unit area A:

Stress,

$$\sigma = \frac{P}{A} \text{ N/mm}^2$$

Strain is a measure of the deformation that has occurred in a material. In the case where the magnitude of deformation is the same over the entire length of a body, strain is defined as:

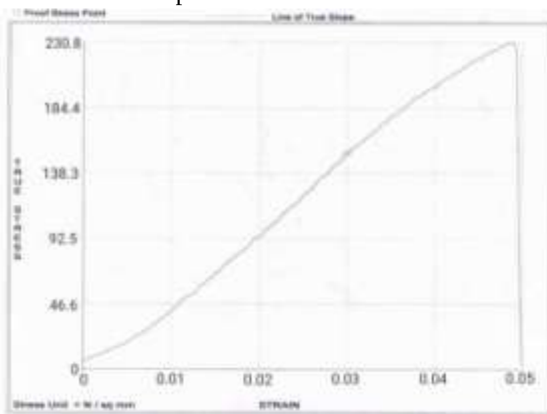
$$\varepsilon = \frac{L_f - L_o}{L_o} \text{ mm/mm}$$

Where,

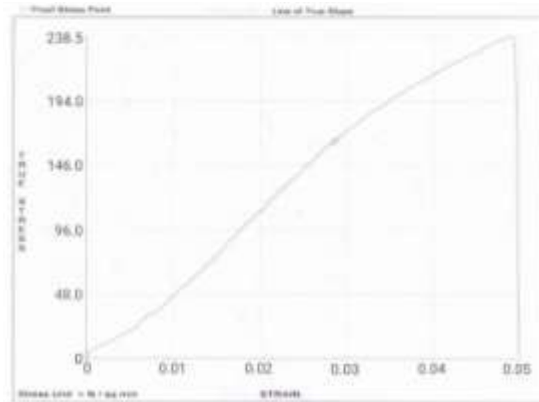
L_f= the initial length

L_o = final length

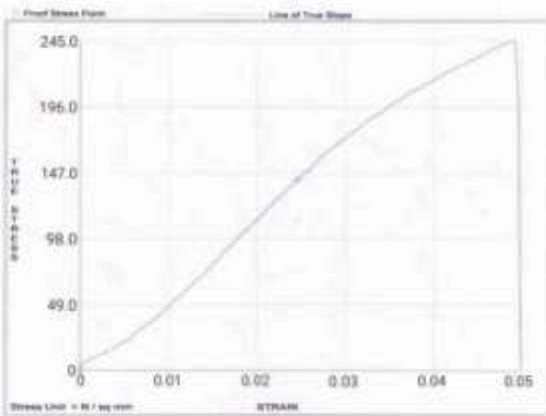
Stress-Strain Graph:



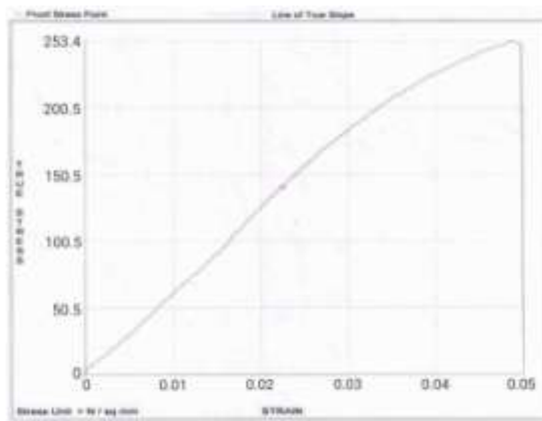
Graph-1: Stress strain curve for 0% SiC



Graph-2: Stress strain curve for 3% SiC



Graph-3: Stress strain curve for 6% SiC



Graph-4: Stress strain curve for 9% SiC

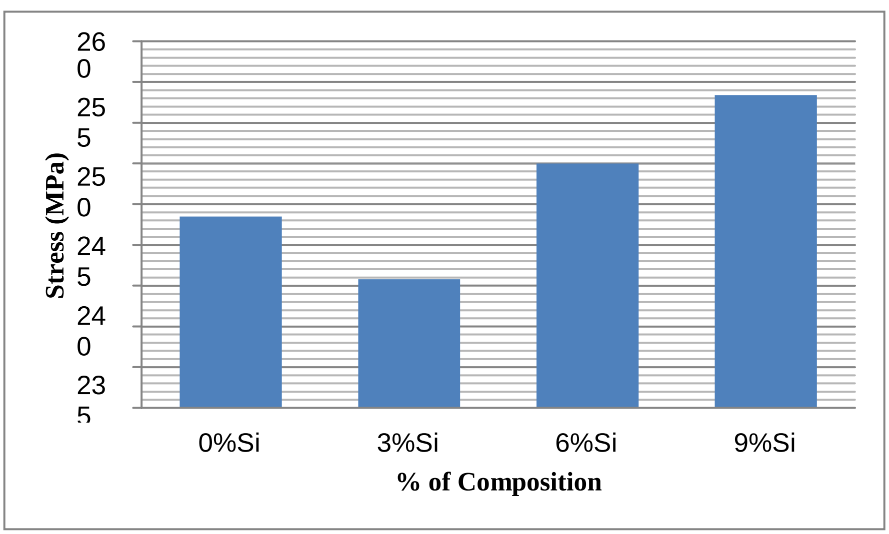


Chart-2: Tensile Strength of Base alloy and Composites

5. FATIGUE CHARACTERIZATION

Fatigue calculation (Theoretical):

The laboratory method for determining the endurance limit of materials, although more precise, is laborious and time consuming. A number of tests are required to prepare one S–N curve and each test takes considerable time. It is, therefore, not possible to get the experimental data of each and every material.

When the laboratory data regarding the endurance limit of the materials is not available, the procedure discussed in this article should be adopted. Two separate notations are used for endurance limit, viz, (S'e) and (Se) where,

S'_e = endurance limit stress of a rotating beam specimen subjected to reversed bending stress (N/mm2)

S_e = endurance limit stress of a particular mechanical component subjected to reversed bending stress (N/mm2)

There is an approximate relationship between the endurance limit and the ultimate tensile strength (*Sut*) of the material. (From the book Design of Machine Elements by V. B. Bhandari)

For steels,

$S'e = 0.5\, S_{ut}$

For cast iron and cast steels,

$Se = 0.4\, S_{ut}$

For wrought aluminium alloys,

$S'e = 0.4\, S_{ut}$

For cast aluminium alloys,

$S'e = 0.3\, S_{ut}$

The relationship between (*Se*) and (*S'e*) is as follows:

$Se = K_a * K_b * K_c * K_d * S'e$

where,

K_a = surface finish factor

K_b = size factor

K_c = reliability factor

K_d = modifying factor to account for stress concentration

Reversed Stresses Design For Finite and Infinite Life:

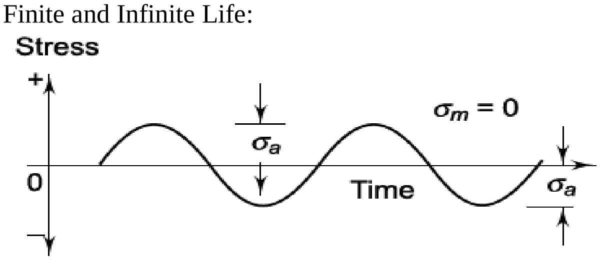


Fig-5: Reversed Stresses

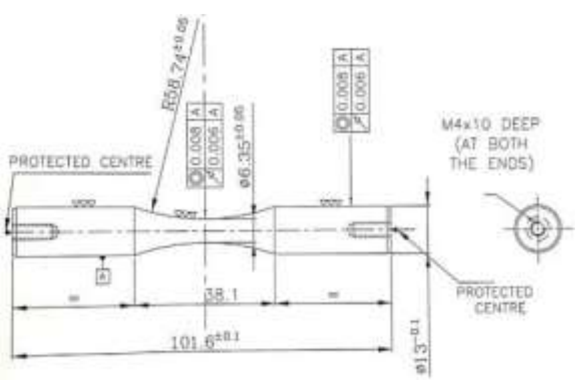


Fig-6: Specimen geometry

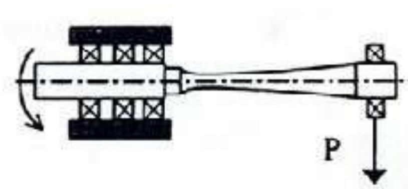


Fig-7: Schematic diagram Cantilever loading type

Stress Calculations:

Bending moment equation,

$$\frac{\square}{\square} = \frac{\square}{\square} = \frac{\square}{\square}$$

Where,
σ = bending stress
Y = distance from the neutral layer to a generic point;
M = Bending Moment
I = the second moment of area of the section about the neutral axis
E = Young's Modulus
R = radius of moment
Therefore,
Bending stress which is also denoted as S_f is,

$$\square\square = \frac{32\square}{\square\square^3}$$

Where,
d = 6.35mm
M = 53.33mm

Load (Kg)	Load (N)	S_f (N/mm^{2})
3	29.43	62.46
3.5	34.33	72.87
4	39.24	83.28
4.5	44.14	93.69
5	49.05	104.10

Calculation for number of cycles (N):

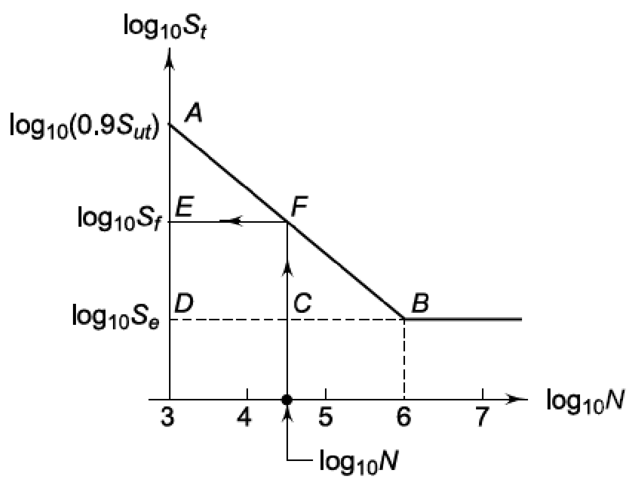


Fig-8: S-N Curve

Fatigue life calculation for specimen reinforced with 0% SiC =
Ultimate Tensile stress S_{ut}= 238.5N/mm^2
0.9S_{ut} = 214.65 N/mm^2
For cast aluminium alloys,
S'e = 0.3 S_{ut}
S'e = 71.55 N/mm^2
Se = K_a*K_b*K_c*K_d*S'e
K_a= Surface finish factor
$k_a = a(S_{ut})^b$ [if k_a >1, set K_a=1]
Take a= 4.51 and b= -0.265
= $4.51(238.5)^{-0.265}$
= 1.057 >1
Therefore, K_a= 1

K_b = Size Factor

[if d < 7.5, take K_b=1]

K_b= 1 …..[Diameter, d=6.35mm]

K_c= Reliability Factor

Taking 90% Reliability,

= 0.897

K_d = Modifying Factor

$K_d = \frac{1}{Kf}$

As,

$K_f = 1 + q(Kt - 1)$ …..[From stress concentration Equation]

= 1 + 0.4(1.75-1)

= 1.3

$K_d = \frac{1}{1.3} = 0.769$

Therefore,

Se = K_a*K_b*K_c*K_d*S'e

= 1*1*0.897*0.769*71.55

= 49.35 N/mm^2

From S-N Curve,

$$\frac{\log(0.9S_{ut}) - \log(S_f)}{\log(0.9S_{ut}) - \log(S_e)} = \frac{\log 10^3 - \log 10^6}{\log 10^3 - \log 10^N}$$

$$\frac{\log(214.65) - \log(49.35)}{\log(214.65) - \log(S_f)} = \frac{\log 10^3 - \log 10^6}{\log 10^3 - \log 10^N}$$

From this equation,

S_f(N/mm^2)	No. of cycles(N)
62.46	330544
72.87	160196
83.28	85536
93.69	49180
104.10	29976

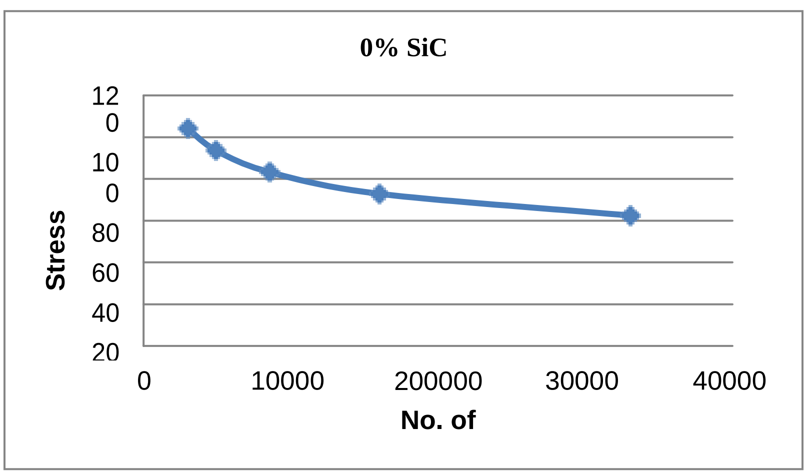


Chart-3: Fatigue life of Composite with 0% SiCp

Fatigue calculation for specimen contains 3% SiC =

Ultimate Tensile stress S_{ut}= 230.8 N/mm^2

$0.9S_{ut}$ = 207.72 N/mm^2

For cast aluminium alloys,

S'e = 0.3 S_{ut}

S'e = 69.24 N/mm^2

Se = K_a*K_b*K_c*K_d*S'e

= 1*1*0.897*0.769*69.24
= 47.76 N/mm^2
From S-N Curve,

$$\frac{\log(0.9\square\square\square) - \log(\square\square)}{\log(0.9\square\square\square) - \log(\square\square)} = \frac{\log 10^3 - \log 10^6}{\log 10^3 - \log 10^\square}$$

$$\frac{\log(207.72) - \log(47.76)}{\log(207.72) - \log(\square\square)} = \frac{\log 10^3 - \log 10^6}{\log 10^3 - \log 10^\square}$$

From this equation,

S_f(N/mm^2)	No. of cycles(N)
62.46	283610
72.87	137430
83.28	73372
93.69	42181
104.10	25708

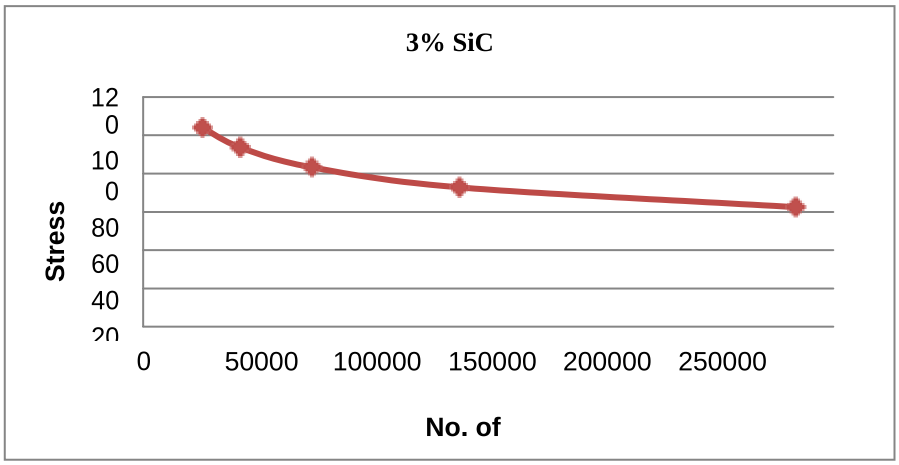


Chart-4: Fatigue life of Composite with 3% SiCp

Fatigue Life calculation for Specimen contains 6% SiC =
Ultimate Tensile stress S_{ut}= 245 N/mm^2
0.9S_{ut} = 220.5 N/mm^2
For cast aluminium alloys,
S'e = 0.3 S_{ut}
S'e = 73.5 N/mm^2
Se = K_a*K_b*K_c*K_d*S'e
= 1*1*0.897*0.769*73.5
= 50.69 N/mm^2
From S-N Curve,

$$\frac{\log(0.9\square\square\square) - \log(\square\square)}{\log(0.9\square\square\square) - \log(\square\square)} = \frac{\log 10^3 - \log 10^6}{\log 10^3 - \log 10^\square}$$

$$\frac{\log(220.5) - \log(50.69)}{\log(220.5) - \log(\square\square)} = \frac{\log 10^3 - \log 10^6}{\log 10^3 - \log 10^\square}$$

From this equation,

S_f(N/mm^2)	No of cycles(N)
62.46	374913
72.87	181708
83.28	97026
93.69	55788
104.10	34005

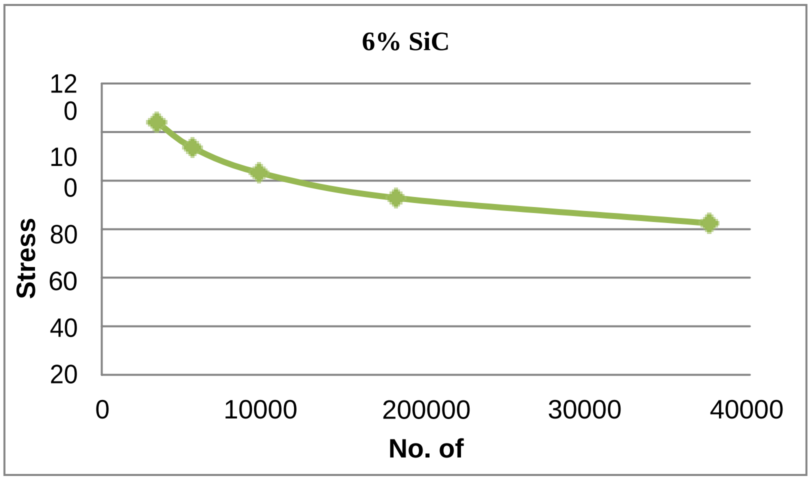


Chart-5: Fatigue life of Composite with 6% SiCp

Fatigue Life calculation for specimen contains 9% SiC =

Ultimate Tensile stress S_{ut}= 253.4 N/mm^2

0.9S_{ut} = 228.06 N/mm^2

For cast aluminium alloys,

S'e = 0.3 S_{ut}

S'e = 76.02 N/mm^2

Se = K_a*K_b*K_c*K_d*S'e

= 1*1*0.897*0.769*76.02

= 52.43 N/mm^2

From S-N Curve,

$$\frac{\log(0.9S_{ut}) - \log(S_e)}{\log(0.9S_{ut}) - \log(S_f)} = \frac{\log 10^3 - \log 10^6}{\log 10^3 - \log 10^N}$$

$$\frac{\log(228.06) - \log(52.43)}{\log(228.06) - \log(S_f)} = \frac{\log 10^3 - \log 10^6}{\log 10^3 - \log 10^N}$$

From this equation,

S_f(N/mm^2)	No of cycles(N)
62.46	439331
72.87	212924
83.28	113693
93.69	65371
104.10	39845

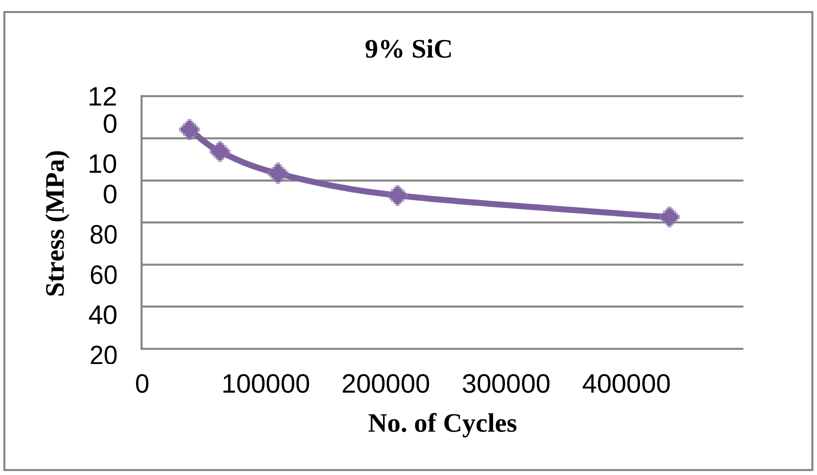


Chart-6: Fatigue life of Composite with 9% SiCp

Finite element Method Analysis:

Among the various tools of FEM, ANSYS 14.5 is used for analysis. For analysis first of all the material properties are assigned in ansys workbench. Then geometry modelled in CAD software CATIA is imported into ansys workbench in .stp format..

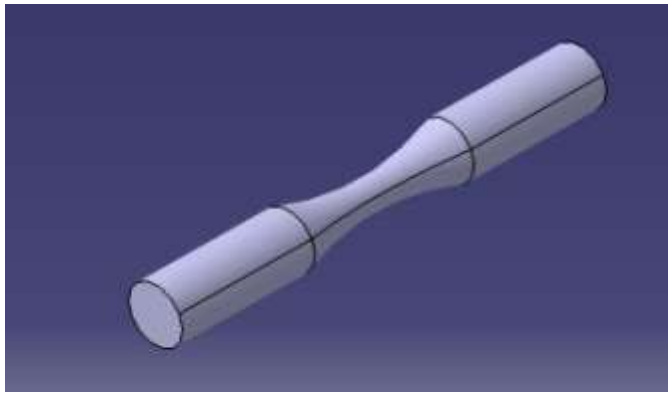


Fig-9:CAD specimen geometry

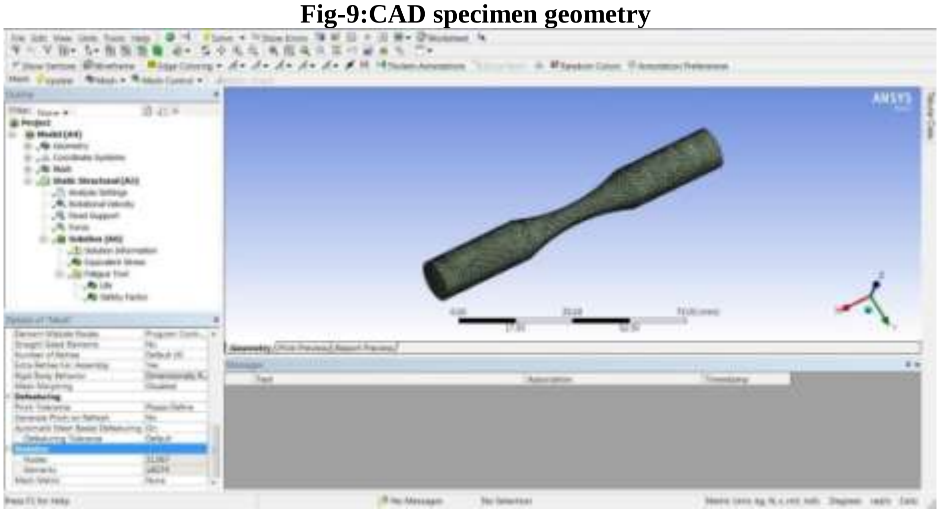


Fig-10: Mashing of Specimen

This geometry is the meshed with element size 1 mm, the node count found as 33367 and element number as 18074.

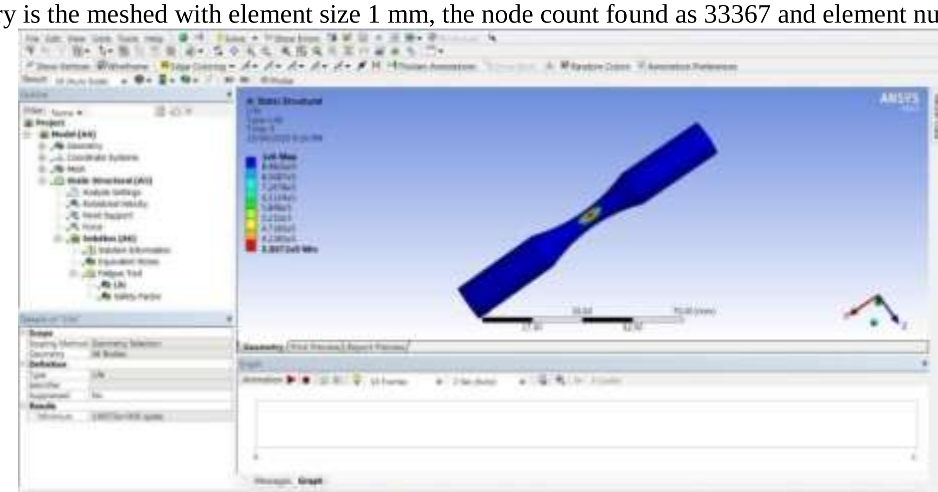


Fig-11:Ansys Result of Fatigue life at 29.43N loading

A fixed support is given to the one collet and force is applied on the another one and rotational velocity as 419 rad/s The equivalent von mices stresses are found from solutions. By inserting fatigue tool, alternating stress and life has found.

Table-6: Ansys Results of fatigue life at Different loading condition

Sr. No.	Load (N)	Bending Stress(Mpa)	RPM	Life(No. of Cycles) 0% Sic	Life(No. of Cycles) 3%SiC	Life (No. of Cycles) 6% SiC	Life (No. of Cycles) 9% SiC
1	29.43	62.46	4000	380720	327400	453400	503970
2	34.33	72.87	4000	183640	157550	208300	244090
3	39.24	83.28	4000	97851	98532	110990	130060
4	44.14	93.69	4000	56233	48233	63789	88425
5	49.05	104.10	4000	34229	29356	38829	45498

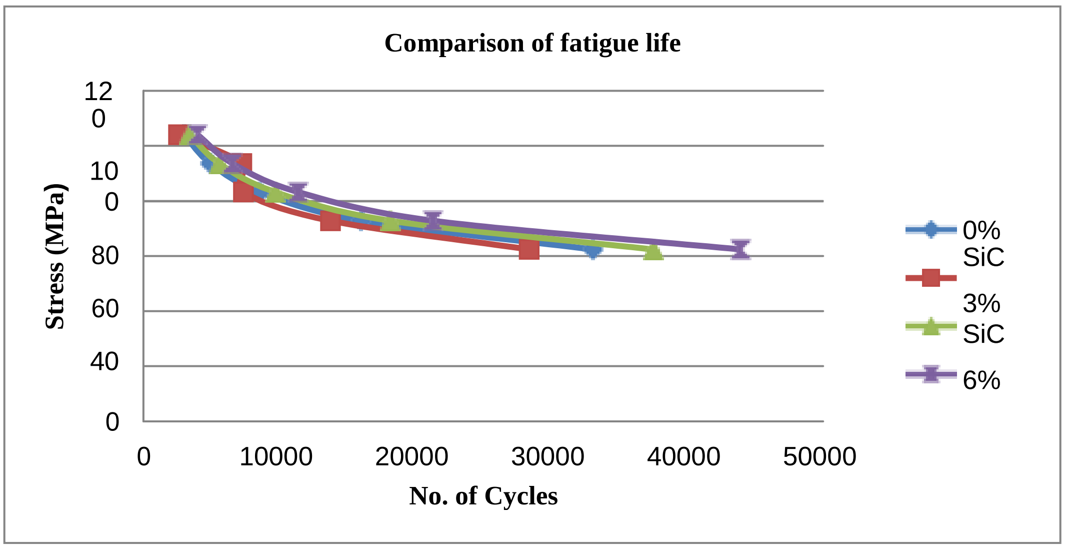


Chart-7: Comparison of fatigue life

6. CONCLUSIONS

The conclusions drawn from the present investigation as various fabrication methods can used for the manufacturing of composites among by the Stir casting process we can manufacture Aluminum Metal Matrix Composite at less cost. For uniform distribution of reinforcement the mechanical stirrer plays important role to ensure proper mixing of silicon carbide particles, Stirring speed and stirring time were important parameters which affect the composition of composite. Also preheating of silicon carbide powder before adding helps to reduce porosity during casting as it remove moisture content present in the powder. From the tests conducted for characterization of mechanical properties, composite material specimens have been found to possess enhanced hardness and tensile strengths compared to matrix alloy specimens, while at the same time, losing ductility as compared to matrix alloy. The mechanical properties of composite depends on these parameters by addition of reinforcement up to a particular level it increases and we can improve various mechanical properties like tensile strength, hardness. From Rockwell hardness test it is observed that hardness of composite material is more as compare to base alloy material also an improvement in tensile strength observed in composite specimen at 6% and 9% of silicon carbide as reinforcement. By Comparing fatigue life at different loading condition it is observed that the fatigue life of the composites is increase with increase in reinforcement content and maximum life was observed at 9%SiCp as reinforcement.

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