

# Finite Element Analysis of Metal Matrix Composite Materials

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## Abstract

Metal matrix composites have attracted a lot of attention in the recent years due to their excellent properties in different applications. In this study, aluminum metal matrix composites reinforced with different weight percentage (1,2,3,5,7,10%) from alumina and silicon carbide have been preparing by using stir casting. A finite element modeling using ANSYS software is used to model aluminum metal matrix composites. Image processing and image analysis are used based upon image J program to transform the image into engineering geometry that is used in the finite element modeling of metal matrix composites. Static and thermo mechanical analysis have been done for each models to know the response of mechanical stresses and thermal residual stresses on prepared composites.

**Key words:** Metal Matrix Composites, Casting Technique, ANSYS, Finite Element Analysis.

## الخلاصة

حظيت المواد المركبة ذات الاساس المعدني باهتمام كبير في السنوات الاخيرة بسبب خصائصها الممتازة في مختلف التطبيقات. في هذه الدراسة تم تحضير معدن الاساس الالمنيوم المقوى بنسب وزنية مختلفة (10%، 7، 5، 3، 2، 1) من ألومينا و كربيد السيليكون بطريقة السباكة بالخلط. تم استخدام التحليل المحدد الذي يوصف برنامج ANSYS في تشكيل المواد المركبة ذات الاساس الالمنيوم، كما تم معالجة الصورة وتحليلها على أساس برنامج image-J لتحويل الصورة الى Engineering Geometry التي أستخدمت في نموذج تحليل العناصر من للمواد المركبة ذات الاساس المعدني. التحليل Static and Thermo mechanical لكل النماذج لمعرفة الاجهادات الميكانيكية والاجهادات الحرارية لمواد المركبة ذات الاساس المعدني.

**الكلمات المفتاحية:** المواد المركبة ذات الاساس المعدني، تقنية السباكة، ANSYS تحليل العناصر المحددة.

## Introduction

Metal Matrix Composites (MMCs) have replaced common materials in many applications, Especially in aerospace and automotive industries, because of their superior properties such as high specific strength, high wear resistance, high thermal conductivity and low coefficient of thermal expansion (Morteza, 2012).

"The most important property of aluminum – silicon carbide with reference to the aerospace industry is its strength to weight ratio, which is three times more than mild steel. In addition, composites containing SiC (reinforcing material) and Al (aluminum )have high modulus, strength values, wear resistance, high thermal stability, less weight and a more effective load carrying as compared to many other materials(Suryanarayanan, 2013).

Aluminum oxides and its hydrates present a variety of useful physical and chemical properties like large hardness, insolubility in solvents and inertness to some chemical compounds. Now days many companies offer aluminum oxide in different form such as powder in the form of particles, form the nano- to microscope and whiskers. The most common allotropic form of crystalline aluminum oxide is very durable corundum  $\alpha$ -alumina(Kaczmar, 2014).

**Experimental Part:**

In this work, the aluminum wire cutting aluminum wires to small pieces in order to ease its melting. After that weighted aluminum and reinforcement materials(silicon carbide and  $\alpha$ -alumina) using Sensitive balance. After that take a percentage of aluminum, for example 99% in the crucible to melt, when the aluminum melts completely and reinforcement covered by thick aluminum foil add 1% from the silicon carbide and continue mixing in order to homogenize the mixture. After dissolving melts are put in the mold lubricated graphite for easy casting. Then all ingots put in the furnace for the purpose of homogenization for a duration of 4 hours at a temperature of 350 °C and slow cooling in the side furnace . Composition for each sample from aluminum and reinforcement materials in this study have been shown in table 1.

**Table 1 Weight Composition of Each Aluminum and Reinforcement Materials (Silicon Carbide and  $\alpha$ - Alumina).**

Number	Weight Percentage Al%	Weight Percentage SiC%	Number	Weight Percentage Al%	Weight Percentage Al <sub>2</sub> O <sub>3</sub> %
1	99	1	1	99	1
2	98	2	2	98	2
3	97	3	3	97	3
4	95	5	4	95	5
5	93	7	5	93	7
6	90	10	6	90	10

Then, cut the rods with 2mm face plate into samples of 6 mm thickness Samples of 12 mm in height and 6mm in diameter are prepared by casting to show the effect of additive percentage on compression strength .

**Results and Discussions :**

**Hardness Results:**

The results that shows hardness is increased when silicon carbide and alumina particles are added to aluminum matrix as these to obstruct and prevent the movement of dislocations on the sliding planes. Moreover, the fact that the rise in additive content make the ability of the indenter of the hardness tester to hit additive particles increases and the additive particles have high hardness as compared with aluminum hardness(Fadhil, 2012) as shown in Fig.1.

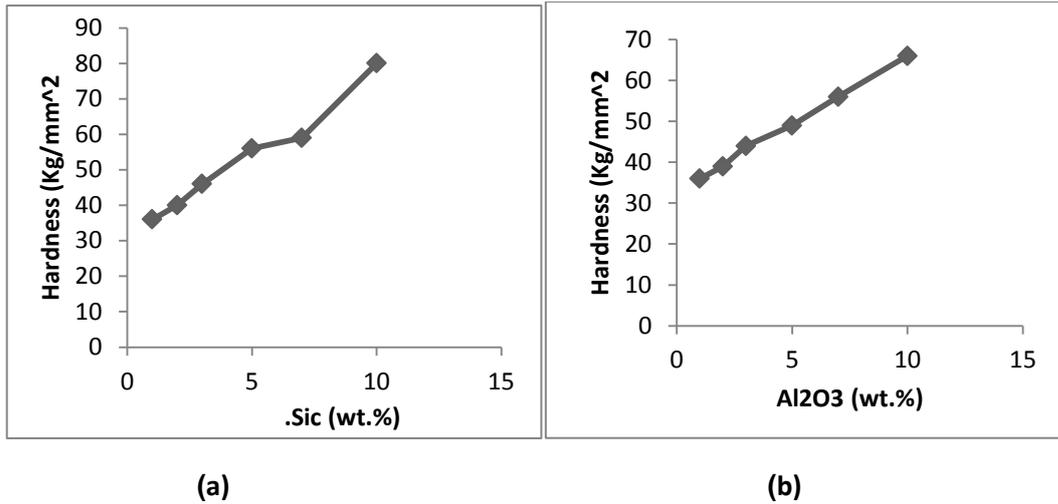
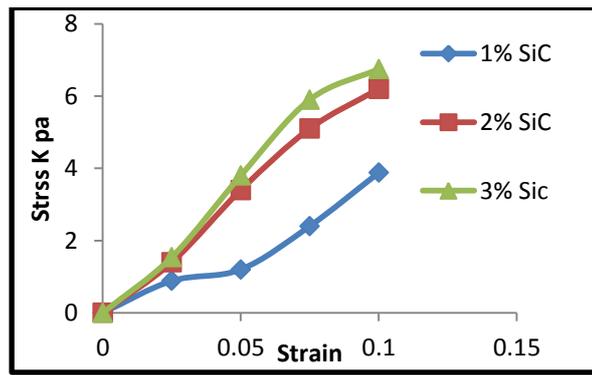


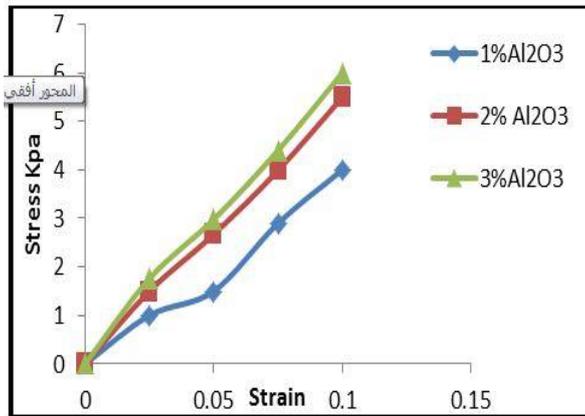
Fig. 1 : (a) : Effect of Wt%SiC Additive on Hardness, (b) :Effect of Wt% Al2O3 Additive on Hardness.

**Compression Results:**

Compression strength as improved when additive ceramic particles to aluminum as shown in Fig.2 .



(a)



(b)

Fig. 2 (a): Stress-Strain Curve Compression of Al +SiC , (b) : Stress –Strain Curve Compression of Al+Al2O3.

**XRF Results:**

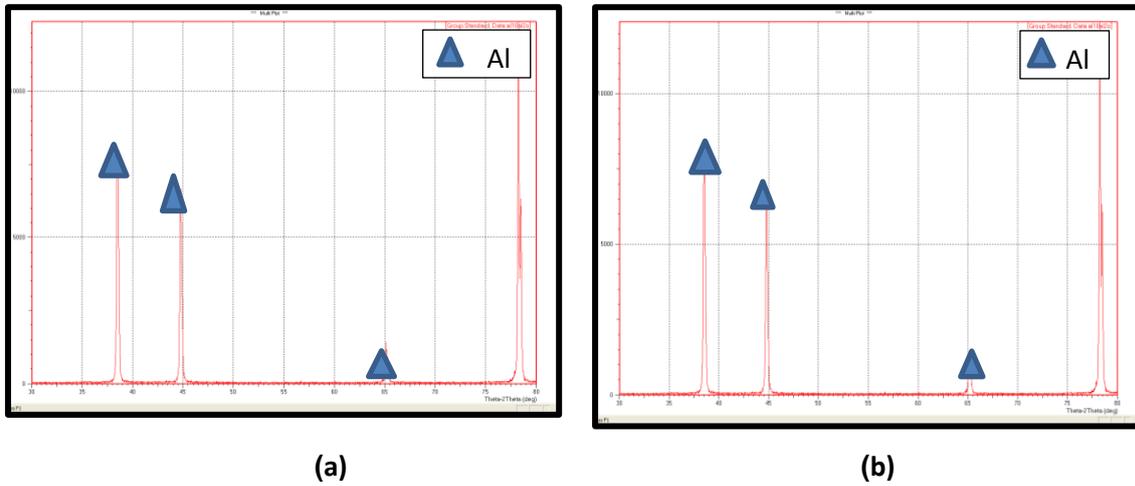
Table (2) shows the obtained results from XRF . The purity of Aluminum was 99.7

Element	Al%	Si%	Fe%	Cu%	Mn%	Mg%	Cr%	Ni%	Ti%	V%
%	99.7	0.036	0.219	0.003	0.001	0.001	0.003	0.001	0.002	0.007

This composition of aluminum wire has been used as matrix material for preparing of metal matrix composites.

**XRD Results:**

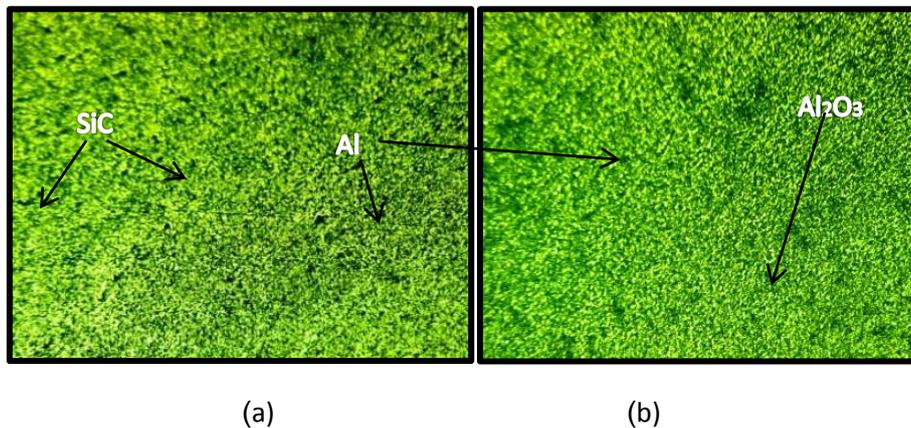
Fig. 3 (a), (b) Shows results of X- ray diffraction carried out after casting for sample 90 Al+ 10 SiC , 90Al+10 Al<sub>2</sub>O<sub>3</sub>. It is clear that silicon carbide and alumina do not appear. samples are a small percentage and other compounds of small solubility do not show up between aluminum and other components.



**Fig.3 (a): XRD Diffraction of Sample 90 Al+10 SiC, (b): XRD Diffraction of Sample 90Al+10Al<sub>2</sub>O<sub>3</sub>.**

**Microstructure Results:**

Fig. 4 Shows the microstructure of **sample** 90 Al+10 SiC , 90 Al+ 10 Al<sub>2</sub>O<sub>3</sub> The microstructure of these samples are fine grains for etched specimens with [HF + H<sub>2</sub>O] etching.



**Fig.4 (a): Microstructure of Sample Al + SiC, (b): Microstructure of Sample Al+ Al<sub>2</sub>O<sub>3</sub>.**

### Finite Element Modeling of MMC:

The finite element method has been most extensively used in the field of solid and structure mechanics. The various type problems solved by the finite element method in this field include the elastic, elasto plastic, and viscoelastic analysis of trusses, frames, plates, shells, and solid bodies and heat transfer (Singiresu, 2011)

The FE method was developed more by engineers using physical insight than by mathematicians using abstract methods." It was first applied to problems of stress analysis, and then to other problems of continua"(Cook, 1994)

### Numerical Analysis Procedure:

An in plane square arrangement of particle is assumed at the first step in the present study . The cross section of such arrangement for open particles is shown in Figure (5)

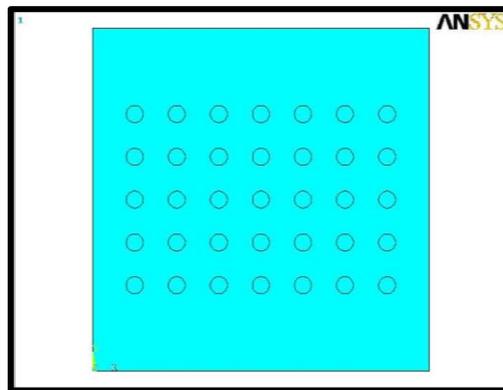


Fig. 5: Square Arrangement of Particles

Hexagonal square arrangement of particles is assumed at the first step in the present study. The cross section of such arrangement for open particles is shown in Fig.6

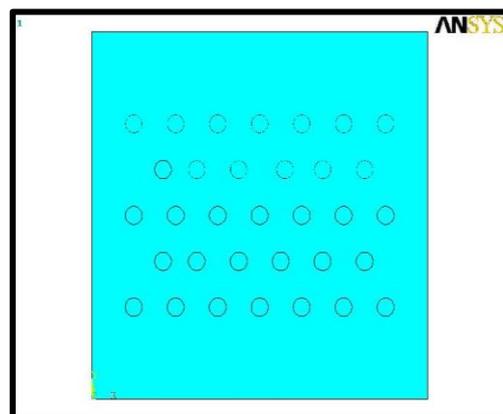
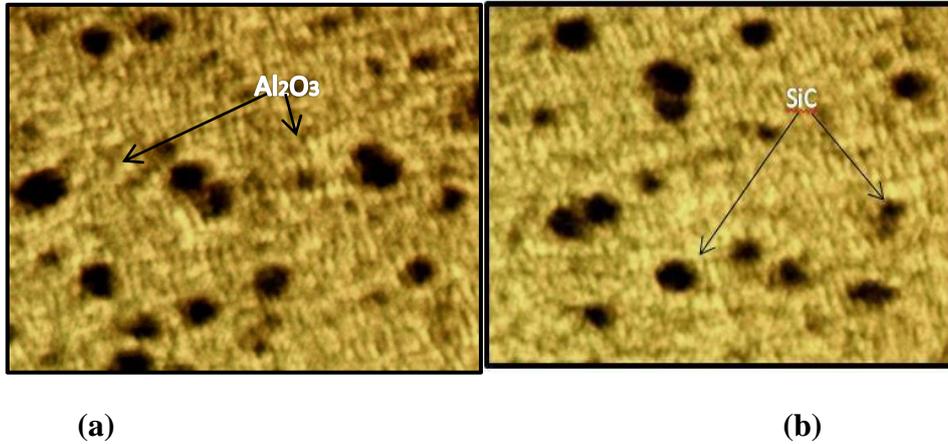
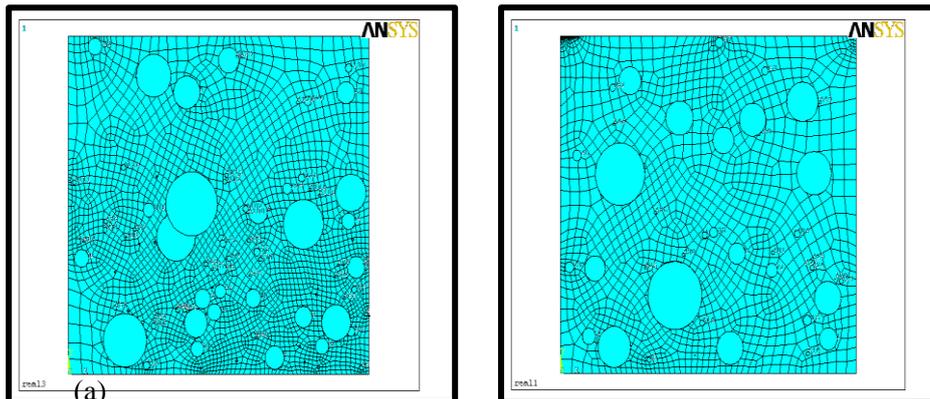


Fig. 6: Hexagonal Arrangement of Particles

Scanned surface section images of microstructure examination specimen have been used in both experimental and modeling studies .Image processing is applied to the microstructure light optical microscope image . The image is processed by microsoft picture manager at first to obtain image without black edges taken from optical microscope it is shown in Fig.7



**Fig. 7 : (a):Light Optical Microscope of Image Al + Al<sub>2</sub>O<sub>3</sub> (b): Light Optical Microscope of Image Al+SiC .**



**Fig.8 (a): Mesh of Image AL + Al<sub>2</sub>O<sub>3</sub> (b): Mesh of Image Al +SiC**

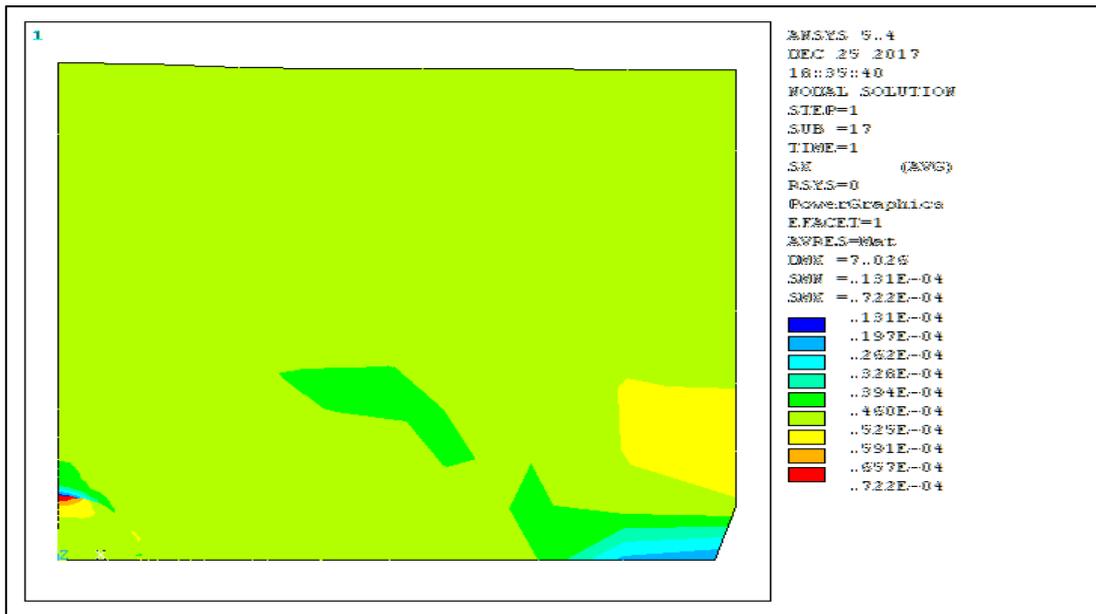
Fig. 8:(a) Mesh of Image Above (b): Mesh of Image Above.Fig.7 show the image of microstructure of un etched alloy specimen with 100X magnification. The equivalent finite element mesh of this image shown in Fig. 8.

### **Numerical Results :**

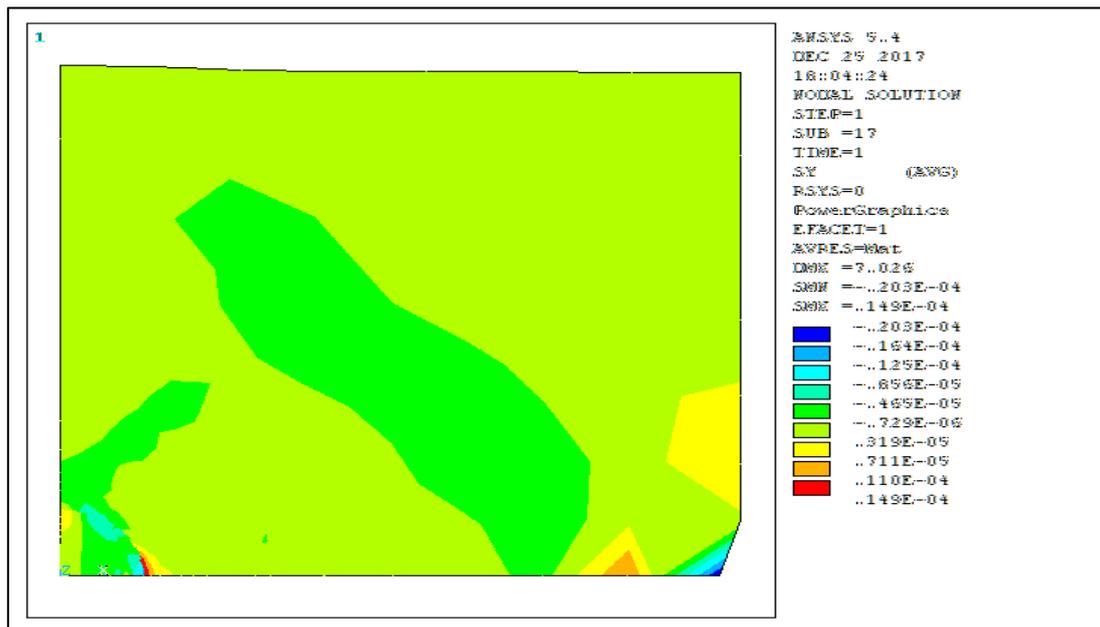
Results contain stress in x and y direction for square and hexagonal in silicon carbide reinforcement of static state.

### **Square Unit Cell FEA:**

Fig. 9 (a)Shows results distribution stress in x- direction of square unit cell FEA. Maximum value near particle size region in last step of load increment.(b) shows distribution stress in y- direction of square unit cell FEA. Maximum value near particle size region in side y-direction in last step of load increment.



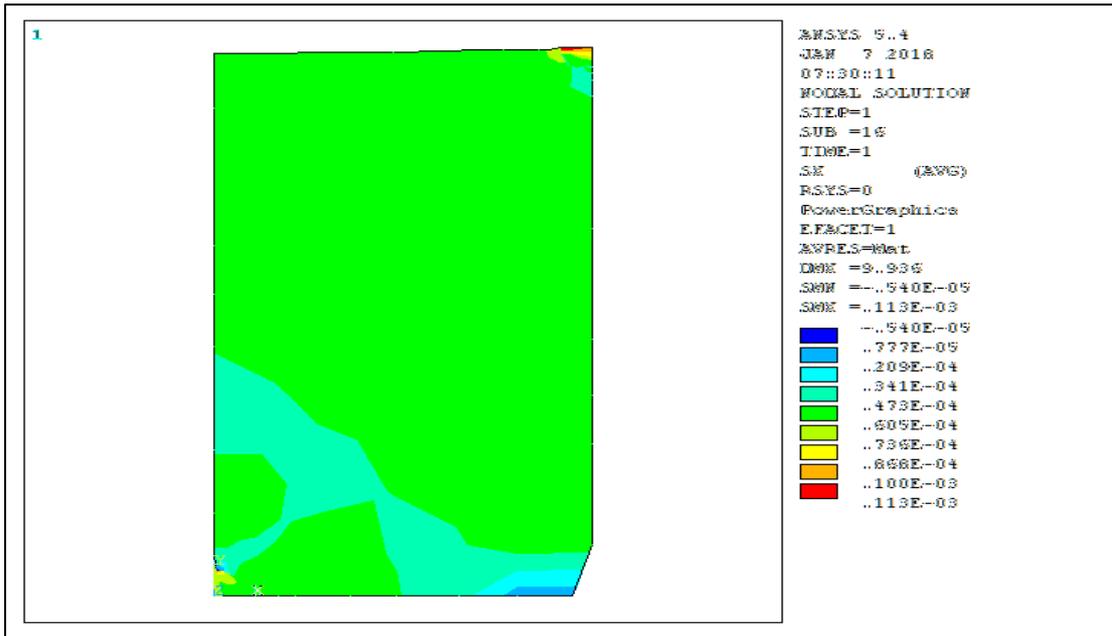
**Fig.9 Stress Contour in X-Direction of Square Unit Cell FEA.**



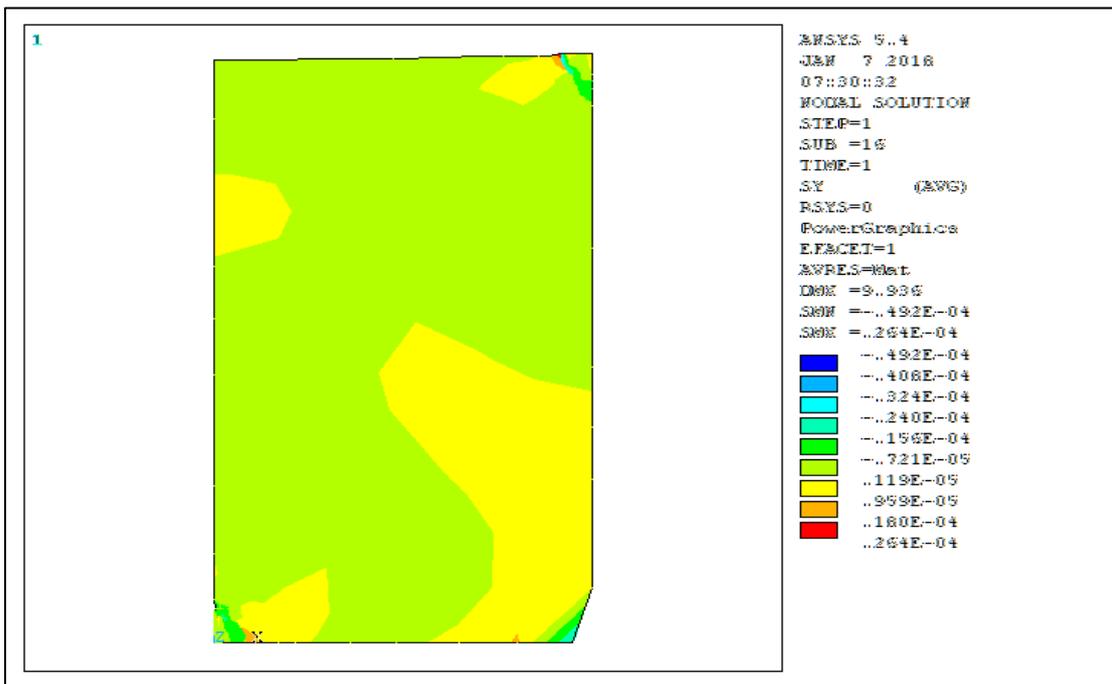
**Fig.9 (B) Stress Contour in Y- Direction of Square Unit Cell FEA.**

**Hexagonal Unit Cell :**

Fig. 10 (a):Shows distribution stress in x-direction of hexagonal unit cell FEA. Maximum value near particle size region in last step of load increment.(b): Shows distribution stress in y-direction of hexagonal unit cell FEA. Maximum value near particle size region in last step of load increment.



**Fig.10(a): Stress Contour in X-Direction of Hexagonal Unit Cell FEA.**



**Fig.10(b): Stress Contour in Y-Direction of Hexagonal Unit Cell FEA.**

**Finite Element Analysis of Coupling State:**

Results contain thermal shear stress of square and hexagonal unit cell in silicon carbide reinforcement in coupling state.

**Square Unit Cell FEA:**

Fig. (11) shows distribution thermal shear stress of square unit cell at 10 % volume fraction. Maximum value near particle size region in last step of load increment.

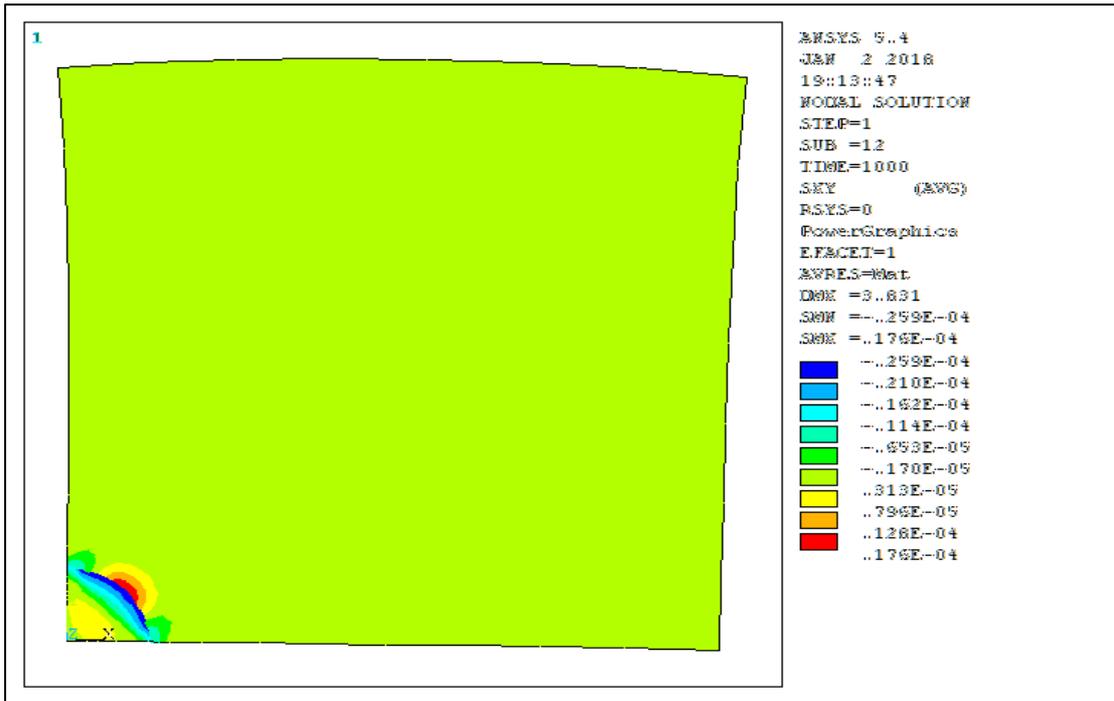


Fig.(11) Thermal Shear Stress of Square Unit Cell FEA.

**Hexagonal Unit Cell:**

Fig.(11) shows distribution thermal shear stress of hexagonal unit cell at 10 % volume fraction. Maximum value near particle size region in last step of load increment.

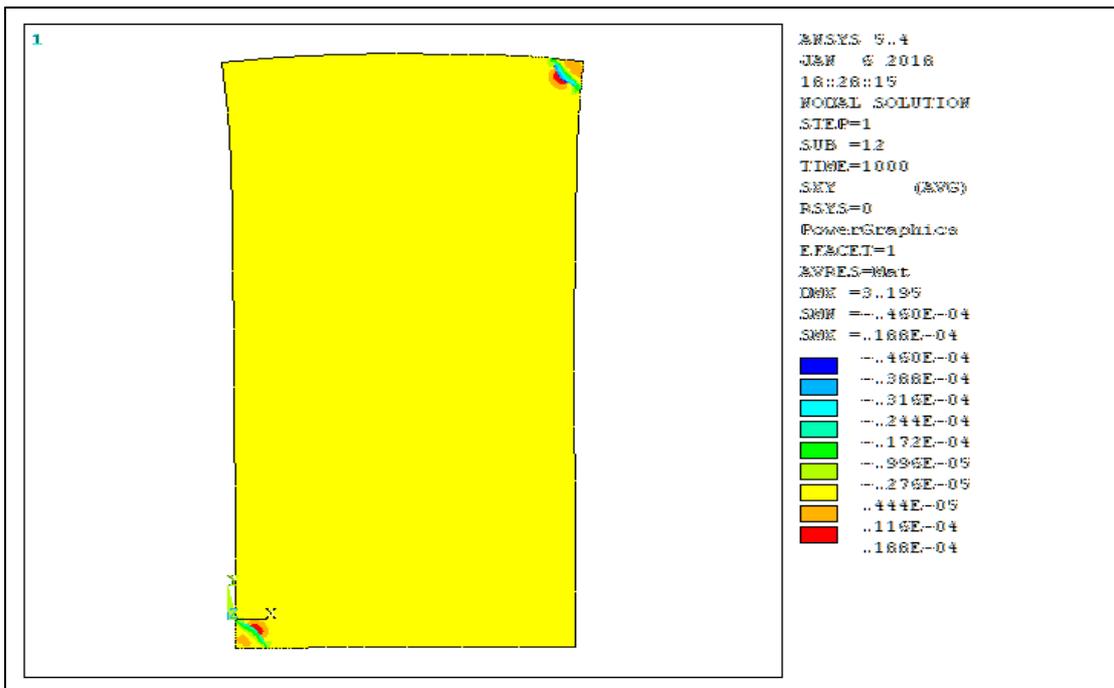


Fig.(12) Thermal Shear Stress of Hexagonal Unit Cell FEA.

## Conclusions:

- 1- Hardness increases with the increasing additive of both (SiC and Al<sub>2</sub>O<sub>3</sub>) .
- 2- Compression strength improves with additive
- 3- Real represent of microstructure LOM image using image analysis with combination of finite element analysis is more accurate than unit cell finite element approach.
- 4- Using image processing and image analysis of LOM images of elemental to determine particle size and particle distribution .

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