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Experimental and Numerical Analysis of Aluminum Metal Matrix Composites

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Abstract: Metal matrix composites have great attentions in the recent years due to their excellent properties in different engineering applications. In this study, aluminum metal matrix composite reinforcing with different weight percentage of alumina and silicon carbide have been prepared by using stir casting. Many composites have been done for 1, 2, 3, 5, 7 and 10 wt.% for each reinforcement materials. Several physical and mechanical properties have been evaluated such as particle size and particle size distribution for reinforcing particles, the average particle size for silicon carbide is about 165.6 μm while average particle size for alumina powder is about 1.048 μm, X-ray diffraction as well as mechanical properties as hardness and compression are also presented. Finite element modeling using ANSYS Software is used to model aluminum metal matrix composites. Two dimensional elements with uniform distribution of reinforcements as square and hexagonal arrays are based in the model. Microstructure based finite element meshing has also presented based on the microstructure of composite prepared in this study. 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 composite. 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 composite, casting technique, ANSYS, finite element analysis, model aluminum, microstructure

INTRODUCTION

Metal Matrix Composites (MMCs) are metals reinforced with other metals, ceramic or organic compounds. They are made by dispersing the reinforcements in metal matrix. Reinforcements are usually done to improve the properties of the based metal like strength stiffness, conductivity, etc. Aluminum and its alloys have attracted most attention as base metal in metal matrix composites. Aluminum MMCs are widely used in aircraft, automobile, aerospace and other various fields. The reinforcements should be stable in the given working temperature and non-reactive too. The most commonly used reinforcements are Silicon Carbide (SiC) and Aluminum Oxide (Al_2O_3). SiC reinforcement increases the tensile strength, 2 density, hardness and wear resistance and of aluminum and its alloys (Ramnath *et al*., 2014).

The attractiveness of aluminum is that it is a relatively low cost, lightweight metal that can be heat treated to fairly high-strength levels and it is one of the most easily fabricated of the high-performance materials which usually correlates directly with lower costs. Disadvantages of aluminum include a low modulus of elasticity, rather low elevated temperature capability (Rambabu *et al*., 2016). Aluminum metal in the real stage is too soft for such uses, and it does not have the "high tensile strength. The aluminum alloys have excellent mechanical properties such as high strength, durability, low density, machinability which is required the manufacturing industries. Aluminum alloys are used in advanced applications due to their combination of availability and relatively low cost as compared to other competing metal (Kumar *et al*., 2016).

The unique properties of the particulate reinforced composite materials are to a great extent dependent on the unique nature on the matrix-particle interface. The requirement for strong, light and stiff materials has extended an interest in MMCs. During the past three decades, MMCs have received substantial attention because of their improved strength, high elastic modulus and increased wear resistance over conventional base alloys (Lokesh *et al*., 2013).

MATERIALS AND METHODS

Experimental part: In this research, the aluminum wire cutting to small pieces in order to ease its melting. After that weighted aluminum and reinforcement materials

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(silicon carbide and α-alumina) using sensitive balance. When the aluminum melts completely and reinforcement covered by thick aluminum foil add and continue mixing in order to homogenize the mixture. After dissolving melts are put in the mold lubricated graphite for easy casting. Composition for each sample from aluminum and reinforcement materials in this study have been shown in Table 1.

Results of experimental part

Microstructure: The microstructure of these samples are fine grains for etched specimens with [HF+H_2O] etching (Fig. 1).

Table 1: Weight composition of each aluminum and reinforcement materials (Silicon carbide and α-alumina)

Weight percentage Al (%)	Weight percentage SiC (%)	Weight percentage Al_2O_3 (%)
99	1	1
98	2	2
97	3	3
95	5	5
93	7	7
90	10	10

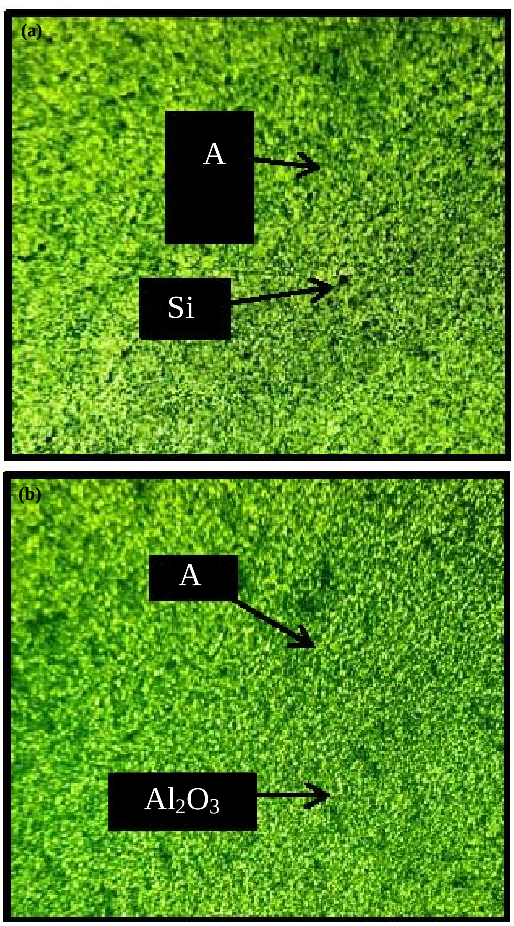

Fig. 1: Microstructure: a) Al+SiC and b) Al+Al_2O_3

Figure 2 shows relationship between strain-stress curve of compression strength. It is clear that compression strength improved.

Image analysis: ANSYS program is an open system where the user has various possibilities for constricting an individual model for the material. ANSYS program is based up on finite element analysis. Our problem which is reality is composed of continuous fields (fields of displacements, strains, stress temperature and state variable) can be solved by an approximate discrete element based solution (Fig. 3 and 4).

After converting the image to a binary image (white and black) several functions have been used to determine the number of the objects (black in image) which are pores their distribution area, centroid and bounding box. The bounding box represents the smallest rectangle that can contain a region on in this case a pore. Furthermore, statistical properties of objects in the image may be obtained using image-J. Statistical properties include maximum diameter of pore area, circle or

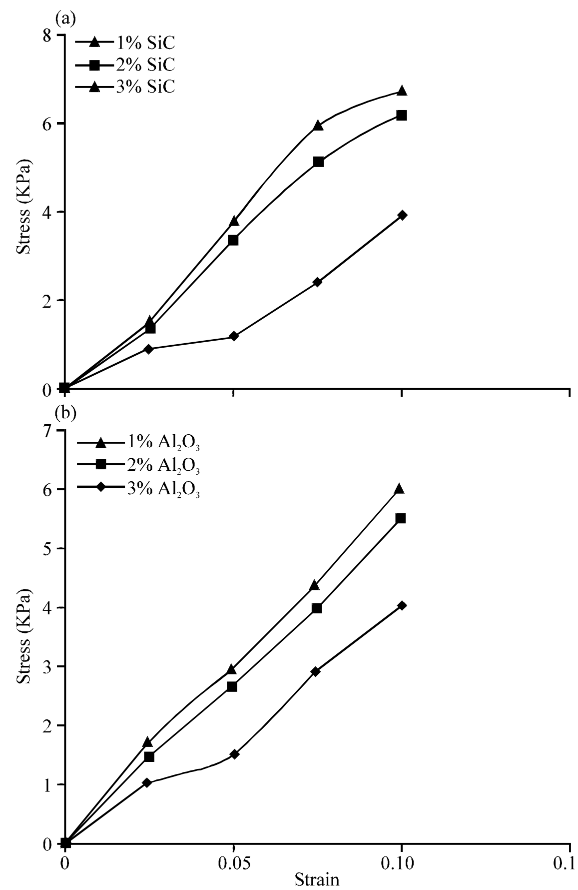

Fig. 2: Strain-stress curve compression: a): Al+SiC and b) Al+Al_2O_3

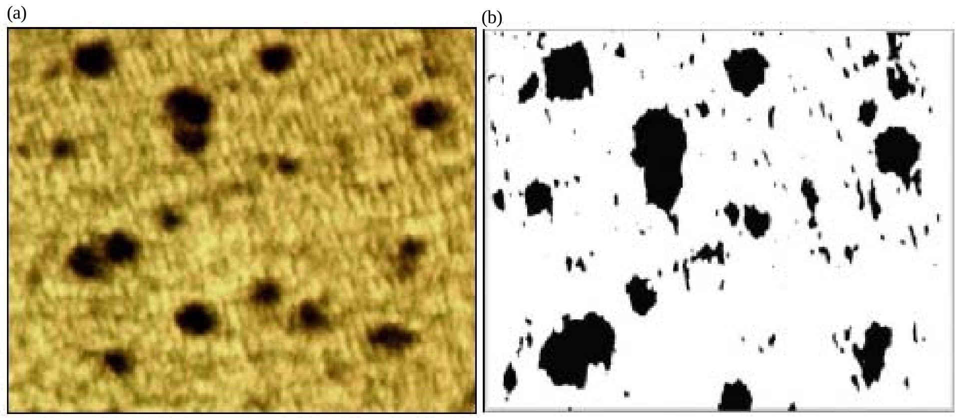

Fig. 3: a) Light optical microscope of sample Al +SiC and b) Binary image of sample Al+SiC

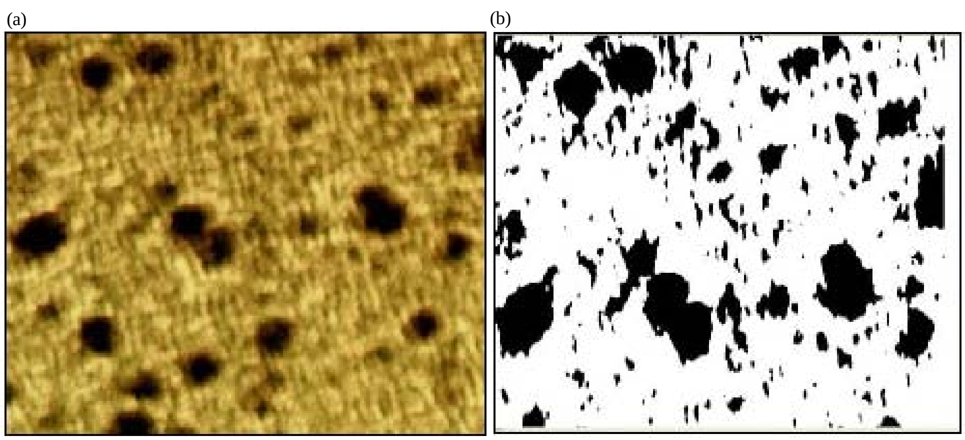

Fig. 4: a) Light optical microscope of sample Al+Al_2O_3 and b) Binary image of sample Al+Al_2O_3

ellipse fitted object and mean of all pore size. This field of knowledge is new and very important in material engineering applications such as analysis of particles, shape and size distribution of particles in the field of casting as in this study and the analysis of the final product microstructure for example pores size and distribution grain size and grain growth in complex metallurgy microstructure (Wojnar, 1998). In this study, image analysis and processing used to give the following:

- Particle size and shape using suitable scale calibration
- Particle distribution based up on accumulated particle number
- Particle size with suitable circle ellipse and feret rectangle best fit with particle shape
- Pore size and shape in the casting image

Image analysis: 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 as shown in Fig. 1.

Meshing: Manual meshing generation was the only way before solid paragon get wide-unfurls among trading fagot. It is still the only choice with some senior and custom software, although in those fettles it is always probable to utilize a general purpose, solid modeling pre-processor to generate the mesh. With manual meshing, the user establish nodes then connects the nodes into elements. After ware, the user applies boundary conditions and loads directly on nodes and/or elements (Barbero, 2007) (Fig. 5).

Boundary condition, material properties: The boundary conditions are the known values of the Degrees of Freedom (DOF) on the boundary and also called support conditions in structural mechanics. In structural analysis, the DOF are displacements and rotation (Fig. 6). Parts

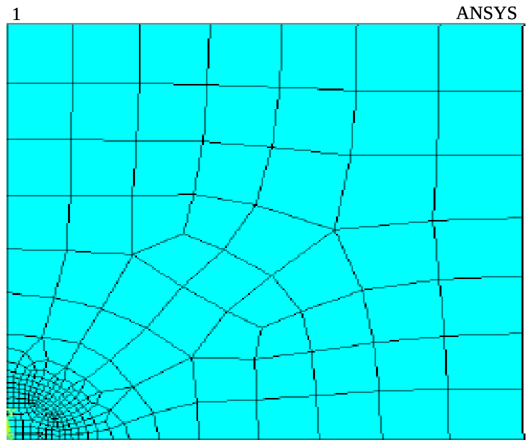

Fig. 5: Square array of meshing

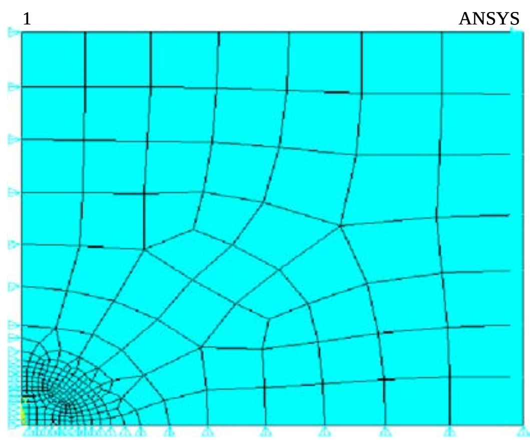

Fig. 6: Boundary condition of square array

must be linked to materials. Adoption on the analysis, material characteristics can be linear (linear elastic analysis) or nonlinear (e.g., damage mechanics analysis), isotropic or orthotropic, fixed or temperature followed. Entering the correct material properties is one of the most important aspects of a successful analysis of composite materials. All elements need material properties but structural elements need additional parameters that vary with the type of the element. These parameters results from analytical integration of the 3D govering equations while formulating the element (Barbero, 2007).

RESULTS AND DISCUSSION

Numerical results: Results contain stress of x and y direction of square and hexagonal static state in silicon carbide reinforced aluminum.

Figure 7 shows results of stress contour of square unit cell at 10% volume fraction. Figure distribution stress in X-direction and maximum value near particle size region in last step of load increment.

Figure 8 shows results of stress contour of square unit cell at 10% volume fraction. Figure show distribution stress in Y-direction and maximum value near particle size region in last step of load increment.

Figure 9 shows results stress contour of hexagonal unit cell EFA at 10% at volume fraction. Figure 9 shows distribution stress in X-direction and maximum value near particle size region in last step of load.

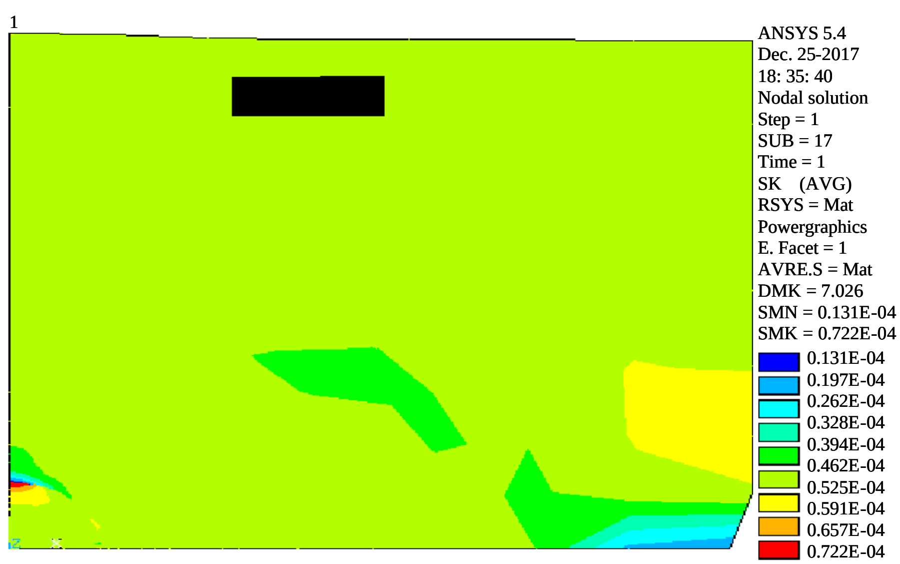

Fig. 7: Stress contour in X-direction for square unit cell FEA

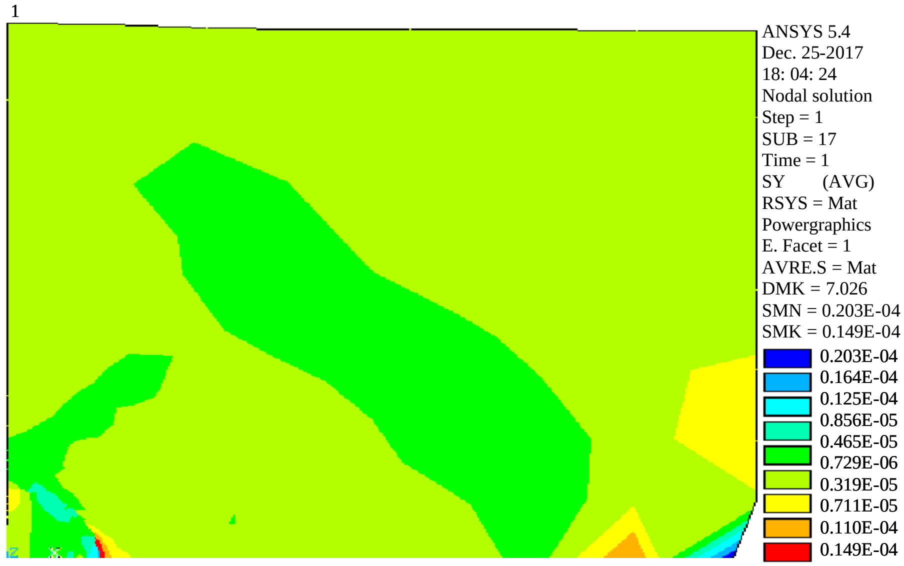

Fig. 8: Stress contour in Y-direction for square unit cell

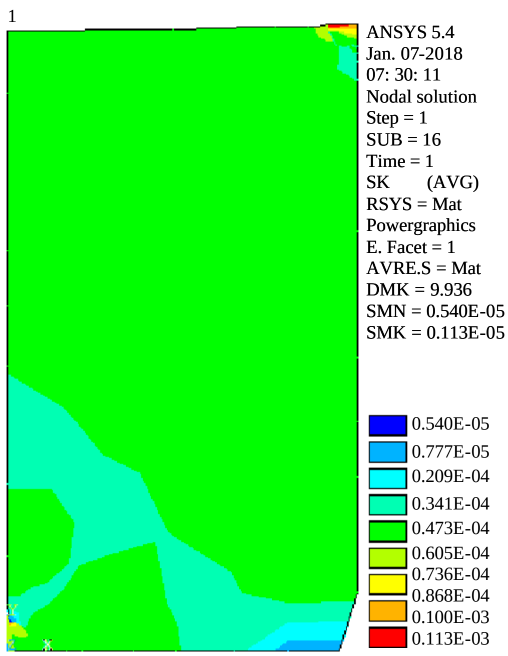

Fig. 9: Stress contour in X-direction for hexagonal unit FEA

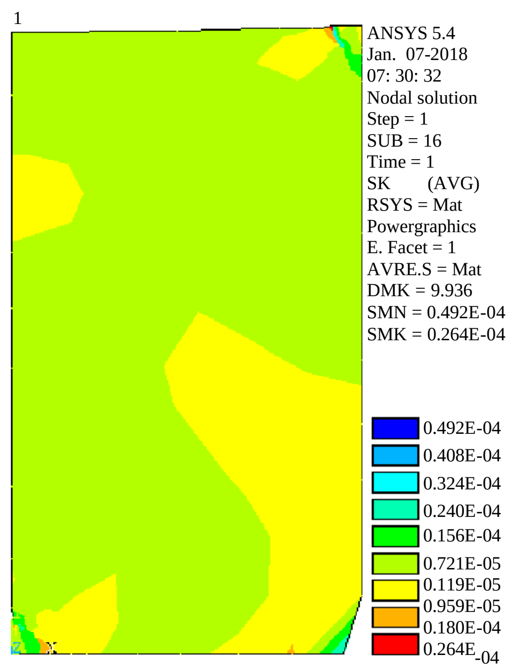

Fig. 10: Stress contour in Y-direction of hexagonal unit cell FEA

Figure 10 shows results stress contour of hexagonal unit cell at 10% volume fraction. Figure shows distribution stress in Y-direction and maximum value near particle size region in last step of load increment.

Shear stress: Results contain shear stress at 5 and 10% volume fraction in silicon carbide reinforced aluminum. Figure 11 shows results of shear stress unit cell FEA at 5% volume fraction. Figure 11 shows distribution shear stress and maximum value. 177E-04 N/μm^2 at last set of load increment. Figure 12 shows results shear stress of square unit cell FEA at 10% volume fraction. Figure 12 shows distribution shear stress and maximum. 156E-04 N/μm^2 at last step of load increment.

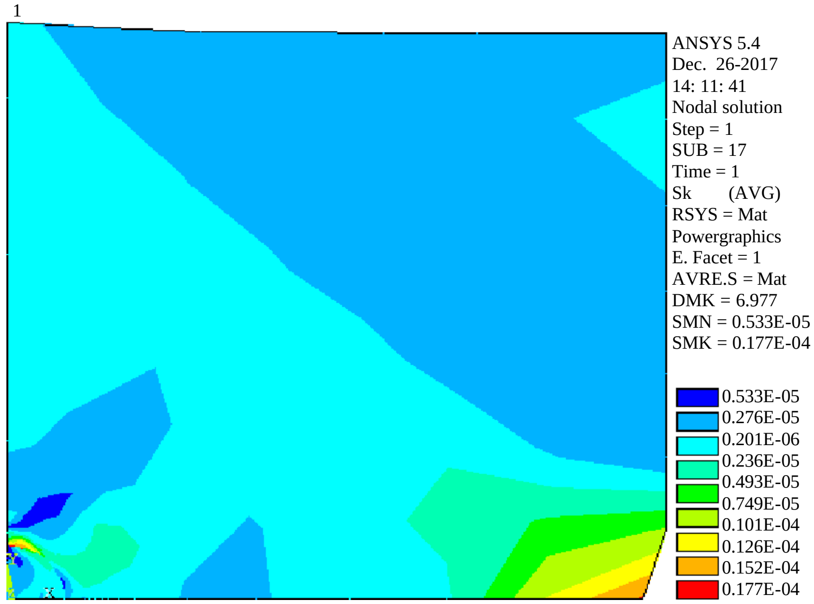

Fig. 11: Shear stress contour of square unit cell FEA

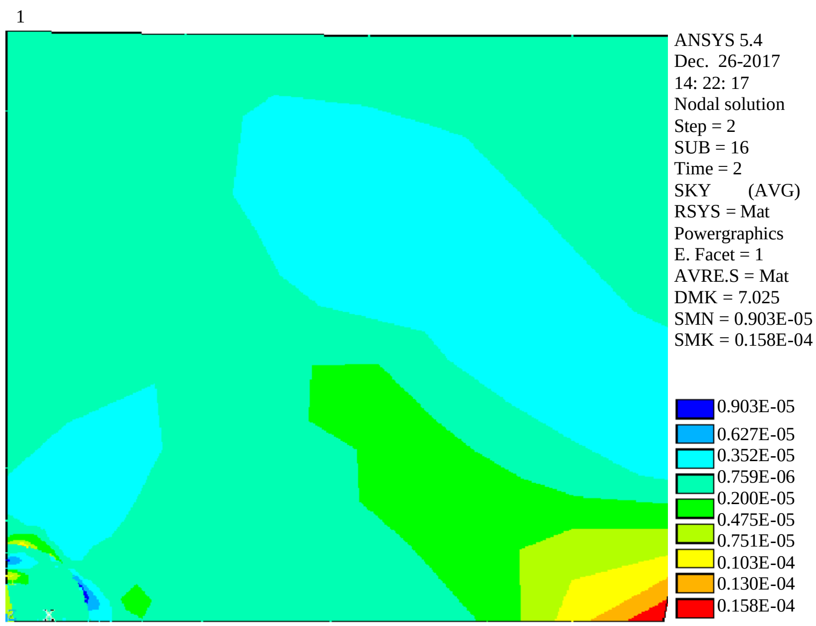

Fig. 12: Shear stress contour of square unit cell FEA

CONCLUSION

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Using image processing and image analysis of LOM images of elemental to determine particle size and particle distribution. The use of unit cell finite element technique with periodic square and hexagonal arrangement is efficient for analysis of metal matrix composite prepared by casting. Real represent of microstructure LOM image using image analysis with combination of finite element analysis is more accurate than unit cell finite element approach.

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