Validation of VAMUCH for Particle Reinforced Composites

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Due to special arrangements of constituents of particle reinforced composites, 3D UCs are required to accurately model the microstructures. We are going to use VAMUCH to analyze several particle reinforced composites to validate its 3D capability. In previous section, we have shown that the prediction of MOC and GMC is not accurate for fiber reinforced composites and one could infer that they can not provide very accurate prediction for particle reinforced composites either. Although HFGMC and G-F provide excellent prediction for fiber reinforced composites, we could not find 3D examples analyzed by these two approaches. It is easy to verify that Sun and Vaidya's FEM approach is equally applicable to particle reinforced composites. Two other approaches we believe will provide critical evaluations for VAMUCH are the 3D version of ECM[1] and an approach based on mathematical homogenization theory and finite element method[2] (later we follow Ref. 1 to name this approach as HFE).

The first example is to predict the effective Young's modulus for a glass/epoxy composite. The UC of this composite is composed of glass spheres embedded in a triply periodic cubic array. Both constituents are isotropic with Young's modulus $E = 76.00$ GPa and Poisson's ratio $\nu = 0.23$ for glass, and Young's modulus $E = 3.01$ GPa and Poisson's ratio $\nu = 0.394$ for epoxy.[a] We plot the change of effective Young's modulus with respect to the inclusion volume fraction in Figure 1. In comparison to HFE, VAMUCH outperforms ECM (both 3rd order and 5th order). We are surprised to find out that it is counter intuitive that the predictions of 5th order ECM are worse than 3rd order ECM for this particular case. It is worthy to point out that the data of HFE and ECM are provided independently by the author of Ref. 1, where ECM data are calculated and HFE data are directly picked out from the plots in Ref. 2.

The second example is a Al_2O_3/Al composite with cubic inclusions in a cubic array. Both constituents are isotropic with Young's $E = 350.00$ GPa and Poisson's ratio $\nu = 0.30$ for Aluminum oxide, and Young's modulus $E = 70.00$ GPa and Poisson's ratio $\nu = 0.30$ for Aluminum. The effective Young's modulus and Poisson's ratio are plotted in Figure 2 and Figure 3, respectively. It can be observed that both VAMUCH and 5th order ECM have an excellent agreement with HFE while the predictions of 3rd order ECM are not as accurate.

The last example is a Al_2O_3/Al composite having rectangular parallelepiped inclusions with the ratio between the three dimensions as $a_1 : a_2 : a_3 = 2 : 1 : 2$ where a_i is the dimension of the inclusion along the corresponding y_i direction. The effective material properties of this composite is not isotropic any more. For the sake of saving space, we only plot the effective Young's modulus E_{33} and effective Poisson's ratio ν_{12} as functions of inclusion volume fraction in Figure 4 and Figure 5, respectively. Again VAMUCH and 5th order ECM have excellent agreements with HFE and outperform 3rd order ECM.

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[a] The isotropic assumption is convenient for comparing with available results in the literature. VAMUCH can deal with constituents with full anisotropic with material properties characterized as many as 21 independent constants.

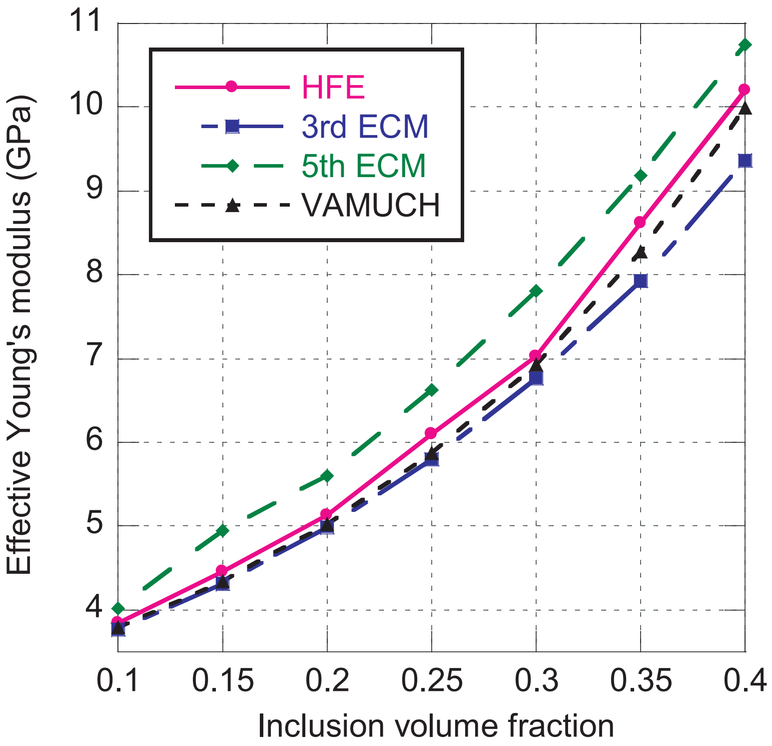

Figure 1. Effective Young's modulus of glass/epoxy composite with spherical inclusions

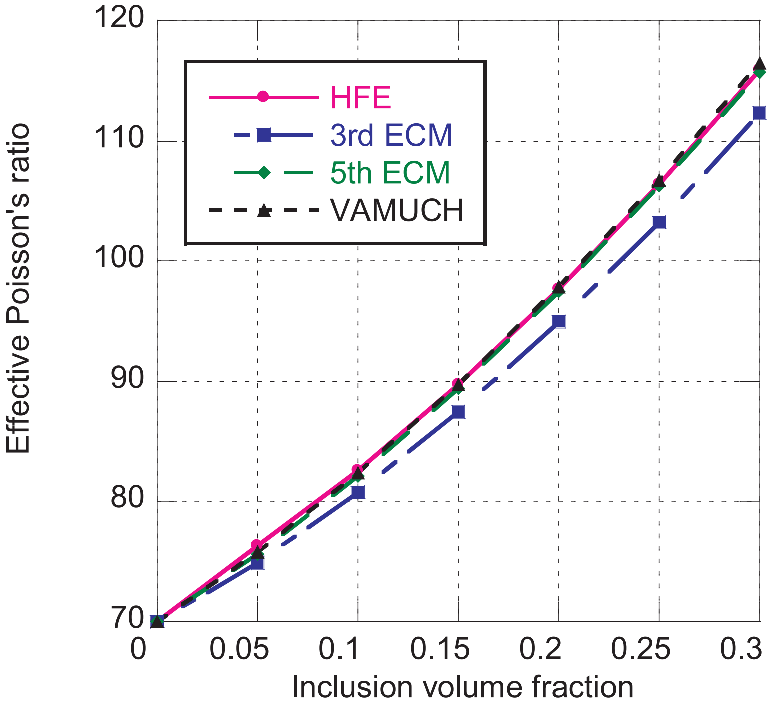

Figure 2. Effective Young's modulus of Al_2O_3/Al composites with cubic inclusions

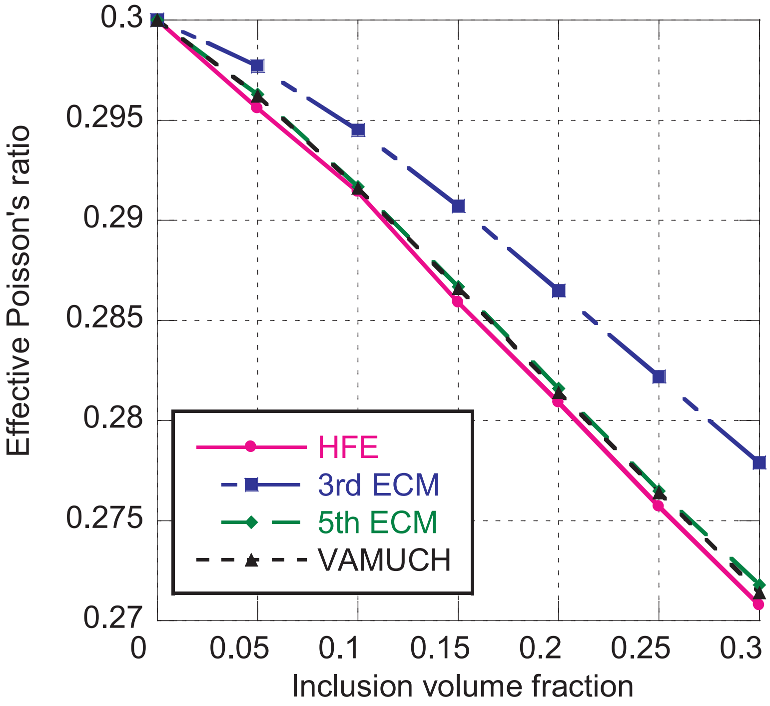

Figure 3. Effective Poisson's ratio of Al_2O_3/Al composites with cubic inclusions

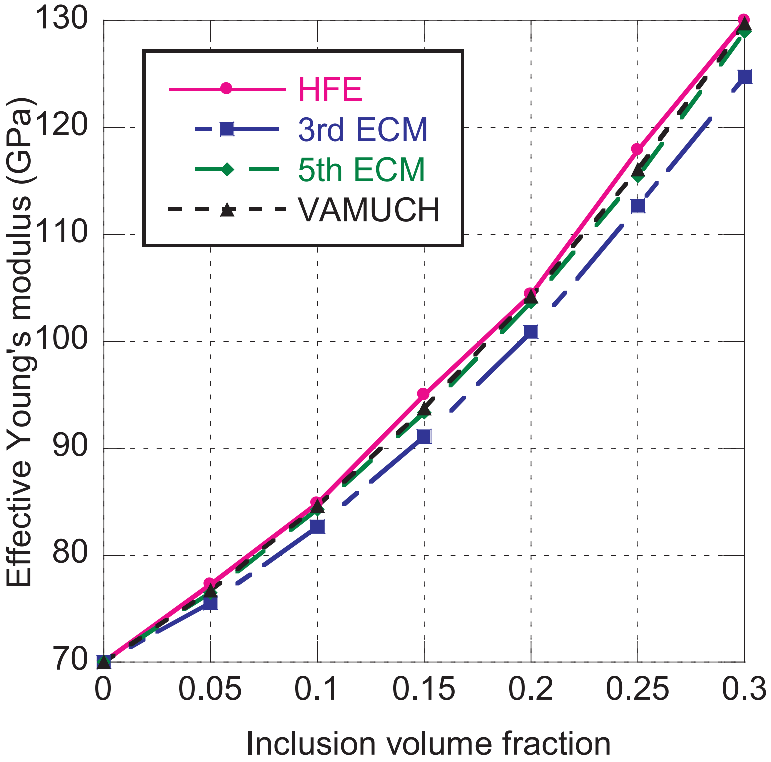

Figure 4. Effective Young's modulus E_{33} of Al_2O_3/Al composites with rectangular parallelepiped inclusions

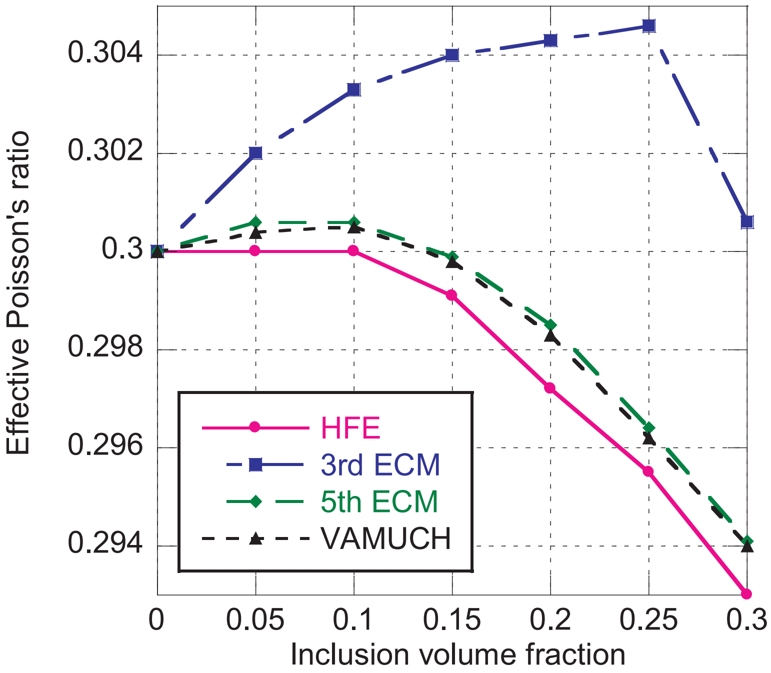

Figure 5. Effective Poisson's ratio ν_{12} of Al_2O_3/Al composites with rectangular parallelepiped inclusions

References

[1] Williams, T. O., "A Three-dimensional, Higher-oder, Elasticity-based Micromechanics Model," *International Journal of Solids and Structures*, Vol. 42, 2005, pp. 971–1007.

[2] Banks-Sills, L., Leiderman, V., and Fang, D., "On the Effect of Particle Shape and Orientation on Elastic Properties of Metal Matrix Composites," *Composites Part B: Engineering*, Vol. 28B, 1997, pp. 465–481.