ANNALS OF FACULTY ENGINEERING HUNEDOARA
- INTERNATIONAL JOURNAL OF ENGINEERING
Tome IX (Year 2011). Fascicule 1. (ISSN 1584 - 2665)

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COMPARISON BETWEEN 2-D AND 3-D TEMPERATURE DISTRIBUTION ANALYSIS AND EFFECTIVE THERMAL CONDUCTIVITY (ETC) FOR VARIOUS SHAPES OF TWO PHASE SYSTEMS USING FINITE ELEMENT METHOD

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ABSTRACT: In this article, the comparison between two dimensional and three dimensional temperature distribution analyses has been carried out in the unit cell for various shapes at different conductivity ratios, contact ratios and concentration by ANSYS software with suitable boundary conditions. Effective Thermal conductivity has been carried for different concentration, contact ratio and conductivity ratio for 2dimensioal and 3 dimensional. This paper presents a numerical method using 3D finite element models to accurately predict the ETC of two phase materials.
KEYWORDS: Two dimensional-Three dimensional; Conductivity ratio; Contact ratio; Concentration

❖ INTRODUCTION

The theoretical estimation of the effective thermal conductivity (ETC) of two phase materials has been always difficult. Use of two-phase materials is regarded as more effective means of energy conservation and energy efficiency in an industrial sector. Numerous models were developed to find out the effective conductivity of mixtures, but one of the major limitations of the models is its suitability for specific application.

Effective thermal conductivity of two phase material is very important to determine heat transfer characteristics. Reddy and Karthikeyan (1) developed the collocated parameter model based on the unit cell approach for predicting the effective thermal conductivity of the two-phase materials. Tai [2] deduced mathematical expressions for the equivalent thermal conductivity of two and three-dimensional orthogonally fiber-reinforced composites in a one-dimensional heat flow model. In this regard, Tai applied the fundamental definitions of thermal conductivity and the simple rule of mixtures to a unit cell of an orthogonally fiber-reinforced material. Tai showed that whether a square slab model or a cylindrical fiber model is used makes little difference to the heat flux; while the fiber volume fraction matters. Jones and Pascal [3] developed a three-dimensional numerical finite-difference to calculate the thermal conductivity of a composite with two or more constituents to better understand how the relative quantities and distributions of the component materials, within a sample, affect the whole sample conductivity. Graham and McDowell [4] estimated the transverse thermal conductivity of continuous reinforced composites containing a random fiber distribution with imperfect interfaces using finite-element analysis. Krach and Advani [5] investigated the effect of void volume and shape on the effective conductivity of a unidirectional sample of a 3-phase composite using a numerical approach consisting of a unit cell. Their findings clearly showed that the influence of porosity on thermal conductivity could not be described solely by the void volume. They found that the shape and distribution of the voids influence the effective thermal conductivity. Al-Sulaiman et al [6] developed correlations based on a finite element analysis that predict the thermal conductivity of fibers utilizing the easy to measure thermal conductivity of the Fiber Reinforced Composite Laminates (FRCL) and the other constituents. In their model, Al-Sulaiman et al considered the FRCL cured at high pressures such that it includes no air voids. Zou et al. [7] come up with an analytical expression for transverse thermal conductivities of unidirectional fiber composites with and without thermal barrier is derived based on the electrical analogy technique and on the cylindrical filament-square packing array unit cell model (C-S model). The effective thermal conductivity modeling of various inclusions has been carried out by A P Senthil Kumar [8-9].

❖ NUMERICAL ANALYSIS FOR VARIOUS INCLUSIONS. BOUNDARY CONDITION

Numerical heat transfer analysis of the unit cell for various inclusion shapes (square, hexagon, octagon and circular cylinders) has been carried out to estimate the Effective Thermal Conductivity of the two-phase materials via the Finite Element simulation. For this heat transfer analysis ANSYS, a finite element software package is used. Solid 90 elements were used for the analysis and an element size of 0.03 was adopted. Software validation and mesh sensitivity test has been carried out.

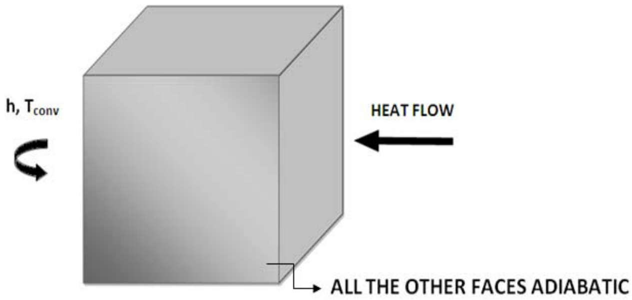


Figure 1.The Thermal boundary condition applied on the unit cell

One face of the unit cell is subjected to constant temperature and the opposite face is subjected to convective thermal environment. All other faces are kept as adiabatic in order to achieve 1D heat transfer. The boundary condition imposed on the unit cell is shown in the Figure 1.

❖ DETERMINATION OF EFFECTIVE THERMAL CONDUCTIVITY

From the results of the finite element analysis, the average surface temperature on the convection wall of the unit cell is computed. Once the temperature of the convective side is known, the effective thermal conductivity across the two walls can be calculated using the following simple heat balance equation

$$hA\left(T_{wall2}-T_{conv}\right)=\frac{K_{eff}\,A\left(T_{wall1}-T_{wall2}\right)}{L} \quad (1)$$

A - Wall area (m^2)
h - Heat transfer coefficient ($W/m^2.K$)
T_{conv} - bulk temperature of the fluid at the convection side (K)
T_{wall1} - fixed wall temperature (K)
T_{wall2} - convective wall temperature (K)

❖ PREDICTION MODELS AND FINITE ELEMENT RESULTS

A two-dimensional and three-dimensional model has been constructed for this analysis. Several simulations were done for a wide spectrum of possible variations in contact ratio, concentration and conductivity ratio.

❖ RESULTS AND DISCUSSION

The finite element simulation can easily be extended to account for two-dimensional and three dimensional heat transfer. The simulation covers wide range of concentration, conductivity ratio and contact ratio. Comparative study of the 2D and 3D prediction model for temperature distribution in the unit cell for various inclusion shapes at different conductivity ratios and contact ratios for different concentration are shown in the Figures 2-5.

The circular shaped inclusion has largest non-dimensional ETC followed by square, hexagon and octagon shaped inclusions respectively. For the same concentration and contact ratio, hexagon shaped inclusion has largest heat transfer area followed by circular, octagon and square shaped inclusions respectively. Since hexagon has the largest heat transfer area it is expected to have larger non-dimensional ETC than other inclusion shapes. But the geometry of hexagon and octagon shapes are not symmetric about its mutual perpendicular axis i.e., hexagon and octagon shapes exhibits anisotropic property. This is the reason for the hexagon shaped inclusion to have lower non-dimensional ETC than circular and square shaped inclusions.

Fig. a, c, e and g shows the model with less conductivity ratio and Fig. b, d, f and h shows the model with high conductivity ratio. In each figures, the temperature profile for the two phase system is compared with both 2D and 3D model. The 2D model even though it is 3D in nature, the solid phase in particular shape was modeled only in one dimension and the shape was assumed to be uniform along the depth in the third dimension.

From the following figures it can also be noted that the temperature profile in 2D case is uniform throughout the depth of the third dimension, whereas there is a variation in temperature profile in the 3D case.

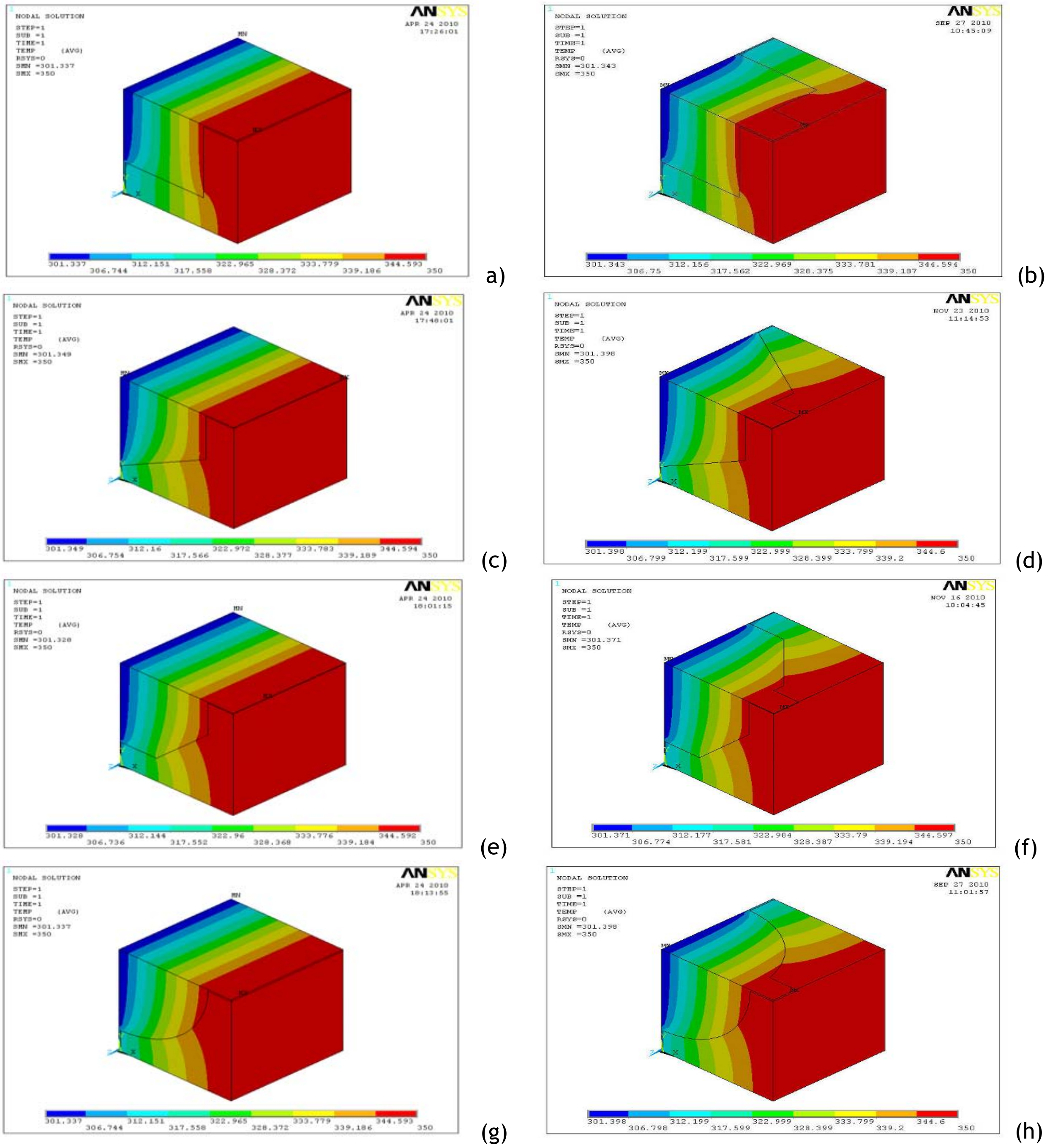
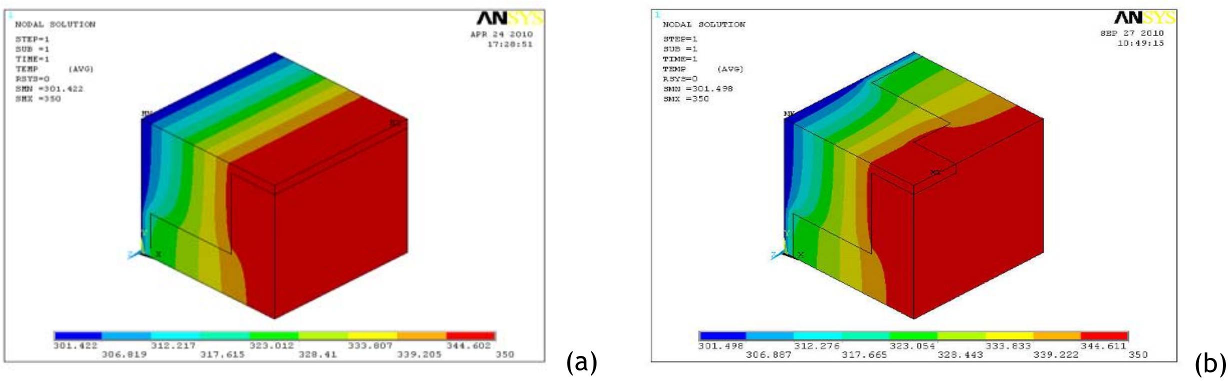


Figure 2. Temperature distribution
(a,c,e,g) 2D-Temperature distribution for various inclusion shapes at α=0.1, υ=0.5 and λ=0.02.
(b,d,f,h) 3D-Temperature distribution for various inclusion shapes at α=0.1, υ=0.5 and λ=0.02.



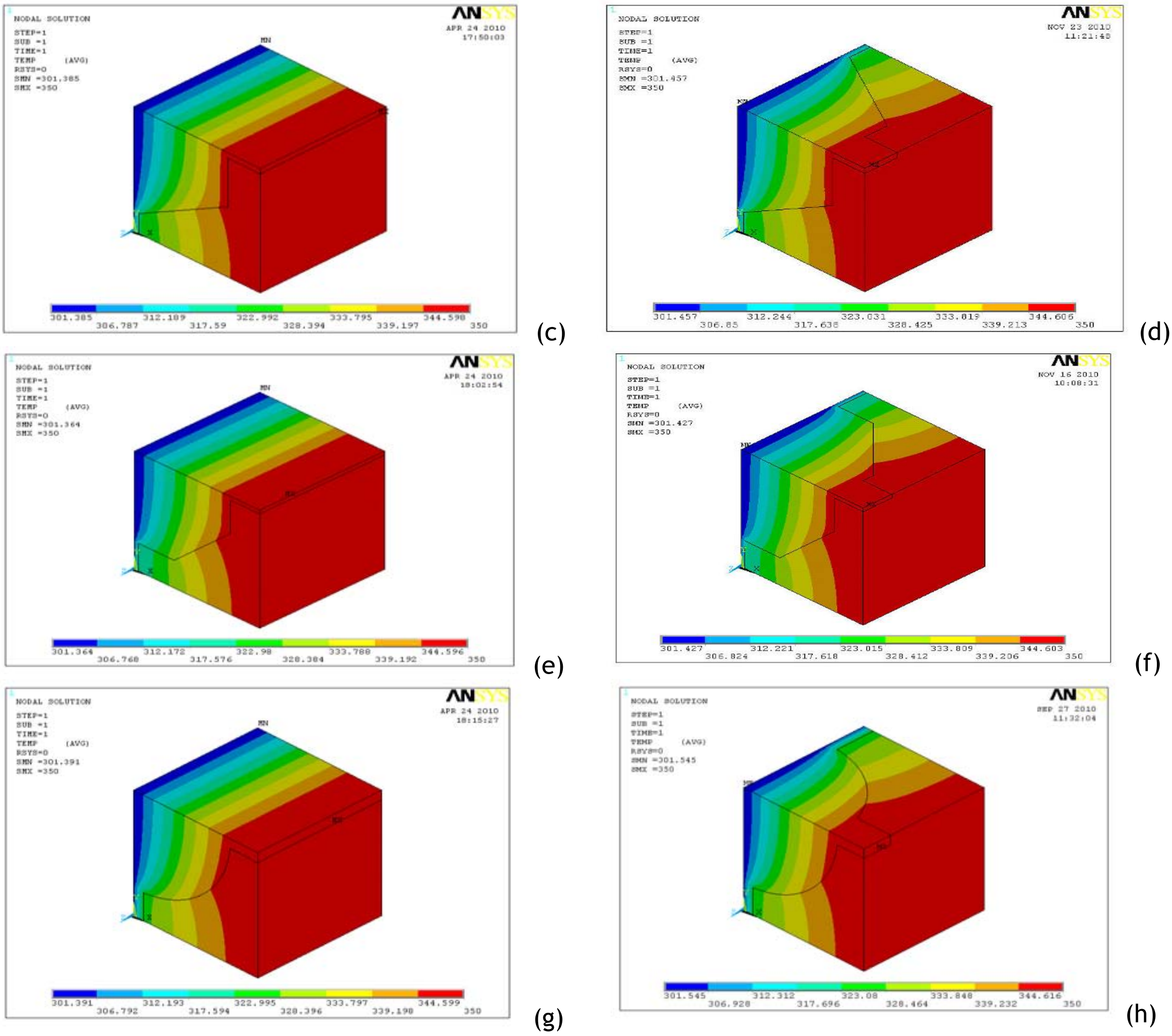
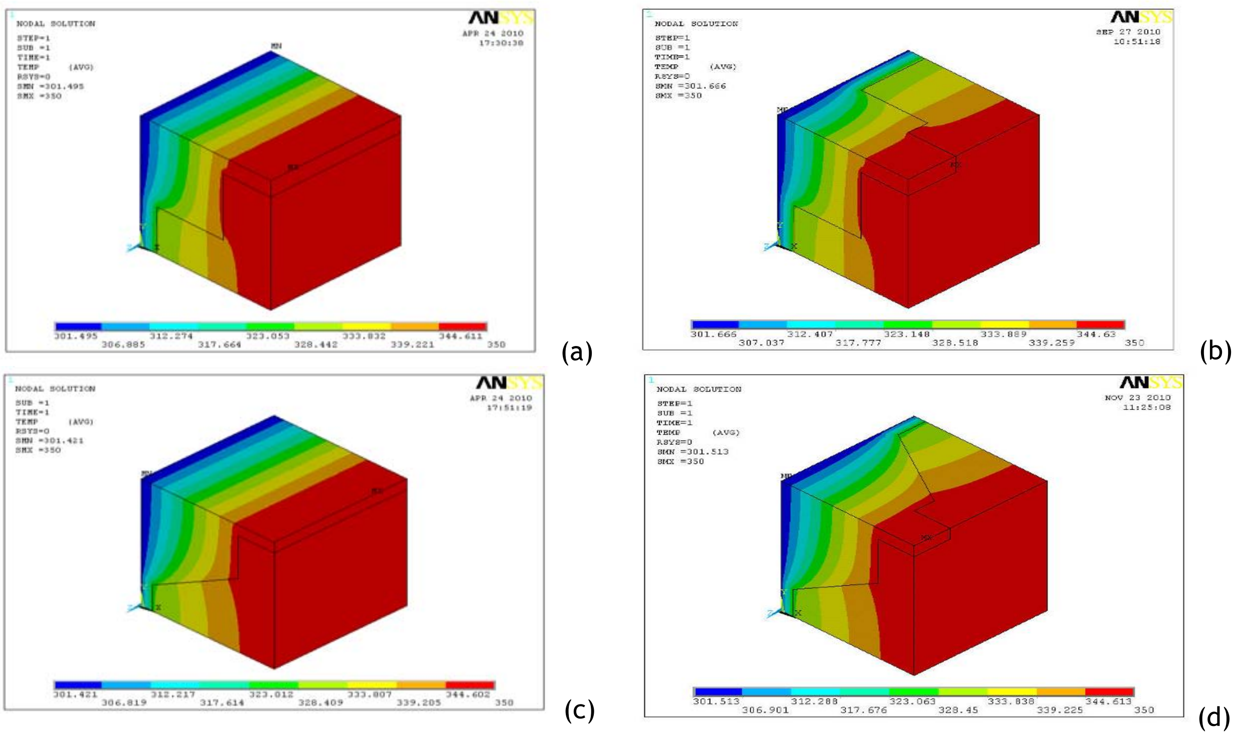
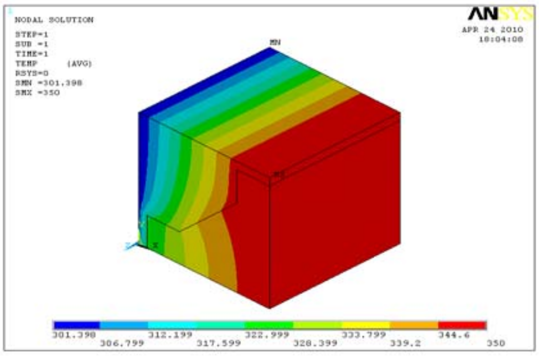


Figure 3. Temperature distribution
(a,c,e,g) 2D-Temperature distribution for various inclusion shapes at α=0.1, υ=0.5 and λ=0.1.
(b,d,f,h) 3D-Temperature distribution for various inclusion shapes at α=0.1, υ=0.5 and λ=0.1.





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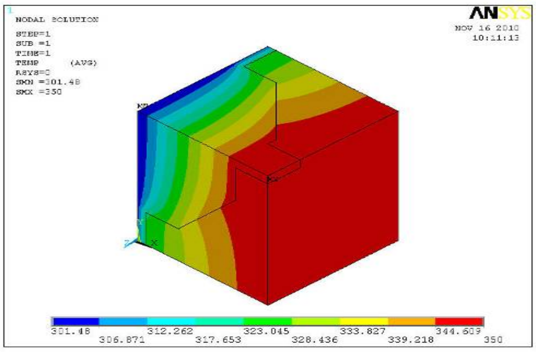

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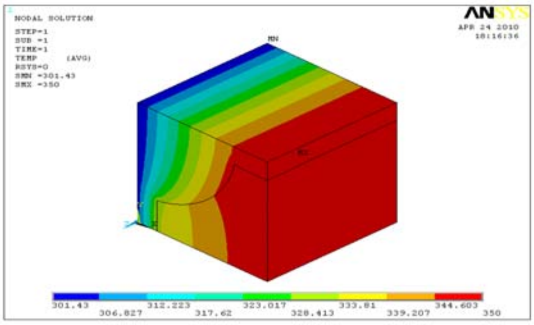

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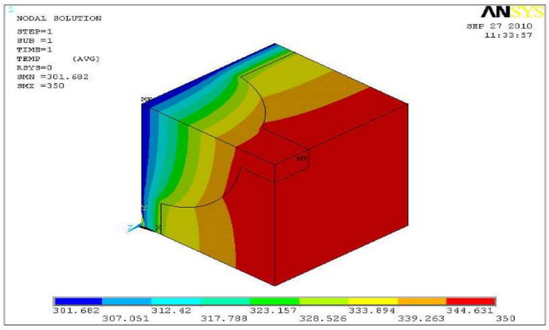
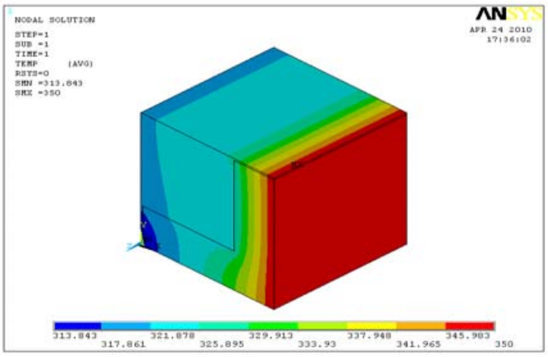
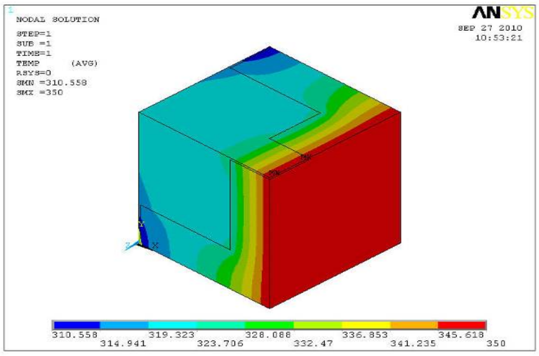


(h)

Figure 4. Temperature distribution
(a,c,e,g) 2D-Temperature distribution for various inclusion shapes at α=0.1, υ=0.5 and λ=0.2.
(b,d,f,h) 3D-Temperature distribution for various inclusion shapes at α=0.1, υ=0.5 and λ=0.2.



(a)



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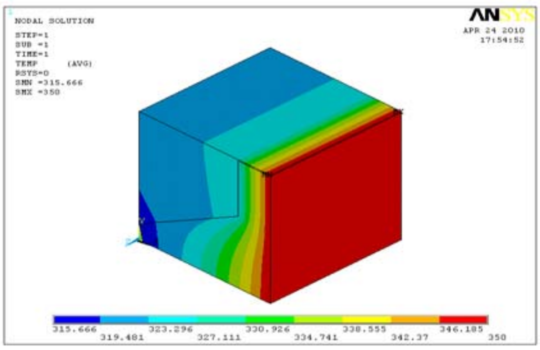

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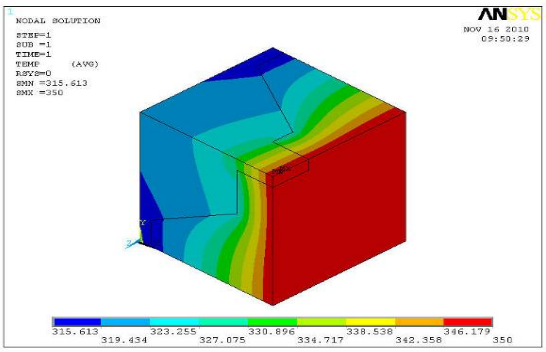

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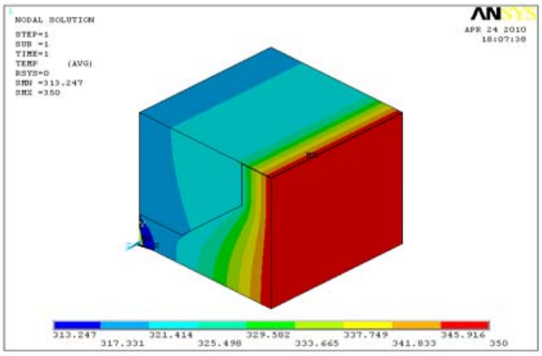

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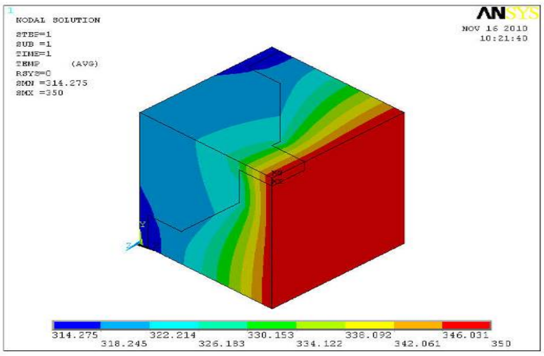

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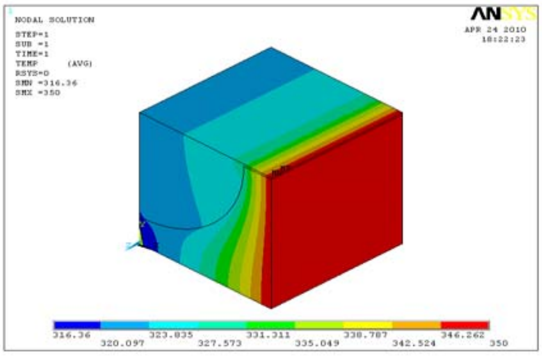
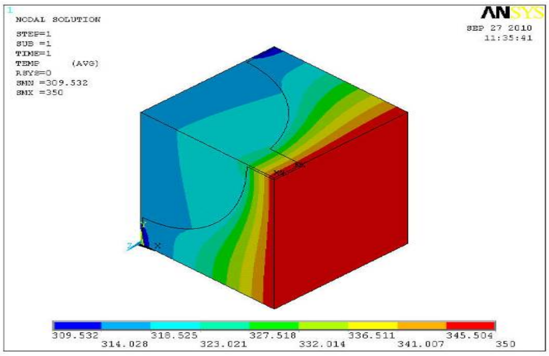
 (g)  (h)

Figure 5. Temperature distribution

(a,c,e,g) 2D-Temperature distribution for various inclusion shapes at α=20, υ=0.5 and λ=0.02.

(b,d,f,h) 3D-Temperature distribution for various inclusion shapes at α=20, υ=0.5 and λ=0.02.

Further from the Fig. a-h, it can be seen that the heat transfer rate is more in solid phase than the liquid phase. The solid phase attains steady state earlier than the liquid phase in all configurations and for all values of conductivity ratio, contact ratio and concentration ratios.

❖ CONCLUSION

It is conclude that, for higher concentration and conductivity ratios, the 3-dimensional model predicting effective thermal conductivity of two phase materials with higher accuracy, but for lower ranges, 2-Dimensional model has been used to predict the effective thermal conductivity.

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