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Evaluation of influence of interphase material parameters on effective material properties of three phase composites

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Abstract

In this paper, evaluation of effective material properties of different types of three phase composites (reinforcement, matrix and in between interphase) using numerical homogenization techniques (representative volume element (RVE) approach) based on finite element method is presented. The influence of interphase parameters like stiffness and volume fraction of interphase on effective material properties of transversely randomly distributed uni-directional fiber composites and randomly distributed spherical particle composites is studied. The RVEs, required for transversely randomly distributed uni-directional fiber composites and randomly distributed spherical particle composites, are generated using a modified random sequential adsorption (RSA) algorithm with periodicity on opposite boundary surfaces. The numerical results are compared with analytical methods like

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asymptotic homogenization method for regular arrangement of uni-directional fiber composites.

Keywords: A. Fibers; A. Coating; B. Interphase; B. Modeling; B. Mechanical properties.

1. Introduction

Interphases, or interfacial zones, in fiber reinforced composite materials are the thin layers between the fiber and the matrix. These interphases are formed due to, for example, chemical reaction between the matrix and fiber materials or the use of protective coatings on the reinforcements during manufacturing to ensure good adhesion between reinforcement and matrix material. Although small in thickness, interphases can significantly affect the overall mechanical properties of the fiber or particle reinforced composites. The effective utilization of the fiber reinforced composites depends on efficient load transfer from the matrix to reinforcements through these interphases. It is the weakest link in the load path, and consequently most failures in fiber or particle reinforced composites, such as debonding and matrix cracking, occur in or near this region. Thus, it is crucial to fully understand the mechanism and effects of the interphase material parameters on the overall material properties of composites. The micro mechanical method provides the overall behavior of the three phase composites from the known properties of their constituents (fiber, matrix and interphase) through an analysis of a periodic representative volume element (RVE) or a unit cell model.

The effective material properties of two phase randomly distributed fiber and particle reinforced composites are extensively studied by using analytical and numerical analysis [1-8]. Pagano and Tandon [9, 10] approximate the effective properties of thermoelastic composites with coated fibers using unit cell approach. They estimate the influence of coating of fiber on overall thermoelastic properties of composites. Dasgupta and Bhandarkar

[11] proposed a method to obtain the effective properties of transversely isotropic thermoelastic composites reinforced with coated cylindrical fibers. Yeh [12] studied the effect of interphase on the transverse material properties of elastoplastic composites. Also Lagache et al. [13] studied the effect of interphase on effective material properties of three phase composites numerically. Liu et al. [14] have modeled the interphases in fiber reinforced composites and studied the influence of interphases using boundary element method. Guinovart et al. [15] developed closed form expressions to evaluate the effective material properties of thermoelastic three phase fiber composites.

Most of the work, which deals with three phase composites, is restricted to regular arrangement of fiber composites. The aim of this paper is to point out the influence of material properties and volume fraction of interphases on the overall mechanical properties of three phase composites using RVE approach. In this work, the conventional numerical homogenization technique reported by Berger et al. [1, 2] and Kari et al. [16] is extended to evaluate the effective material properties and influence of interphase of complex microstructured three phase composites like transversely randomly distributed fiber and randomly distributed spherical particle composites. The consideration of randomly distributed inclusions opens new possibilities to investigate more realistic composites which incorporates automatically such effects like the influence of different distances between the particles. All calculations are made under the assumption of small strains and elastic material behavior. In order to validate our developed numerical homogenization tools, comparisons are made between our numerical results and results reported in literature for uni-directional regular arrangement of fiber composites.

2. RVE models for numerical homogenization techniques

The RVE models and corresponding finite element modeling used to evaluate the effective material properties of regular arrangement of uni-directional three phase fiber composites are shown in Fig. 1.

The three phase uni-directional transversely randomly distributed fiber composite RVE models are generated using our developed user defined FORTRAN algorithms which are based on modified RSA algorithm reported by Wang [17]. The generation of microstructure for this case is based on two-dimensional X_1 - X_2 plane. First, random coordinates are generated for the center of one circular disc with prescribed radius (fiber radius plus interphase thickness corresponding to given interphase volume fraction) and is deposited on the X_1 - X_2 plane. The next randomly generated coordinates of centers of circular discs are checked for non-overlapping condition with previously deposited discs. If there is no overlap between the current disc and previously deposited discs, and the periodicity is satisfied, then the current disc will be deposited on the X_1 - X_2 plane. This process will be terminated when desired volume fraction is achieved or when no more discs can be added because of the jamming limit, which can occur at a certain volume fraction in RSA algorithm. Fig. 2 shows an example of RVE model and the corresponding finite element model of three phase transversely randomly distributed uni-directional fiber composite.

Also the RVE models of randomly distributed spherical particle composites with interphase between the particles and matrix are generated using modified RSA algorithm. The center distance between spherical particle i and all other particles, which are previously accepted $j=1\dots i-1$ have to exceed a minimum value $(2*r+s)$, where r is radius of the spherical particle plus interphase thickness and s is the minimum distance between any two spherical particles, imposed by the practical limitations for creating an adequate finite element mesh. If any surface of the spherical particle i cuts any of the cubic RVE surfaces, this condition has to

be checked with the spherical volumes on the opposite surfaces because the microstructure of the composite is periodic. Fig. 3 shows the RVE model and the corresponding finite element modeling of the three phase spherical particle composites.

3. Results and discussion

The method of evaluation of effective material properties of three phase fiber and particle reinforced composites using numerical homogenization techniques is similar to the method explained in Berger et al. [1, 2] and Kari et al. [16]. For the detailed description of the numerical homogenization techniques and corresponding periodic boundary conditions used to evaluate the effective stiffness coefficients for different types of composites one can refer to [1,2,16]. The material properties of constituents of three phase composites are taken from the literature given by Benveniste et al. [18]. Table 1 shows the material properties of the fiber, matrix and interphase used in this work.

3.1. Influence of volume fraction for square and hexagonal fiber arrangement

The effective material properties are obtained by increasing the volume fraction of fibers up to 70% by keeping the volume fraction of interphases constant at 0.075%. The effective material properties obtained using numerical homogenization technique are compared with analytical asymptotic homogenization method reported by Guinovart et al. [15,19,20]. Also a comparison is made between the square and hexagonal arrangements of fiber composites. Fig. 4 shows these comparisons. There is a good agreement between the analytical results and numerical predictions for all volume fractions considered in this study. Along the longitudinal direction, the type of arrangement of fibers does not influence the

effective material properties. But along the transverse direction, the effective Young's modulus E_t^{eff} is having higher value when compared with hexagonal arrangement. This is due to the fact of tetrahedral symmetry in square arrangement. The transverse shear modulus is having higher value for hexagonal arrangement when compared with square arrangement. This is due to the fact that hexagonal arrangement is having transverse isotropy symmetry.

3.2. Influence of interphase material property on overall behavior of composites

In order to study the influence of interphase material properties on overall material behavior, the effective material properties are calculated by increasing the interphase Young's modulus from 10 to 250 GPa. The effective material properties are evaluated by keeping volume fraction of fiber, interphase and matrix materials and individual material properties of fiber and matrix as constant. Fig. 5 and 6 show the variation of effective material properties with increase of interphase Young's modulus for transversely randomly distributed uni-directional fibers at 30% volume fraction and randomly distributed spherical particle composites at 15% volume fraction. In these cases the volume fraction of interfaces is 1% for the uni-directional fiber model and 3.78% for the spherical particle model. From Fig. 5, it can be observed that the transverse effective Young's modulus increases rapidly with the increase of interphase Young's modulus up to a certain value (say 100 GPa) and from that the influence is not so high. But the effective longitudinal Young's modulus is not much affected by increase of stiffness of interphase (5% difference between the interphase Young's modulus of 10 GPa and 250 GPa). Similarly the transverse shear modulus and Poisson's ratio are affected severely if the interphase material stiffness is too low. From Fig. 6, it can be observed that the overall material properties of randomly distributed spherical particle composites are

also affected in all directions by interphase material properties especially if the interphase Young's modulus is too low.

3.3. Influence of interphase volume fraction

In this section, the influence of interphase volume fraction on effective material properties is studied by increasing the volume fraction of interphase from 1% to 10% for different interphase Young's moduli as shown in Fig 7.

From Fig. 7, it can be observed that, if the interphase Young's modulus is low, by increasing the volume fraction of the interphase, the effective material properties are decreasing. This effect is more significant in case of transverse shear modulus than in longitudinal shear modulus. But by considering the interphase Young's modulus is equal to Young's modulus of fiber, then the effective material properties are increasing with the increase of interphase volume fraction. Also a decrease of effective material properties with increase of interphase volume fraction can be observed for randomly distributed spherical particle composites with an interphase Young's modulus of 34.48 GPa. Fig. 8 shows the variation of effective material properties with increase of interphase volume fraction for randomly distributed spherical particle composites.

In general, in case of uni-directional transversely isotropic composites, the material properties along transverse direction are much influenced by the interphase material parameters like, stiffness and thickness of interphase, than the material properties along longitudinal direction. For randomly distributed spherical particle composites, the effective material properties are sensitive to interphase material parameters in all directions.

4. Conclusions

The effective material properties of three phase composites having regular fiber distribution like square and hexagonal arrangement are evaluated for different volume fractions and results are compared with analytical asymptotic homogenization method. The effects of interphase volume fraction and their material stiffness on the overall behavior of transversely randomly distributed fiber composites and randomly distributed spherical particle composites are studied. From these studies it is observed that, if the interphase material is not stiff enough to transmit the load between the phases, the resulting overall material properties are significantly affected especially across the transverse direction for transversely randomly distributed uni-directional fiber composites and for isotropic randomly distributed spherical particle composites. So it is necessary to choose appropriate materials at the interfaces to get an efficient load transfer between the phases.

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References

- [1] Berger H, Kari S, Gabbert U, Rodriguez-Ramos R, Guinovart-Diaz R, Otero JA, Bravo-Castillero J. An analytical and numerical approach for calculating effective material coefficients of piezoelectric fiber composites. *Int J Solids Struct* 2005;42:5692-5714.

- [2] Berger H, Kari S, Gabbert U, Rodriguez-Ramos R, Guinovart-Diaz R, Otero JA, Bravo-Castillero J. Unit cell models of piezoelectric fiber composites for numerical and analytical calculation of effective properties. *J Smart Mater Stru* 2006;15:451-458.
- [3] Böhm HJ, Eckschlager A, Han W. Multi-inclusion unit cell models for metal matrix composites with randomly oriented discontinuous reinforcements. *Comput Mater Sci* 2002;25:42-53.
- [4] Segurado J, Llorca J. A numerical approximation to the elastic properties of sphere-reinforced composites. *J Mech Phys Solids* 2002;50:2107-2121.
- [5] Gusev AA. Representative volume element size for elastic composites: a numerical study. *J Mech Phys Solids* 1997;45:1449-1459.
- [6] Gusev AA, Hine PJ, Ward IM. Fiber packing and elastic properties of transversely random unidirectional glass/epoxy composite. *Comp Sci Tech* 2000;60:535-541.
- [7] Hine PJ, Lusti HR, Gusev AA. Numerical simulation of the effects of volume fraction, aspect ratio and fibre length distribution on the elastic and thermoelastic properties of short fibre composites. *Comp Sci Tech* 2002;62:1445-1453.
- [8] Guinovart DR, Castillero BJ, Rodriguez RR, Sabina JF. Closed-form expressions for the effective coefficients of a fiber-reinforced composite with transversely isotropic constituents- I Elastic and hexagonal symmetry. *J Mech Phys Solids* 2001;49:1445-1462.
- [9] Pagano NJ, Tandon GP. Elastic response of multidirectional coated fiber composites. *Comp Sci Tech* 1988;31:273-293.
- [10] Pagano NJ, Tandon GP. Thermo-elastic model for multidirectional coated-fiber composites: Traction formulation. *Comp Sci Tech* 1990;38:247-269.
- [11] Dasgupta A, Bhandarkar SM. A generalized self-consistent Mori-Tanaka scheme for fiber-composites with multiple interphases. *Mech Mater* 1994;29:1141-1157.

- [12] Yeh JR. The effect of interphase on the transverse properties of composites. *Int J Solid Stress* 1992;29:2493-2502.
- [13] Lagache M, Agbossou A, Pastor J. Role of interphase on elastic behavior of composite materials: Theoretical and experimental analysis. *J Compos Mater* 1994;28:1141-1157.
- [14] Liu YJ, Xu N, Luo JF. Modeling of interphases in fiber-reinforced composites under transverse loading using boundary element method. *J Appl Mech* 2000;67:41
- [15] Guinovart DR, Rodriguez RR, Castellero BJ, Sabina JF, Maugin GA. Closed-form thermoelastic moduli of a periodic three phase fiber reinforced composite. *J Therm Stresses* 2005;28:1067-1093.
- [16] Kari S, Berger H, Rodriguez RR., Gabbert U. Computational evaluation of effective material properties of composites reinforced by randomly distributed spherical particles. *Compos Struct* 2005;71:397-400.
- [17] Wang JS. Random sequential adsorption, series expansion and Monte Carlo simulation. *Physica A* 1998;254:179-184.
- [18] Benveniste Y, Dvorak GJ, Chen T. Stress fields in composites with coated inclusions. *Mech Mater* 1989;7:305-317.
- [19] Guinovart-Díaz R, Rodríguez-Ramos R, Bravo-Castillero J, Sabina FJ. Modeling of three-phase fibrous composite using the asymptotic homogenization method. *Mech Adv Mater Struc* 2003;10(4):319-333.
- [20] Guinovart-Díaz R, Rodríguez Ramos R, Bravo Castillero J, Sabina FJ, Maugin GA. A recursive asymptotic homogenization scheme for multi-phase fibrous elastic composites. *Mech Mater* 2005;37:1119–1131.

Figure Captions

Fig. 1. FE models of RVEs for three phase regular arrangement of fiber composites. (a) Square arrangement and (b) Hexagonal arrangement.

Fig. 2. Geometry and FE modelling of RVE of three phase transversely randomly distributed fiber composite. (a) RVE model.(b) Only interphase volumes. (c) FE model of RVE

Fig. 3. Geometry and FE modelling of RVE of three phase randomly distributed spherical particle composite. (a) RVE model. (b) Only interphase volumes. (c) FE model of RVE.

Fig. 4. Variation of effective material properties with change in volume fraction for three phase composites and comparison between analytical homogenization method (AHM) and numerical (FEM) results as well as between square (SQU) and hexagonal (HEX) arrangement.

Fig. 5. Variation of effective material properties with increase of interphase stiffness for transversely randomly distributed fiber composites.

Fig. 6. Variation of effective material properties with increase of interphase stiffness for randomly distributed spherical particle composites.

Fig. 7. Variation of effective material properties with change in volume fraction of interphase.

Fig. 8. Variation of effective material properties with increase of interphase volume fraction.

Table 1
Material properties used to analyze the three phase composites

Material	Young's modulus (GPa)	Poisson's ratio
Matrix (Nickel)	214	0.31
Fiber/particle (Tungsten)	345	0.28
Interphase (Carbon coating)	34.48	0.20

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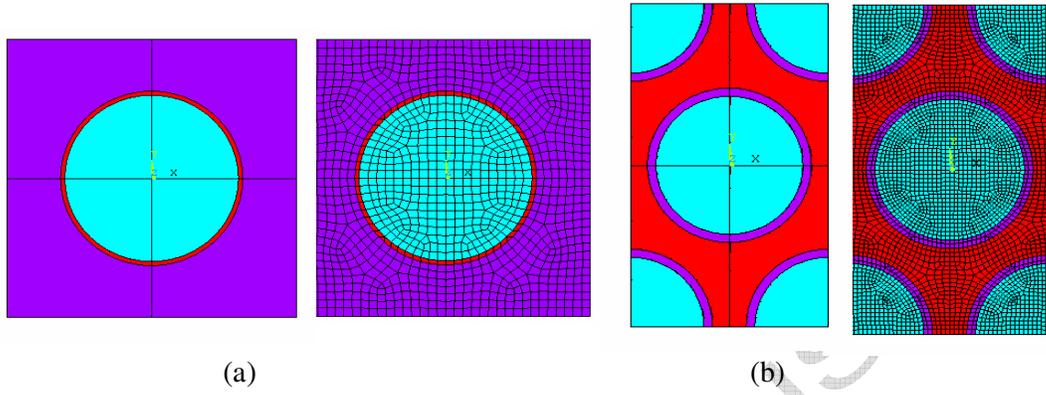


Fig. 1

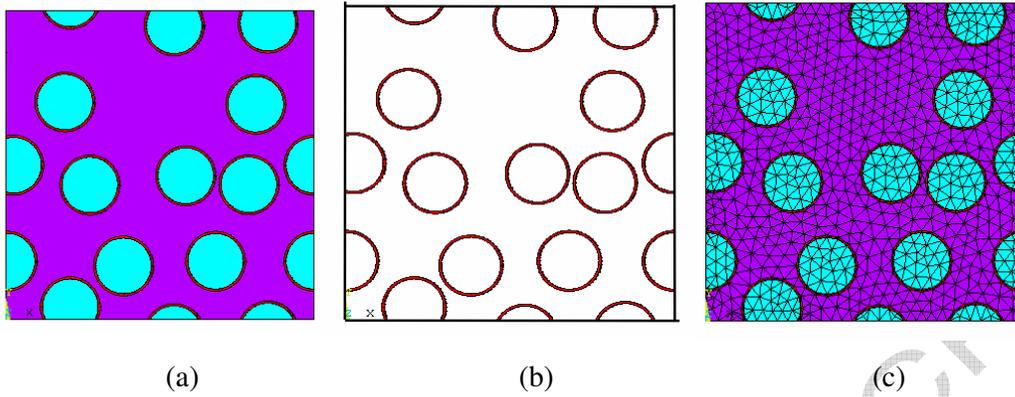


Fig. 2

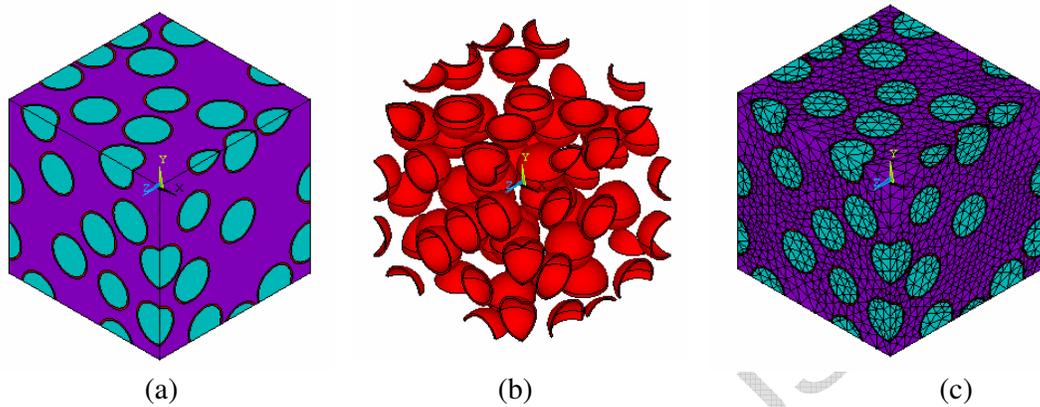


Fig. 3

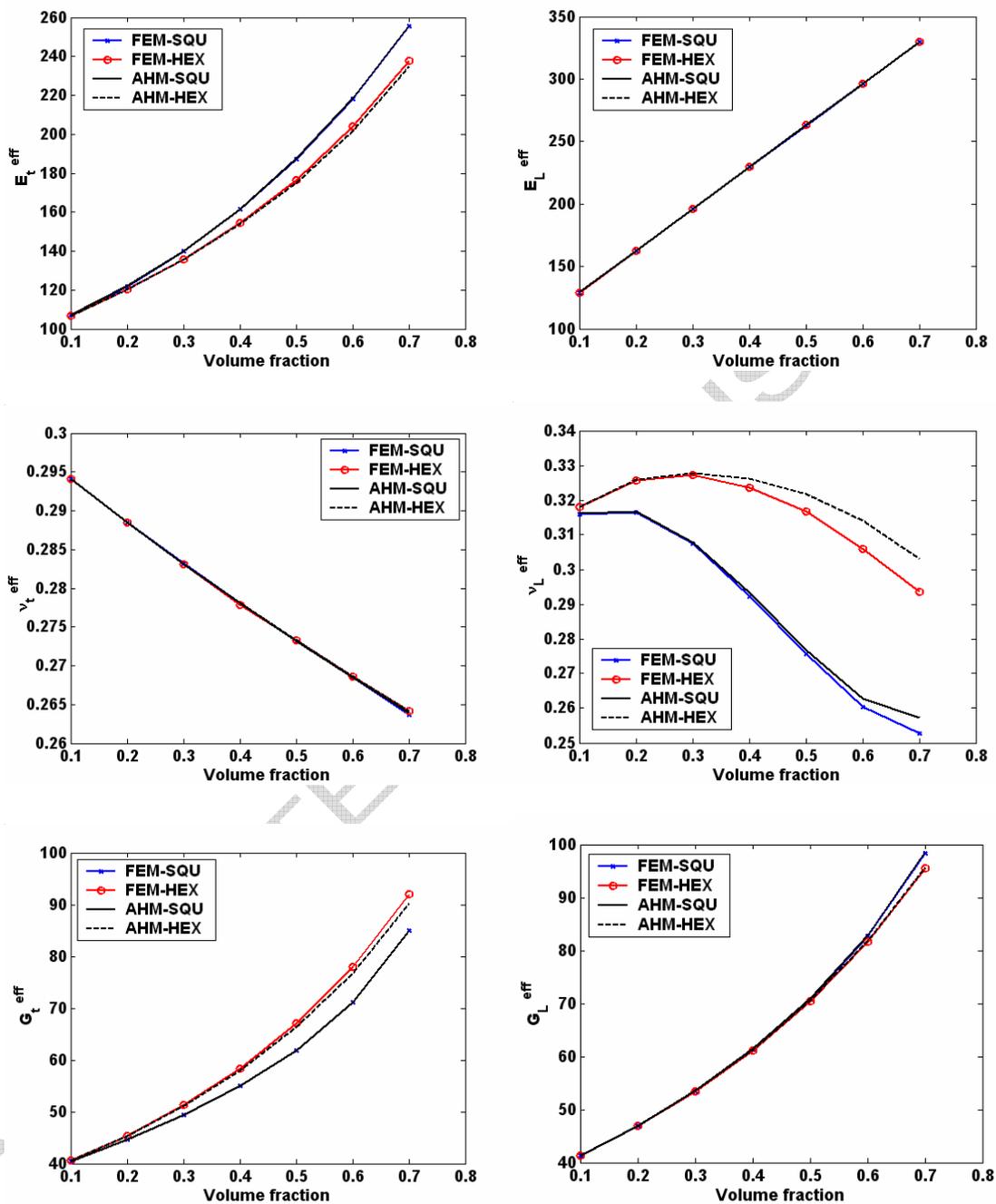


Fig. 4

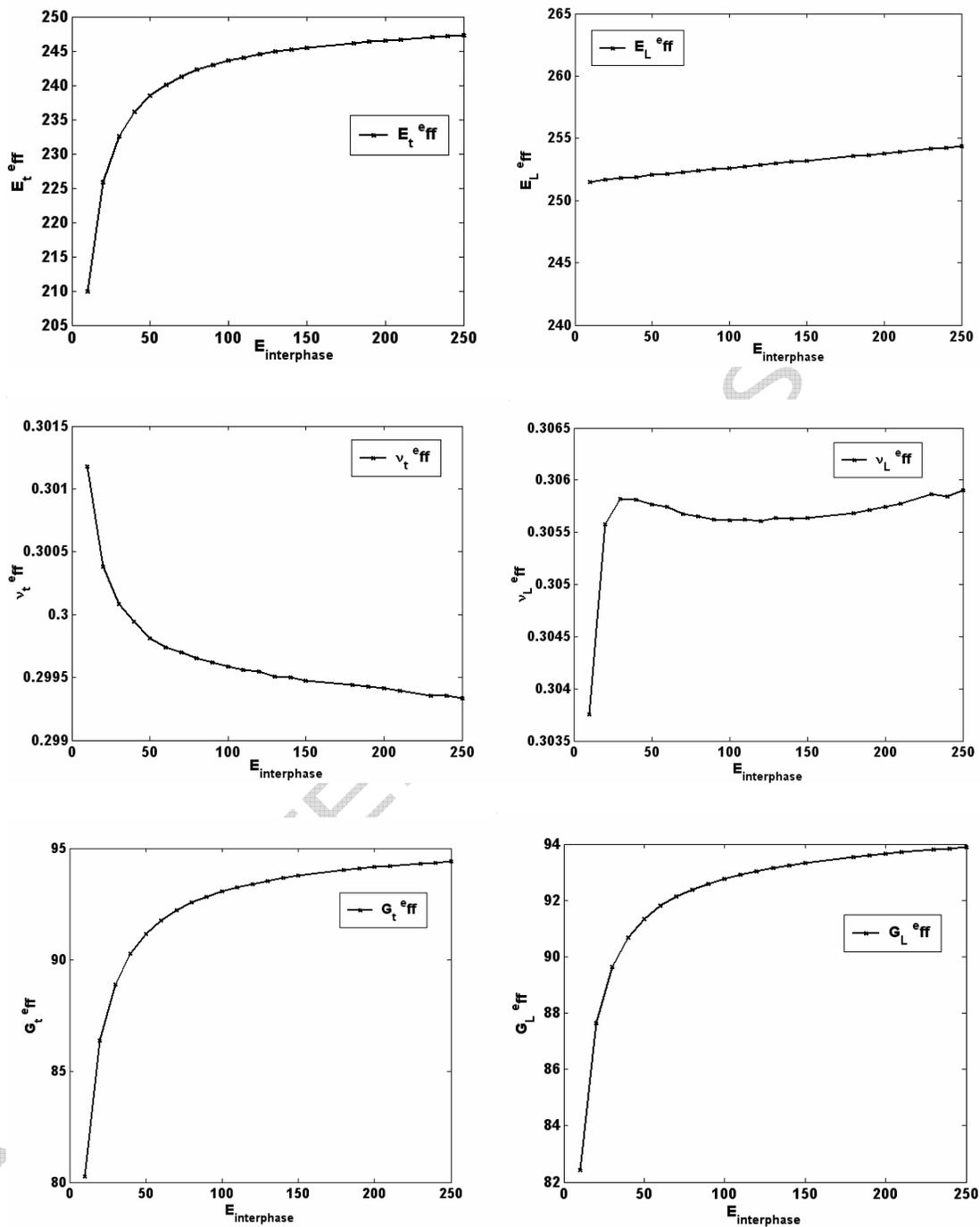


Fig. 5

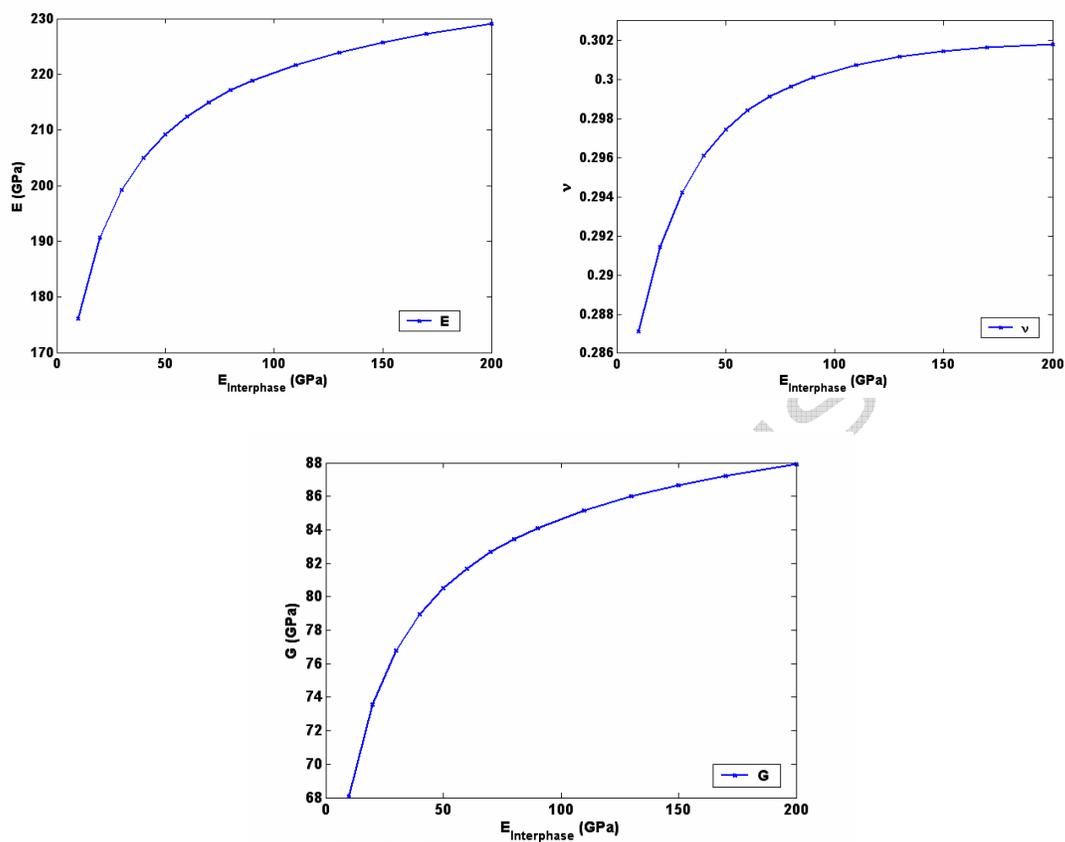


Fig. 6

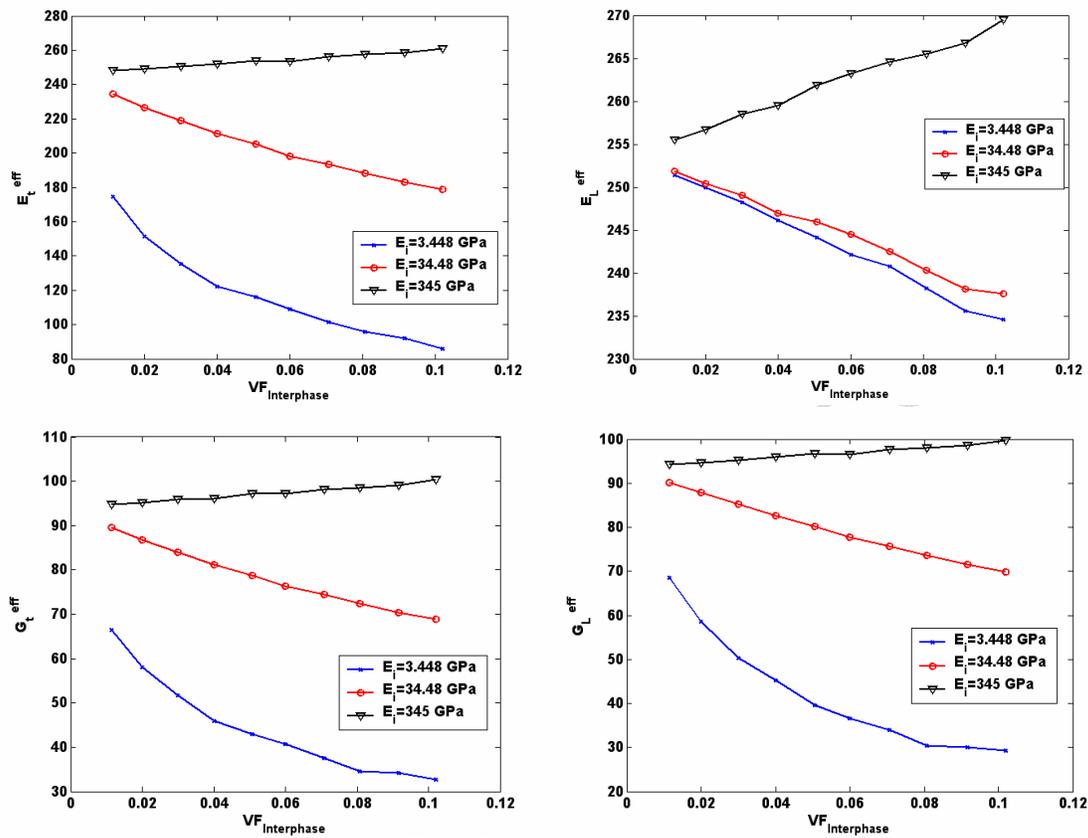


Fig. 7

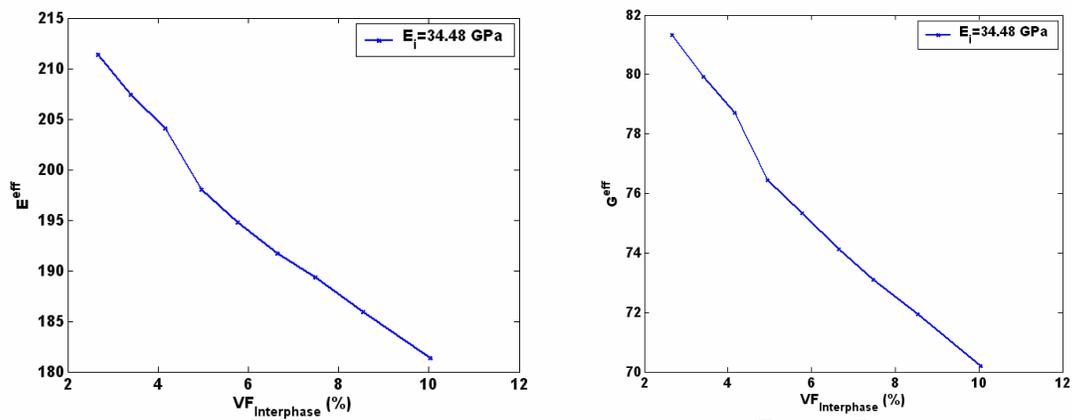


Fig. 8