Influence of volume fraction, density and porosity on strength and stiffness of Aluminum alloy7075/ 500nm SiC metal matrix composites, the tensile test experimental results are comparison by FE simulation tests

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***Abstract*:** The aluminum alloy is having one of the superior material properties which is used in different industrial sectors like aerospace, automobile and general engineering industries because of their favourable microstructure and mechanical behavior. The Metal matrix composites of aluminum alloy reinforced with silicon carbide reinforcement are useful in. In this work, Composites of aluminum alloy Al7075 and 500nm silicon carbide were fabricated by using popular method of stir casting techniques. Further test of MMC's like density, porosity and experimented and FEA analysis. Al7075 metal matrix composite as compared to the Al7075 alloy without silicon carbide addition. The 500nm silicon carbide content varies with the 0%, 2%, 4%, 6% &8%wt.fractions. Comparison of experimented tensile results with FEA analysis and density of MMC's were studied in this paper.

Keywords: 500nµSiC, Al7075, MMC's Fabrication, Tensile test with FEA density test and porosity and ABQUS software.

1. Introduction

Metal matrix composites are obtained by popular aluminum alloy series such as 2XXX, 3XXX,6 XXX & 7XXX etc. Which are mainly used in aircraft structure design due to their high strength and weight ratio. Due to the demand in high performance of the aircrafts weight reduction methods are used in aviation sector and new materials are under search.(1-5).Aluminum alloys reinforced with nano size of silicon carbide (MMC's) have shown greater signs in order to decrease the weight and consequently proved to be better structural components to provide strength to the structure. Vast research work has been undergoing 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 (6-10).

Present work describes the production of MMC's by using stir casting technique tensile test with FEA, analysis and density and porosity of Al7075 Aluminum alloy with reinforcement of silicon carbide with various %wt and compositions of AA7075 shown in below fig.

Table:1 composition of the Al7075

Element	Wt.%	Element	Wt%
Copper	1.6	Zinc	5.5
Magnesium	2.5	Chromium	0.15
Silicon	0.4	Titanium	0.2
Iron	0.5	aluminum	Balance
Manganese	0.3		

2. Development of metal matrix composites

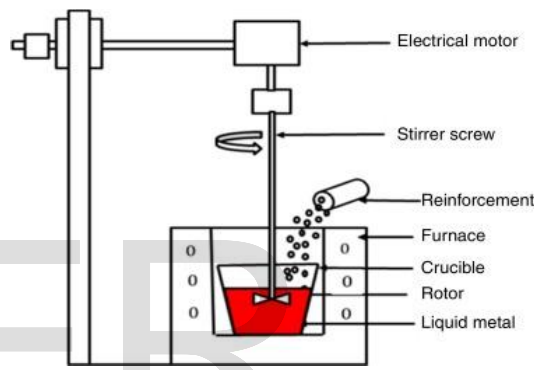

Fig:1 Stir casting set up

The MMC's were fabricated by using the stir casting technique that setup have been shown in the fig:1. The AA 7075 is kept into the crucible furnace and supply to heat by using the electric heating source, when it is reaches to the temperature 650^{0}C -750^{0}C the AA7075 is melted in crucible than pour the weight % of SiC in the molten metal while stirs the stir by using the electrical motor. Similarly fabricated the MMC's at different weight % of SiC.

Cast product

3. Experimentation

3.1 Density test

The density test of MMC's has been conducted to know about the density and porosity of MMC's of increased SiC into AA7075.

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

$\rho_c = f_m\rho_m + \quad f_r\rho_r$ [18]

Measured Density = Mass/Volume

- Theoretical Density calculated buy rule of mixture

$\rho_c = f_m\rho_m + \quad f_r\rho_r$

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

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

For 2% wt of SiC

M_c is the mass of the Composite Specimen (Matrix Reinforcement) = 25.081 gram

R_m is the mass of reinforcement (for2%wt of SiC) = 0.516 gram

M_m is the mass of matrix =(25.081 -0.516)=25.284 gram

$$f_m = \frac{M_m}{(M_m + R_m)} = \frac{25.284}{25.284 + 0.516} = 0.98 \qquad 2$$

$$f_r = \frac{R_m}{(M_m + R_m)} = \frac{0.516}{(25.284 + 0.516)} = 0.02 \qquad 3$$

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

$$\rho_c = f_m\rho_m + \quad f_r\rho_r = 0.98 \times 2.821 + 0.02 \times 3.21 = 2.828\ \text{gram}/cm^3$$

- The porosity of MMC's were calculated by using this formula

$$\%\ Porosity = Theoritical\ Density - Measured\ \frac{Density}{Theoritical}\ Density \times 100$$

Sl No.	Compositions	Measured density (g/cc)	Theoretical Density (g/cc)	Porosity %
1	Pure AA7075	2.821	2.810	0.079
2	2% SiC	2.8241	2.828	0.069
3	4% SiC	2.853	2.836	0.0122
4	6% SiC	2.854	2.812	0.0033
5	8% SiC	2.856	2.848	0.0059

Table:2 Density of compositions

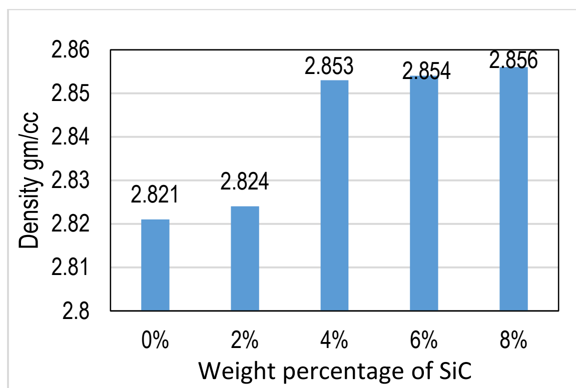

Fig:2 Density results

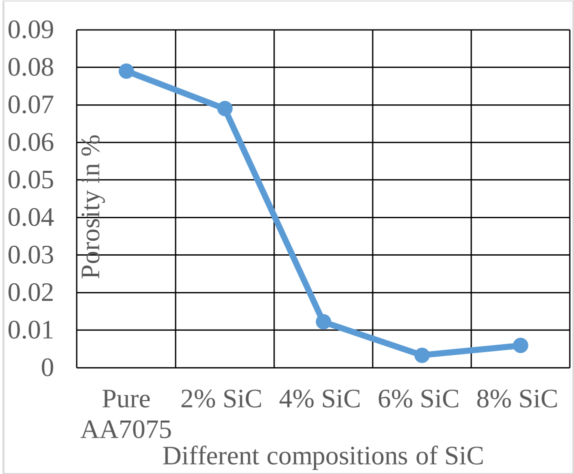

Fig:3 Porosity results

ASTM E-8 Tensile Specimen

3.2 FEA analysis of tensile test results

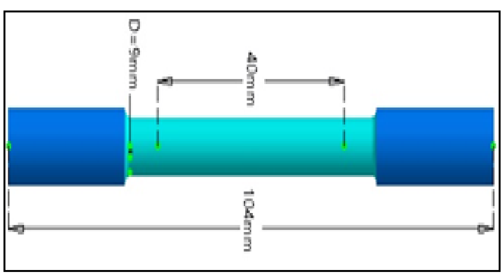

Fig:4 Tensile Specimen

- **Young modulus of MMC's calculated by using the Volume fraction method [19]**

$$V_{p\,(SiC)} = \frac{m_{SiC}/\rho_{SiC}}{\left(\frac{m_c - m_{SiC}}{\rho_{Al}}\right) + \frac{m_{SiC}}{\rho_{SiC}}} \times 100$$

$$\mathbf{V\_(p\ (\ 2\%\ SiC)) = (0.516/3.21)/([(25.801 - 0.516)/(2.821)] + 0.516/3.21 = 0.017}$$

- **Young's modulus of MMC's is given by Kerner Equation**

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

$$\mathbf{E_{c2\ \%SiC} = 71.7\left[1 + \frac{0.0176}{1 - 0.0176} \times \frac{15(1 - 0.33)}{8 - 10(0.33)}\right] = 74.5\ GPa}$$

Compositions	Volume fractionin %	Young's (Karner Eqn.)Modulus GPa
Pure AA7075	--	71.7
2% SiC	0.0176	74.5
4% SiC	0.0354	77.3
6% SiC	0.0532	80.3
8% SiC	0.0711	83.4

Table:3 Volume fraction and Young's modulus of MMC's

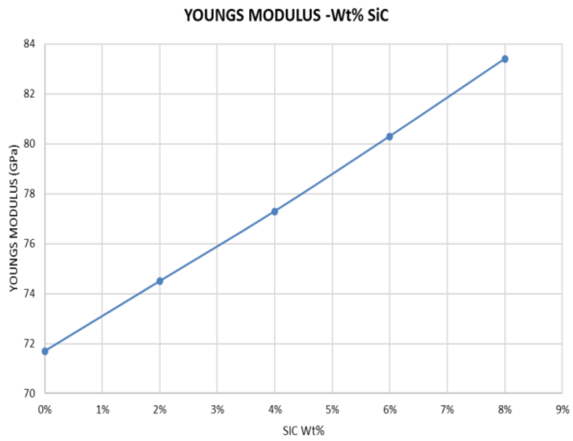

Fig:5 Young modulus using karner eqn.

4. Numerical Analysis (FEA)

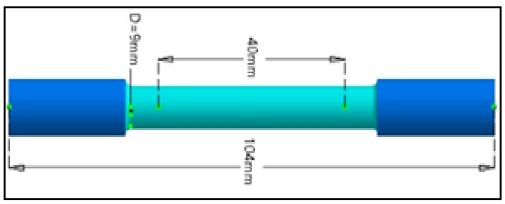

Fig:6 FEA Model

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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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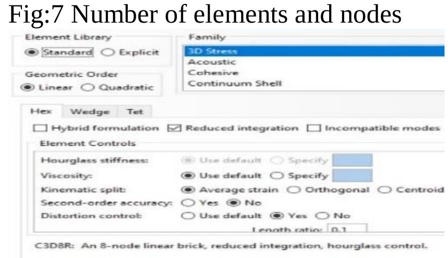
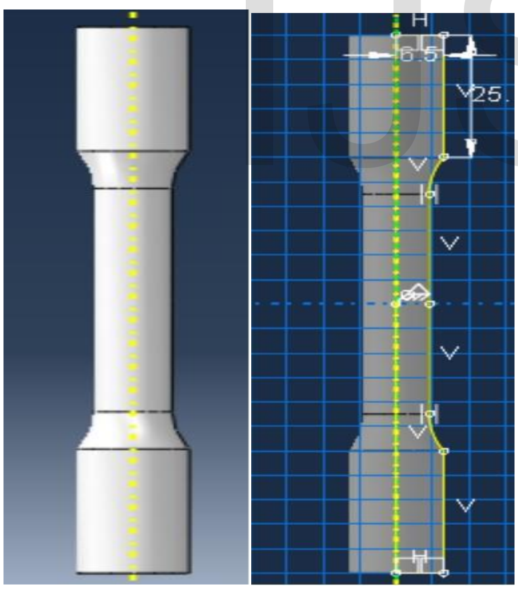
Fig:7 Number of elements and nodes





Boundary conditions

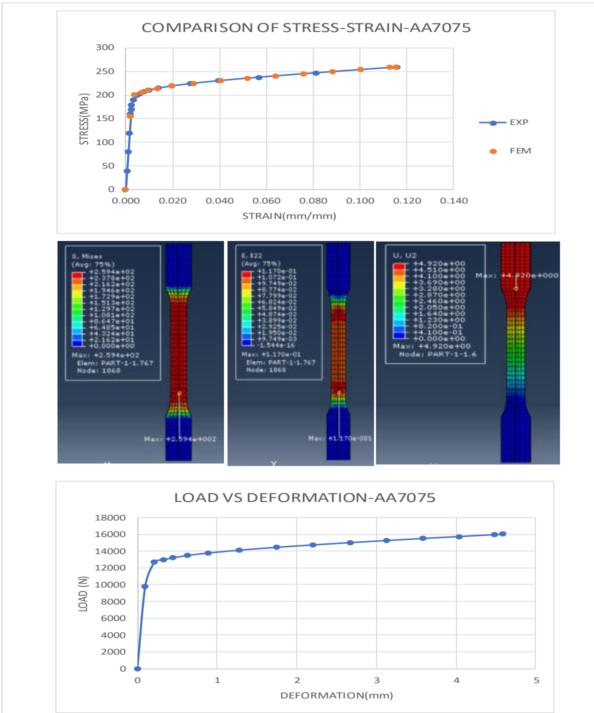
The FEA model of tensile test specimen prepared as per the ASTM E-8 by using ABAQUS software and Finite element analysis at the maximum stress, strain and Deformation

The Ultimate tensile strength condition for the different compositions of MMC's[11].

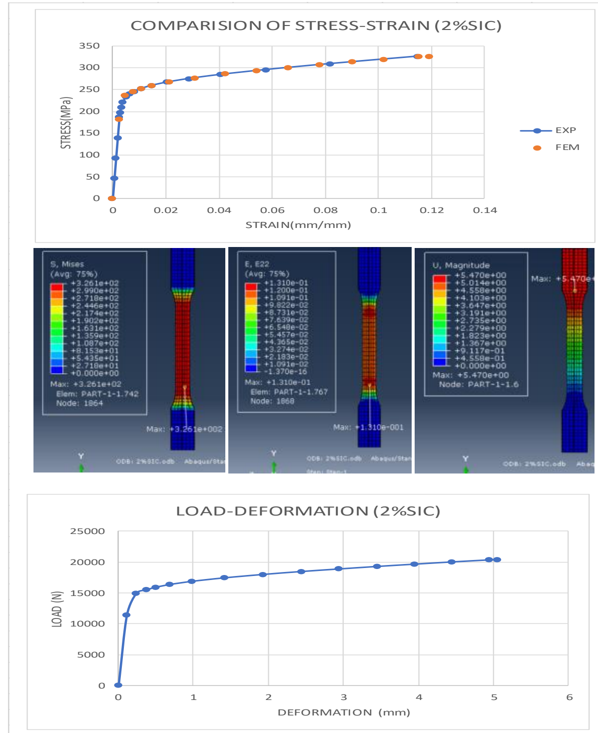
With this analysis of this the experiment results are correlated with the Finite element results. That model is created by using the ABAQUS explicitly software. That analysis results are shown in the below fig.

It can be determined from both experimental observation and numerical simulations. In the upsetting tests and tensile tests, the locations of maximum deformation are the equatorial area and the center of round bars, respectively.

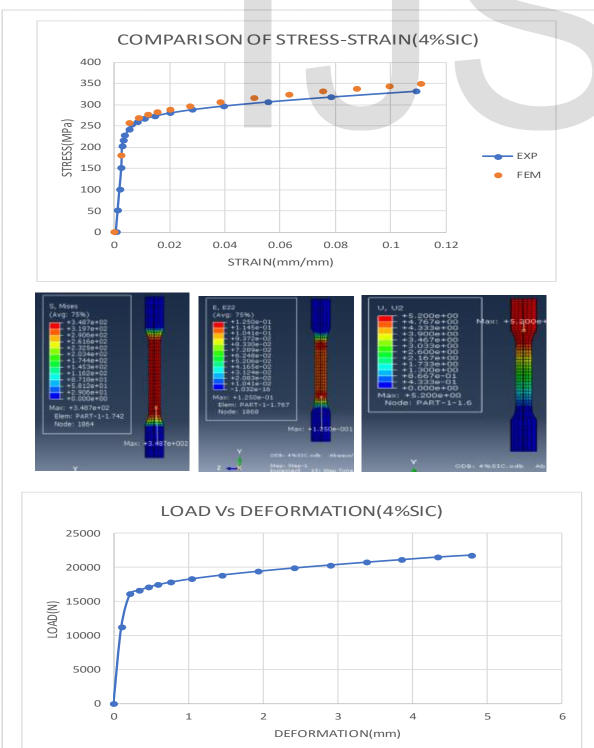
In addition, two different meshes were developed for each specimen. Comparisons of equivalent plastic strain at center of the maximum load distributions are illustrated in Fig.8(a-e).


COMPARISON OF STRESS-STRAIN-AA7075
STRESS(MPa)
STRAIN(mm/mm)
EXP
FEM
LOAD VS DEFORMATION-AA7075
LOAD (N)
DEFORMATION(mm)

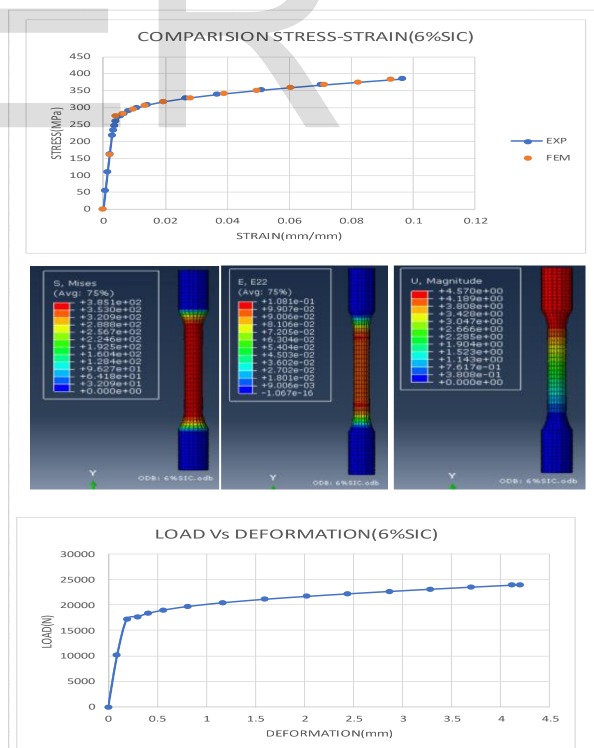
(a)


COMPARISION OF STRESS-STRAIN (2%SIC)
STRESS(MPa)
STRAIN(mm/mm)
EXP
FEM
LOAD-DEFORMATION (2%SIC)
LOAD (N)
DEFORMATION (mm)

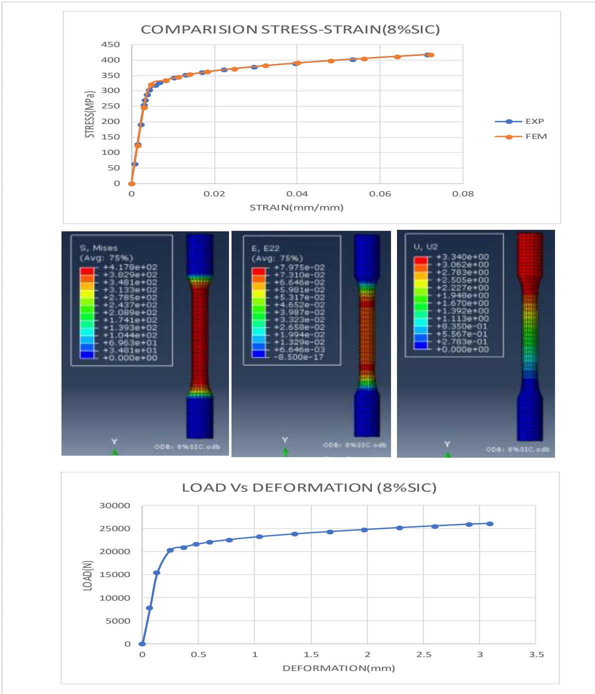
(b)


COMPARISON OF STRESS-STRAIN(4%SIC)
STRESS(MPa)
STRAIN(mm/mm)
EXP
FEM
LOAD Vs DEFORMATION(4%SIC)
LOAD(N)
DEFORMATION(mm)

(c)


COMPARISION STRESS-STRAIN(6%SIC)
STRESS(MPa)
STRAIN(mm/mm)
EXP
FEM
LOAD Vs DEFORMATION(6%SIC)
LOAD(N)
DEFORMATION(mm)

(d)



(e)

Fig:8 (a-e) Tensile test experimented results compare with the FEA analysis on MMC's

Table:4 FEA results on MMC's

Compositions	Engg Stress UTS MPa	True Stress UTS MPa	FEA Results MPa
Pure AA7075	235.71	255.15	259.05
2% SiC	285.66	309.50	310.44
4% SiC	313.54	339.54	347.5
6% SiC	351.86	380.12	376.5
8% SiC	386.14	415.0	404.59

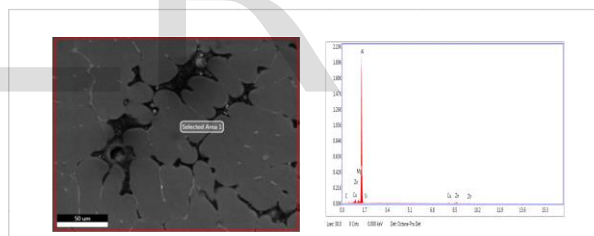
Table:5 Average load on MMC's

Compositions	Average Load applied on UTM Specimens N	Average Load applied on FEA model N
Pure AA7075	15700	15700
2% SiC	18220	18220
4% SiC	20640	20640
6% SiC	23170	23800
8% SiC	25420	26900

FE analysis of tensile test results

The samples were machined the specimen for tensile test. The shape and dimensions of the tensile specimen as per the ASTM E-8. The computer interfaced UTM (universal testing machine) was used for the tensile test. The specimens were loaded hydraulically. The loads at which the specimen has reached the yield point and broken were noted down. The extensometer was used to measure the elongation. The load vs deflection graph was also obtained for each specimen from the computer attached to the machine. This is the experimented results were obtained. Using this results comparison with the FE analysis by using the ABAQUS software.

4. SEM and EDX analysis



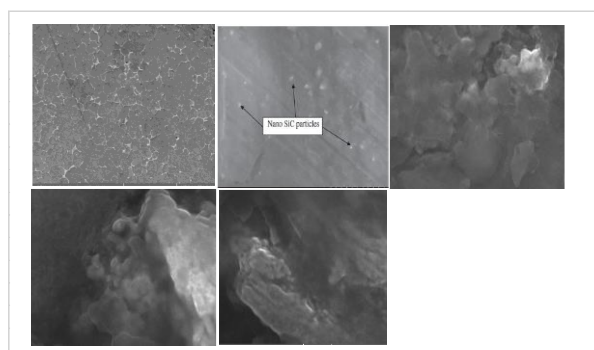


Fig:11 SEM Images

Figures:11 is presented with the microphotographs (SEM analysis) of cast Al7075-nanoSiC samples respectively.

Suitable sizes were taken from the prepared samples. These pieces are prepared carefully by polishing the surface using graded sequence of abrasive materials to get flat scratch free surface for the micro structural analysis. The distribution of reinforced SiC particles in Al7075 matrix with 0, 2, 4, 6, and 8 weight percentages was studied using scanning electron microscope. The above images shows silicon carbides of mesh 600 under magnification 1500x and the images reveal the uniform distribution of SiC particles in Matrix material.

4.4 **XRD analysis**

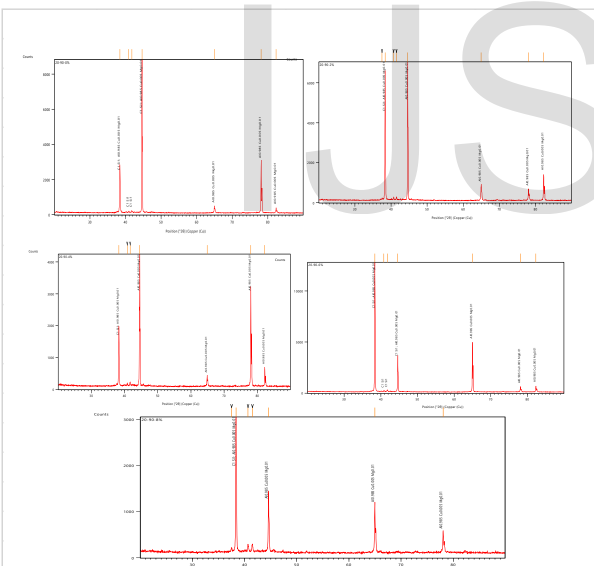


Fig:12 XRD Images

The EDS spectrum of the worn surfaces of Al composites shows that the upper surfaces are rich in aluminum (Al) and carbide (C) [10]. This observation confirms the phenomenon of material and the oxidation of this material.The presence of SiC particles Al/SiC particles result in increased material transfer from the counter face to the interface. In this scenario, the aluminum (Al) peak in the EDS spectrum of Al/SiC composites is greater than those of the Al/SiC composite. the interface of Al/SiC composites is also higher than that of the base alloy that can shown in fig. Similar results were also obtained in the SEM and EDX analyses of Al composites by other investigators [1-5]. In the EDX results of Al composites, the presence of a small oxygen peak confirmed the formation of oxide layers at the interface. The increase in temperature and environmental conditions are the factors that lead to the formation of these layers at the interface.

4. Results and Discussions

Density and porosity

From Table:2 this composite density calculated by the Rule of mixture presents the as cast density of various AA7075 –SiC carbide composites prepared in the investigation 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.

Mechanical properties

The tested tensile specimens are shown in Fig. 4.The young's modulus is calculated by using the Karner equation. The young's modulus of MMC's increased linearly with increased SiC that shown in fig:5. The average values of yield strength, ultimate tensile strength, and ductility in terms of tensile elongation. Effect of matrix alloy on mechanical properties table.4 & 5 shows the influence of matrix alloy on the yield strength (YS) of Al-SiC composites. It can be seen that the reinforced with SiC Al7075 matrix alloy exhibits larger YS than unreinforced SiC of Al 7075alloys that shown in the fig:8(a-e).The influence of matrix alloy on the UTS of metal matrix composites and unreinforced alloys.

The increased SiC with Al 7075 metal matrix alloy contributes larger UTS than the base material of Al 7075 alloys. these experimented and FEA results are comparison by using the ABQUS software the FEA UTS results of metal matrix composites is slightly higher also be correlated with the unreinforced Al-alloys of experimented results shown in fig.8 (a-e).The effect of metal matrix alloy on the ductility (measured in terms of tensile elongation) of metal matrix composites is decreased with increased SiC results are comparisons with the unreinforced alloys. The variation in the ductility of composites is largely effected by the change in matrix alloy. And comparison of experimented and FE analysis results are same obtained of different compositions of SiC with the AA7075 alloys.

From the fig.8 (a-e).this phenomena indicated to load increases with the increased SiC of MMC's due to the load carrying of MMC's also be increased that confirmation also obtained from the using the FE analysis with correlated both the results show in table:6.

The confirmation of reinforced SiC in composites conduct the SEM,EDX and XRD analysis as per the standard procedure. With the analysis of XRD analysis, to confirm the major elements in the composites Fig11-12.

Conclusion

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 500 nano micron meter size of SiC have been used as reinforcement.

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

3. The tensile yield stress and ultimate tensile strength of metal matrix composite increased with incorporation of silica carbide particles. There was some decrease in percentage elongation with increased SiC. The higher amount of silica carbide shows the more influence effects on these properties.

4. The experimented tensile test results are correlated with the FE analysis of both yield stress and ultimate tensile strength of MMC's have been obtained same with increased SiC.

5. The elongation of different composition of MMC's of experimented results and FE analysis results both are correlated and

increased reinforced SiC of weight percentage of elongation is decreased.

6. The Load carrying of different composition of MMC's of experimented results and FE analysis results are correlated and increased reinforced SiC of weight percentage the load carrying capacity of metal matrix composite increased.

7. To confirm the reinforcement of SiC presence in the composite by the analysis of SEM and EDX.

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13. Aluminum alloy 7075-SiC composites were prepared by using the stir casting techniques without any other defects of MMC"s, and 500 nm size of SiC have been used as reinforcement.

14.The density of metal matrix composites is increases with increased SiC and porosity of MMC's is decreases with increased SiC.

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