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EFFECT OF RVE SIZE ON MAXIMUM VOLUME FRACTION AND HOMOGENIZED COEFFICIENT IN STEEL FIBRE REINFORCED CONCRETE

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Abstract. Tremendous developments have seen in science and technology for heterogeneous materials from last few decades. In the context of composites, the microstructure typically consists of particulate or fibrous inclusions and pores, known as heterogeneities. The aim of this work is to do micromechanical analysis of heterogeneous material, its modeling and to determine the effect of RVE size on maximum volume fraction and homogenized coefficient in steel fiber reinforced concrete.

Index Terms: **Heterogeneous materials, finite element mesh, inclusions, steel fibre reinforced concrete, RVE.**

1. INTRODUCTION

Heterogeneous materials have physical properties that fluctuate all through their microstructures [Temizer, (2012)]. The materials termed as heterogeneous materials are alloy systems containing precipitates and pores, polymers, ceramic or metal-matrix composite materials containing distributed fibers, whiskers or particulates in the matrix. A number of studies are reported on the study of these heterogeneous materials [Ghosh, et al (1995)]. The basic objective of the theories proposed for the heterogeneous materials is the prediction of effective or average macrosopic properties incorporating the effect of relative composition and/or distribution of the individual particle or phases and its properties.

Various computational methods utilize the homogenization hypothesis for reflecting the effect of material microstructure on macroscopic behavior. These methods are predominantly based on asymptotic analyses with assumptions on periodic repetition of microstructures. The distribution of shapes, sizes and the spatial coordinates of the secondary phase have a profound influence on the mechanical behavior of the overall structure and should be considered in their analysis [Ghosh and Mukhopadhyay (1993)]. Homogenization is the determination of the properties of the homogeneous material that approximates the behavior of the original heterogeneous material. These properties can also be termed as effective, apparent or macroscopic properties. To predict the macroscale properties of the heterogeneous materials, one of the most widely used methods is the concept of 'Representative Volume Element (RVE) method [Zhang et al. (2008)]. A finite sized sample from the heterogeneous materials which characterizes its macroscopic behavior is called representative volume element (RVE), and the homogenization method rely on the identification of a representative volume element. A general requirement for a sample to qualify as an RVE is that the dimension of the heterogeneities (d) be smaller than the dimension of the RVE (L): d << L. The sample would be expected to resemble a homogeneous material macroscopically if $d/L \rightarrow 0$. A microscopically heterogeneous macrostructure requires that the RVE size (L) be much smaller than the dimension of the macrostructure (D) for the applicability of homogenization theory i.e. L << D. After identification of RVE, the RVE is subjected to certain boundary conditions for the specified loadings.

A number of models are proposed in literature which is found to be suitable for such representation of the heterogeneities in the materials. Out of this model, there are few engineering based methods which show a good agreement with other empirical methods and the experimental results. The homogenization theory is one of the most prominent mathematical models representing the averaged global properties of the heterogeneous materials. Hashin and Shtrikman (1963) derive the bounds for the effective elastic moduli of multiphase materials, with the aid of some variational principles in elasticity. A self-consistent mechanics of composite materials was developed by Hill (1965). Over the past few years various models are developed for the analysis of heterogeneous materials. One of the model is micromechanics based model which is found to be suitable for the prediction of homogenized elastic mechanical/thermal properties of the materials. This work is preliminary work for the prediction of elastic material properties using quadrilateral finite elements.

2. GOVERNING EQUATION

Some important formulation used for the modeling the finite element mesh are presented. Linear momentum balance equation.

$$div(\sigma)+\rho b=\rho\ddot{u} \qquad (2.1)$$

Subjected to boundary conditions: $u=\bar{u}$ On ∂R^u, $t=\sigma n=\bar{t}$ on ∂R^t. The equation in weighted integral form

$$\int_{\Re_0}\omega\left(div(\sigma)+\rho b-\rho\ddot{u}\right)dV+\int_{\partial\Re_0^p}\omega\left(\bar{t}-t\right)dA=0 \qquad (2.2)$$

If ω is differentiable than, this equation is converted into the weak form as:

$$-\int_{\Re_0}\frac{\partial\omega}{\partial X}\sigma dV+\int_{\Re_0}\omega\left(\rho b-\rho\ddot{u}\right)dV+\int_{\partial\Re_0^p}\omega\bar{t}\,dA=0 \qquad (2.3)$$

Using the iso-parametric linear quadrilateral elements having four nodes with shape functions given as:

$$\phi^1=(1-\xi)(1-\eta)/4$$
$$\phi^2=(1+\xi)(1-\eta)/4$$
$$\phi^3=(1+\xi)(1+\eta)/4$$
$$\phi^4=(1-\xi)(1+\eta)/4$$

(2.4)

the Eq. (2.3) is converted into the following form of the finite element equation

$$[K]\{u\}=\{f\} \qquad (2.5)$$

3. RESULTS AND DISCUSSION

The results of the analysis are obtained for steel fiber reinforced composite material. The young's modulus and Poisson ratio values for both steel and concrete are taken from literature Ren and Li (2013). Effect of RVE size on maximum volume fraction and homogenized coefficient is tested. Increasingly larger sample sizes may be generated randomly by packing more and more particles in the sample volume. The edge length of the RVE is increased to accommodate more and more particles in the sample volume as depicted in Figure 3.1. The RVE size increases and accommodates more and more number of particles. In this example the size of the RVE is increased and accommodates 4, 6, 64, 256 and 350 numbers of particles. The results obtained will show the saturation behaviour in the homogenized coefficients as the RVE size increases. The microstructures obtained by increasing the RVE size are represented in Figure 3.1. The theoretical maximum volume fraction that can be reached by the packing configuration is when all the particles lie within the box. This theoretical maximum volume fraction is set to 0.4 and is used to compute the size of the packing volume. Further in this case the particles are not allowed to lie across the boundaries. The results are tabulated in table 3.1.

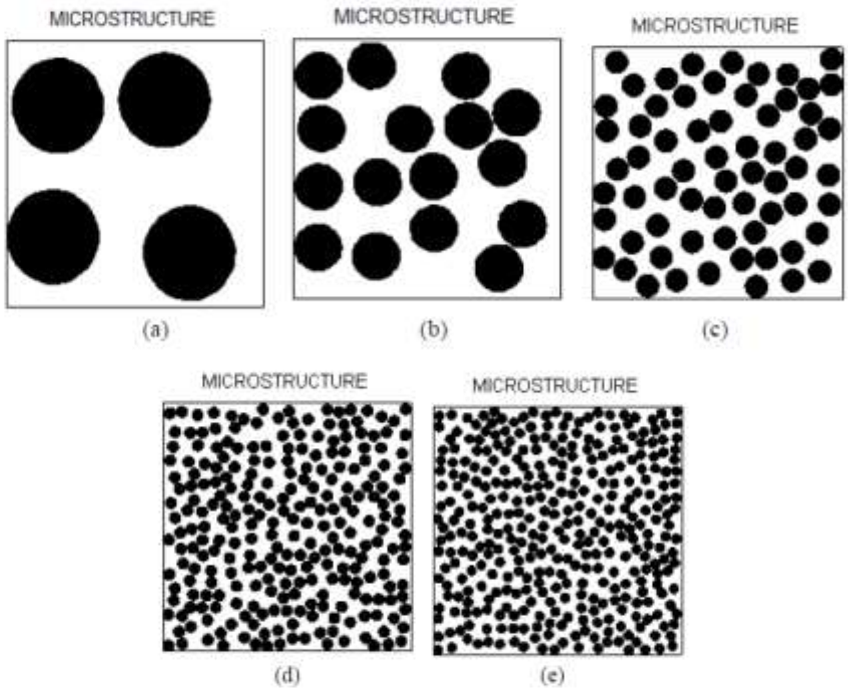

Figure 3.1. Successive enlargement of the RVE (a) 4 particles, (b) 16 particles, (c) 64 particles, (d) 256 particles and (e) 350 particles.

Table 3.1 Effect of RVE size on maximum volume fraction and homogenized coefficient when particles are not allowed to lie across the boundaries

RVE size in terms of no. of particles accommodated	Numerical Volume fraction	Homogenized coefficient (GPa)
4	0.4055	48.298
16	0.4024	46.212
64	0.4010	46.082
256	0.3999	45.588
350	0.3999	45.527

The resulting microstructures are shown in Figure 3.2. This concept of increasing sample size or RVE size is another fundamental concept in micromechanics because the responses of the samples typically exhibit a convergence behaviour or saturation behaviour with increasing sample sizes. Now if the particles are allowed to lie across the boundaries, the actual volume fraction is always less than theoretical maximum volume fraction. However as the sample size increases the effect of these cross-boundary particles diminish, and one approaches to theoretical maximum. The results obtained with these configurations are tabulated in Table 3.2.

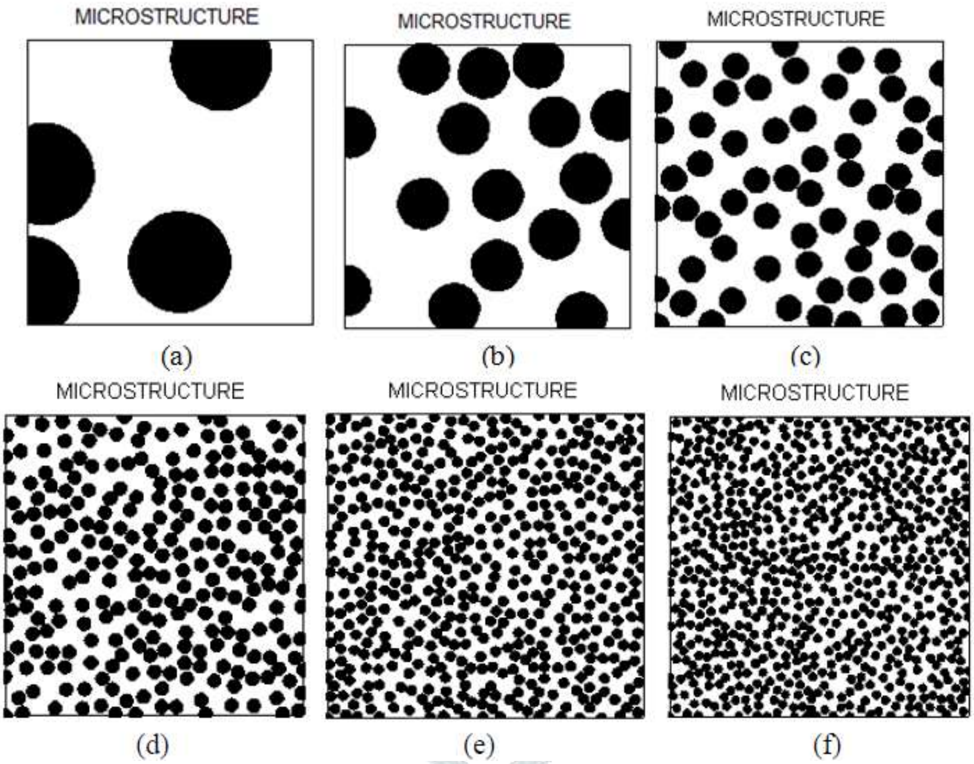

Figure 3.2 Successive enlargement of the RVE with particles allowed to lie across the boundaries (a) 4 particles, (b) 16 particles, (c) 64 particles, (d) 256 particles, (e) 500 particles and (f) 700 particles.

Table 3.2. Effect of RVE size on maximum volume fraction and Homogenized coefficient when particles are allowed across the boundaries

RVE size in terms of no. of particles accommodated	Numerical Volume fraction	Homogenized coefficient (GPa)
4	0.2839	39.315
16	0.3535	42.973
64	0.3629	43.144
256	0.3846	44.354
500	0.389	44.491
700	0.3918	44.702

It is observed that as the RVE size increases the volume fraction converges to 0.40 i.e., to the theoretical volume fraction. This is the effect of increasing the sample size, where the convergence behaviour is observed for increasing the sample size. This suggests that the properties associated with the microstructures should be extracted from samples that are very large with respect to the dimension of the underlying micro-structural constituents. It means there is a saturation behaviour in the properties of the microstructure as we keep on increasing the RVE size.

4. CONCLUSION

In the present work, micromechanical model is used for the analysis of heterogeneous materials using finite element method. The analytical and computational effort required for the treatment of problems involving heterogeneous materials is greatly reduced by this homogenization method. The results are in close agreement with the respective experimental/analytical observations available in the literature. The analysis is done for steel fiber reinforced concrete composite. The effect of RVE size on maximum volume fraction and homogenized coefficient in steel fibre reinforced concrete is investigated.

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