Influence of volume fraction, density and porosity on strength and stiffness of Aluminum alloy LM12/ SiC(23 microns) metal matrix composites and comparison of tensile test experimental results with FE simulation tests

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***Abstract*:** Nowadays aluminum alloys are produces excellent and superior properties and these alloys are used in different industrial sectors like, agriculture, constructions, aerospace, automobile, utensils, and general engineering industries because of this alloys is very favourable in microstructure behavior, hardness, less weight ratio, high strength and having good mechanical properties. In this work the aluminum alloy LM12 is the base material this is reinforced with the silicon carbide. The metal matrix composite fabricated by using the stir casting techniques with the uniform distribution of SiC and this confirmed by using the SEM, EDX and XRD analysis. The MMC's evaluate the mechanical properties such as tensile test experimented results are comparison with the Finite element analysis. The FEA model has been prepared by using the ABQUS software evaluate the maximum stress, deformation and load carrying capacity and calculate the Density and Porosity of MMCs'.In this all MMC's obtained results are compared with the pure AALM12 alloy without of silicon carbide addition. The reinforced silicon carbide varies with the 0%, 5%, 10%, 15% &20%wt.fraction. Increment of SiC in MMC's the tensile test results are increases, density of MMC's also increases but porosity is decreases with increasing of SiC.These are the properties evaluations are presented in this paper.

Keywords: 23µmSiC, AALM12, MMC's Fabrication, Tensile test experiment results compare with FEA, Density and Porosity test SEM ,EDX and XRD analysis of MMC's.

1. Introduction

Aluminum alloy metal matrix composites are very popular aluminum alloy many series used in different industrial sectors. These are mainly used in aircraft structure design one of the major criteria due to their high strength ratio and less in weight ratio. Due to this mandate in high recital of the aircrafts weight reduction methods are used in aviation sector and new materials are under search in automobile sectors used. (1-3). The aluminum alloys reinforced with silicon carbide (MMC's) having possess superior symbols in order to decrease the weight and consequently proved to be improved structural components to provide strength to the structure. Enormous research work has been experiencing in the area of MMC's. Because of their weight to strength ratio, MMC's are gradually replacing the popular aluminum .alloys which were used post world war in Aircraft and in other Applications like agriculture, automobile sectors and construction fields etc. (4-6).

Current work is describes the production of MMC's by using the popular technology of stir casting technique, tensile test experimented results as well as FEA results are analysis, density test and porosity. Aluminum alloy LM12 with reinforcement of silicon carbide with various %wt and compositions of AALM12 has been shown in below fig.

Element	Wt.%	Element	Wt%
Copper	09-11	Zinc	0.8 max
Magnesium	0.2-0.4	Lead	0.1 max
Silicon	2.5 max	Tin	0.05 max
Iron	1.0 max	Titanium	0.2 max
Manganese	0.6 max	aluminum	Balance
Nickel	0.5 max		

Compositions of AALM12

2. Development of metal matrix composites

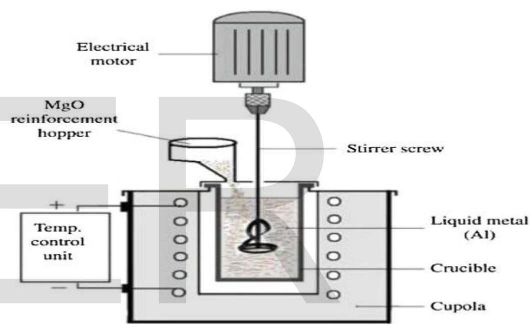


Fig:1 Stir casting set up

The MMC's are fabricated by using the popular stir casting technique, this setup have been shown in the fig:1. The AALM12 aluminum alloy bars were kept inside the crucible furnace which is made up of graphite material and the heating source is supplied by the electrically. The aluminum alloy is slowly turn into molten stages when it is exceeded the temperature of 650^0C -750^0C. Their after calculated weight percentage of SiC slowly pour into the molten metal with uniform speed, meanwhile maintain the stirrer speed in uniformly ranges from 300rpm-400rpm and this is operated by supporting of electrical motor and Also different wt% SiC composites are fabricated with followed same procedure.

Fig:2 Cast product and SiC

3. Experimentation

3.1 Density measurement test

Density and Porosity From the literature review, it is found that the density of the composite mainly depend on the relative proportion of the matrix and its reinforcing materials. The measured density of the material is defined as ratio of weight of the composite material with its volume. But the theoretical density of the composite material in terms of weight fraction of the different constituent based on the concept of "Rule of Mixture".by the following equation as given in Eq.

Measured Density = Mass/Volume Theoretical Density calculation by using rule of mixture using of tensile test specimen ASTM E-8 as per the ASTM D792 - 20

$$\rho_c = f_m\rho_m + f_r\rho_r \quad [15]$$

Where:

ρ = density of matrix

m = mass of matrix

R= Mass of reinforcement

f = Mass fraction

saffics m is the matix and Saffics r is the reinforcement

Calculate the density composition of 5% wt of SiC

M_c is the mass of the Composite Specimen (Matrix Reinforcement) = 62.5536 gram

R_m is the mass of reinforcement (for 5%wt of SiC) = 3.12768 gram

M_m is the mass of matrix =(62.5536 - 3.12768)=59.425 gram

$$f_m = \frac{M_m}{(M_m + R_m)} = \frac{59.425}{59.425 + 3.127} = 0.95$$

$$f_r = \frac{R_m}{(M_m + R_m)} = \frac{3.127}{(59.425 + 3.127)} = 0.05$$

Substituting (2) & (3) in (1)

$$\rho_c = f_m\rho_m + f_r\rho_r = 0.95 \times 2.94 + 0.05 \times 3.21 = 2.953 \text{ gram}/cm^3$$

$$\% \, Porosity = Theoritical \, Density - Measured \frac{Density}{Theoritical} Density$$

$$5\% \, SiC \;\; Porosity = 2.945 - 2.896/2.945 \times 100 = 1.961$$

Similarly method used to calculate the porosity of MMC's.

Table:1 Properties

Compositions	Theoretical density (gm/cm^3)	Measured density (gm/cm^3)	Density (%)	Porosity (%)
Pure LM12	2.94	2.881	0.596	2
5%SiC	2.945	2.896	0.707	1.961
10% SiC	2.967	2.928	0.389	1.314
15% SiC	2.98	2.959	0.201	0.704
20% SiC	2.994	2.975	0.181	0.634

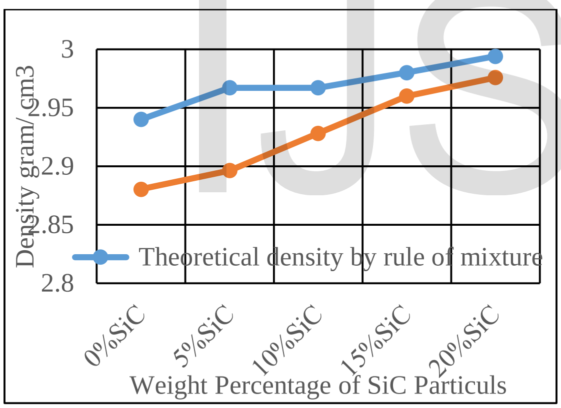
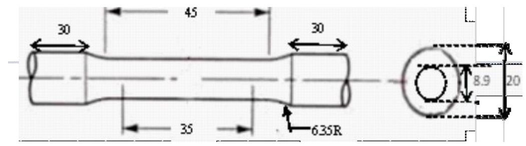


Fig:3 Density of MMC's

The average theoretical and measured density values of the AALM12 alloy and its respective composites were given in table 4 It was observed that the addition of SiC particles into the AALM12 alloy matrix significantly increases the density of the resultant composites in compare to the base alloy show in fig:3.

3.2. Tension test



ASTM tensile specimen(E8)

Fig:4 Tensile test samples

Calculation the Elasticity of composites by using volume fraction method

Elastic modulus is measure of the stiffness of a materials.Anisotrop prevails in many Composites. Silicon carbide (SiC) is much stiffer than LM12 aluminium alloy. **Kerner** found equation for estimating the modulus of a composite is linearly increases that contains spherical particles in a matrix as follows:

for $E_p \geq E_m$ and m_m is the matrix poison's ratio. $V_{p\,(SiC)}$ is the volume fraction and E_m is the elastic modulus of the matrix, m is the mass,ρ is the density and subscripts SiC and Al refer to the Silica carbide and aluminum alloy respectively

Volume fractions of SiC were calculated using the formula

The addition of SiC particles into the AALM12 alloy matrix significantly increases the volume fraction of the resultant composites in compare to the base alloy.

Volume fraction $V_{p\ Sic} = \frac{V_p}{V_p+V_m} \times 100$

$V_{p\ (SiC)} = \frac{m_{SiC}/\rho_{SiC}}{\frac{m_{Al}}{\rho_{Al}}+\frac{m_{SiC}}{\rho_{SiC}}}$ x100 [16]

$V_{(p\ (5\%\ SiC))}$

$= (3.180/3.21) /([(59.4314)/(2.945)] + 3.180/3.21 = 4.686 = 0.0468$

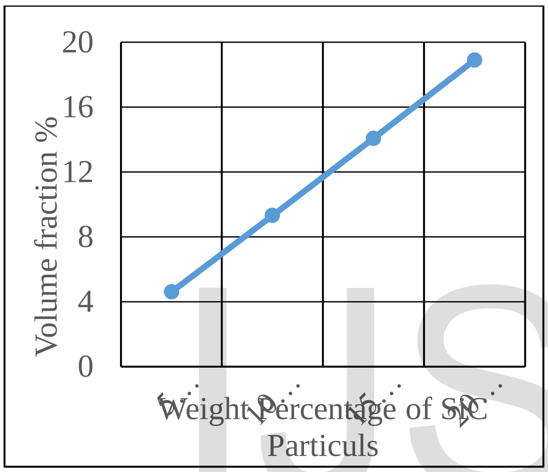


Fig:5 Volume fraction

The volume fraction of the MMC's is increased linearly with increased reinforced that show in fig:5.

3.3. SEM and EDX analysis

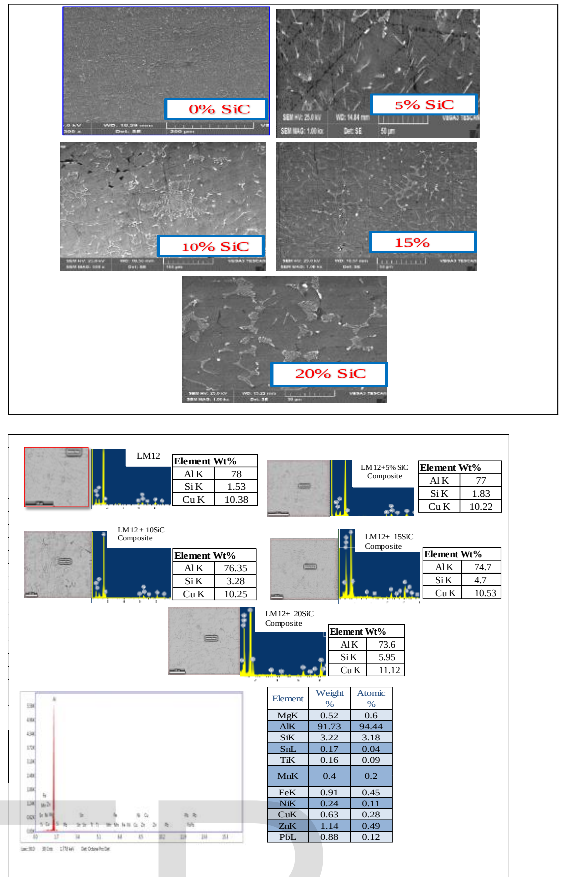
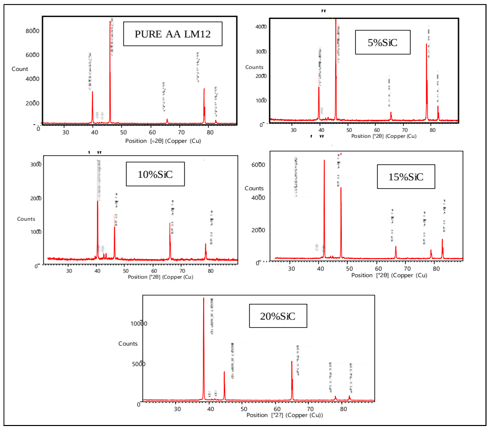


Fig:6 SEM and EDX images

The SEM analysis is carryout the studied of the reinforcements of SiC is distribution and confirmation of inside the matrix are essential to the final properties of composites prepared through stir casting process shown in fig To investigate distribution of reinforcements on composites by using the SEM analysis was performed that observed from the images and it showed that particles were homogenously and uniformly distributed [6]. That showed in SEM images and some clusters of SiC particles are observed in SEM micrographs few researcher



XRD analysis of MMC's

The EDX analysis is observed in the aluminum alloy LM12 metal matrix composites from the SEM images that shown in the fig: 6.10. But Al, Mg and Cu particles are shown in XRD and EDX analysis composites. It shows the qualitative analysis and indicating the presence of Al, Mg, SiC and Cu in the composites material of different reinforced SiC. On the other hand, a high amount of SiC have been indicating due to the surface modification of composites, which are the compositions are having in the composites that is confirmed from this analysis show in fig:6. [7]

Young's modulus of MMC's is given by Kerner equation

$$\mathbf{E_c = E_m\left[1 + \frac{V_p}{1 - V_p} \times \frac{15(1 - m_m)}{8 - 10m_m}\right]}$$

Where E_m is Youngs modulus of the Matrix i.e 71 GPa

V_p is the volume fraction of particulate

M_m = poisons ratio

$$\mathbf{E_{c5\%SiC} = 71\left[1 + \frac{0.04606}{1 - 0.04606} \times \frac{15(1 - 0.33)}{8 - 10(0.33)}\right] = 78.199\ GPa}$$

The calculated the young's modulus of metal matrix composites by using the karner question, the results shows that linearly increased with increased reinforced SiC.

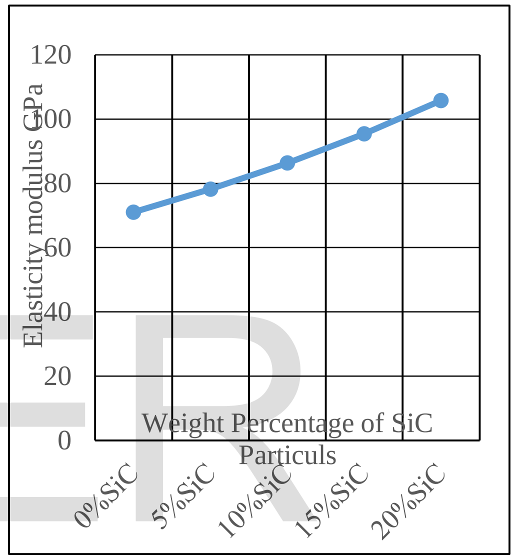


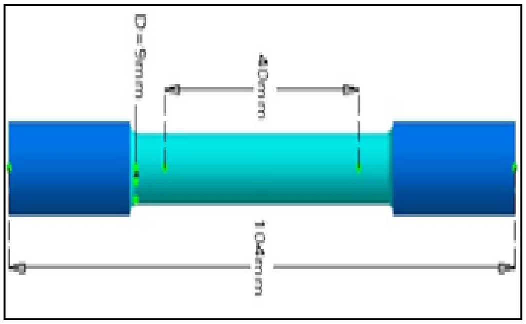
Fig:7 Elasticity modulus

Table:2 Properties

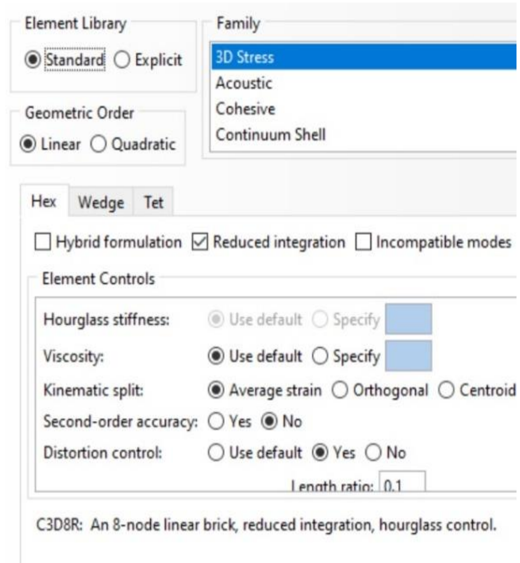
Compositions	E using Karner Eqn.	Volume fraction in %
Pure	71	---
5%SiC	78.199	4.606
10%SiC	86.312	9.313
15%SiC	95.426	14.076
20%SiC	105.766	18.908

The Elasticity modulus of metal matrix composites linearly incrases with increased SiC as shown in fig:7.

4. Numerical Analysis (FEA)



FEA Model



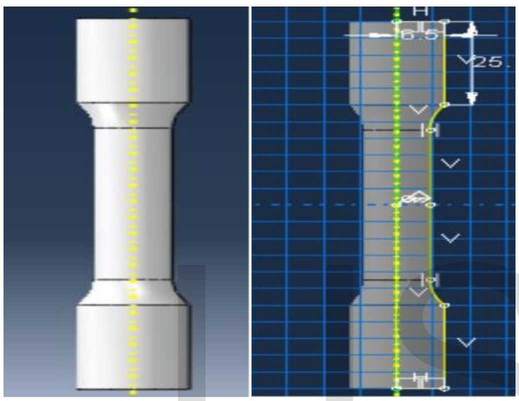
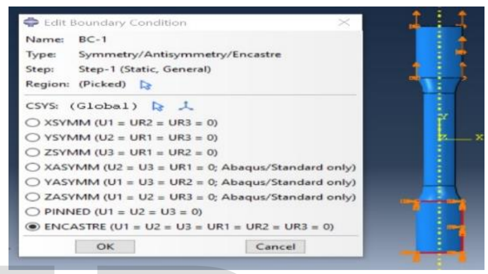


Fig:8 FEA Model



Boundary conditions

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NUMBER OF ELEMENTS IS                                    2296
NUMBER OF NODES IS                                       2964
NUMBER OF NODES DEFINED BY THE USER                      2964
TOTAL NUMBER OF VARIABLES IN THE MODEL                   8892
(DEGREES OF FREEDOM PLUS MAX NO. OF ANY LAGRANGE MULTIPLIER
 VARIABLES. INCLUDE *PRINT,SOLVE=YES TO GET THE ACTUAL NUMBER.)
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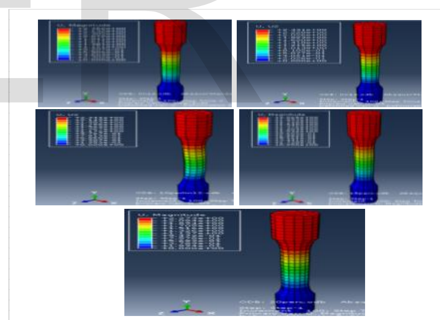
Fig:9 Number of elements and nodes

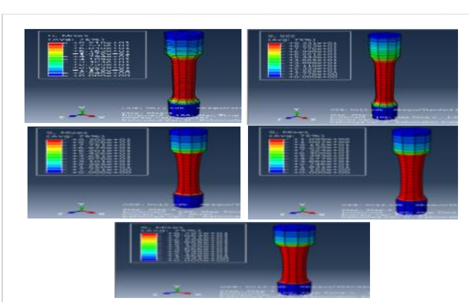
FE analysis of Deformation



(b)

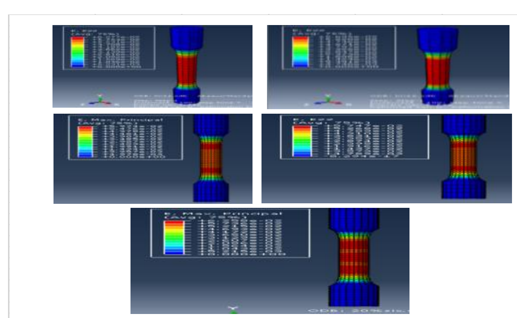
FE analysis of MMC's

FE analysis of maximum Stress



(a)

FE analysis of Strain



(c)

Fig:10 FE analysis (a-c)

The FEA model of tensile test specimen prepared as per the ASTM E-8 by using ABAQUS software and Finite element analysis at the maximum stress, strain and Deformation at Ultimate tensile strength condition for the different compositions of MMC's[11].

5. Results and Discussions

Density and porosity

From the indicating the table:1 the density calculated by using the Rule of mixture this is present to the cast density of AALM12 –SiC composite is prepared and founded density is increases with increased SiC.it is found that the density values are very close to theoretical ones that indicates the soundness of the composites but marginal difference could be due to the presence of entrapped gases and shrinkage porosity is decreased

SEM, EDX and XRD analysis

That showed in SEM images and some clusters of SiC particles are observed in SEM micrographs for the confirmed in the composites. The EDX analysis is observed in the al alloy LM12 metal matrix composites from the SEM images that shown in the fig:6. But Al, Mg and Cu particles shows SEM image, XRD and EDX pattern A Alloy LM12composite. It shows the qualitative analysis, indicating the presence of Al, Mg, SiC and Cu.

Mechanical properties

The tested tensile specimens FEA model are shown in Fig:8.The young's modulus of MMC's calculated by using the Karner equation. The young's modulus of MMC's increased linearly with increased SiC that shown infig:7.Three samples were tested for each trial of test. The average values of yield strength and ultimate tensile strength. Effect of matrix alloy on mechanical properties are shown in the influence of matrix alloy on the yield strength (YS) of Al-SiC composites. It can be seen that the reinforced with SiC of Al alloy LM12 matrix alloy exhibits larger YS than unreinforced SiC of Al alloys LM12.The influence of SiC on the MMC's the UTS of metal matrix composite increased with increased SiC as compared with unreinforced alloys Experimented and FEA results as shown in Fig.13.

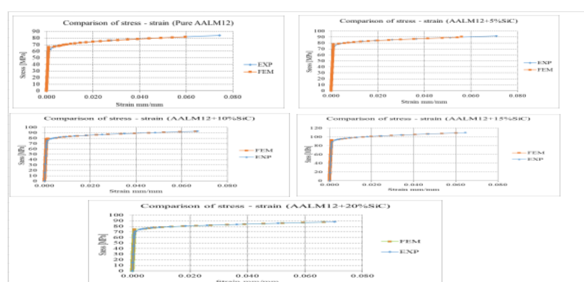


Fig:13 EXP and FEA Results comparison

The increased SiC with AALM12 metal matrix alloy contributes larger UTS than base material of AALM12 alloys and decreases the elongation of MMC's due to hardened material.

Table:3 UTS Properties of MMC's

Compositions	EXP		FEA	
	UTS MPa	Deformation mm	UTS MPa	Deformation mm
Pure Al alloy LM12	84.03	2.64	82.18	2.57
5%SiC	91.77	2.42	93.31	2.3
10% SiC	93.01	2.25	93.02	2.21
15% SiC	109.85	2.15	109.9	2.04
20% SiC	87.97	2.25	87.97	2.16

The comparison of experimental ultimate tensile strength and Finite element analysis results means numerical approach method both the results are correlated.as well as deformation of MMC's also followed same phenomena. The both results are increased with increased reinforced SiC as show in above table: 3

Conclusions

Based on the results of this investigation following conclusions were drown

1.Aluminum alloy LM12-SiC composites were prepared by using the stir casting techniques succeffully, the 23micron meter size of SiC have been used as reinforcement.

2. The density and volume fraction of metal matrix composites is increased with increased SiC and porosity of AALM12 MMC's is decreases.

3.The tensile yield stress and ultimate tensile strength of metal matrix composites Increased with incorporation of silica carbide. Higher amount of silica carbide shows more influence on properties.

4.The maximum stress developed in the middle of the component and in the region of gage length due to the sudden change in the cross section near the gage length which is leads to high stress concentration as shown in the figure:10. Equivalent Stress and Maximum Principle Stress is obtained for each specimen and outcomes were obtained as shown in the figure.

5. The finite element analysis is approaches to the simulation of the tensile test results are presented by using the ABAQUS software. In this analysis the experiment Increased with increased SiC that can show in both the cases results are correlated. The percentage elongation.

The composite is decreased with increased SiC because the uniform distribution of reinforcement in composites that's changes the properties of composites and make it strength and strong so percentage elongation is decreases.

ultimate tensile strength results compare with the FE analysis results both the results are very near to each other's. The Ultimate tensile strength

References

1. Channakeshava fracture mechanism of commercial Al-alloys. J.Bull. Material Sci. 28(1), 101-105.

2. Rohatgi P, Asthana R and Yarandi E (1990)
Solidification of metal matrix composites. In: Minerals Metals Materials Soc. pp:51-75.

3. Qu S, Geng L and Han J (2007) SiC/Al composites fabricated by modified squeeze casting technique. J. Materials Sci. Technol. 23(5), 641-644.

4. Seleznev ML, Seleznev IL, Cornie JA, Argon AS and Mason RP (1998) Effect of composition, particle size and heat treatment on the mechanical properties of Al-4.5wt.%Cu based alumina particulate reinforced composites, SAE international congress and exposition, Detroit, MI, Feb 23-26, Paper no. 980700.

5. Zhou W and Xu ZM (1997) Casting of SiC reinforced metal matrix composites. J. Materials Proc. Technol. 63, 358-363.

6. Zlaticanin B, Filipovic M, Valcic A, Aleksic R, Nikolic S, Radonjic B and Bosnjak B (2004) The effect of magnesium and titanium addition on the microstructure and properties of as-cast Al-5%Cu alloys. Materiali in Tehnologije. 38, 1-2.

7. Sijo, M. T. & Jayadevan, K. R. Analysis of stir cast aluminium silicon carbide metal matrix composite : A comprehensive review. Procedia Technol. 24, 379–385 (2016).

8. A. C. R. Influence of Volume Fraction, Size, Cracking, Clustering of Particulates and Porosity on the Strength and Stiffness of 6063/Sicp Metal Matrix Composites. Int. J. Res. Eng. Technol. 04, 434–442 (2015).

9. Annual Book of ASTM Standards (1988). Section 3: Metals Test Methods and Analytical Procedures.

10. Armero F. and Simo J. (1993) A priori stability estimates and unconditionally stable product formula algorithms for non-linear coupled thermoplasticity, International Journal of Plasticity 9, 149-182.

669+9+11. Bridgman P. (1952) Studies in Large Plastic and Fracture, McGraw-Hill Book Company, London. 12.Celentano D., Gunasegaram D. and Nguyen T. (1999) A thermomechanical model for the analysis of light alloy solidification in a composite mould, International Journal of Solids and Structures, Vol. 36, 2341-2378.

12.Celentano D. (2001) A large strain solidification of S.G. cast iron in a green sand mould, International Journal of Plasticity 17, 1623-1658.

13. Coleman B. and Gurtin M. (1967) Thermodynamics with internal state variables, The Journal of Chemical Physics 47 (2), 597-613.

14. Crisfield M. (1991) Non-linear Finite Element Analysis of Solids and Structures, Vols. 1 and 2. John Wiley & Sons, Chichester.

15.Jerry, S., Fabian, A. & Selvam, B. Densification behaviour of Aluminium reinforced with Tungsten Carbide particulate Metal Matrix Composite processed by P/M. IOSR J. Mech. Civ. Eng. 24–29 (201).

16. Y Seo, Y. H. & Kang, C. G. The effect of applied pressure on particle-dispersion characteristics and mechanical properties in melt-stirring squeeze-cast SiCp/Al composites. J. Mater. Process. Tech. 55, 370–379 (1995).14).