Modification of Procedure to Estimate Viscosity of Bimodal Alumina/Epoxy Mixtures during a Centrifugal Process

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The coefficient of viscosity η is one of the major parameters to govern the movement of particles in alumina/epoxy mixtures during the centrifugal process. During the centrifugal process, the particle fraction and corresponding values of η at a certain point varies spatiotemporally. In the present contribution, theoretical consideration to explain dependency of η_b of bimodal alumina/epoxy mixtures on particle fractions is conducted. It is found that η_b can be estimated as a function of two η 's obtained for the unimodal mixtures that contain the fine and coarse particles, respectively. A modification about the definition of the coarse particle fraction from the conventional method was successfully introduced, resulting in better approximation of η_b under the conditions of high particle fractions.

Keywords: functionally graded material, alumina/epoxy mixture, viscosity, bimodal system, centrifugal method

1. Introduction

Functionally graded materials (FGMs) are a new class of materials in which the composition and/or the microstructure spatially varies. They have promising potentials in the development of new solid insulation materials for future power apparatus⁽¹⁾⁽²⁾. The authors are using a centrifugal method to fabricate FGM's with large size from alumina-particles/epoxy-resin mixtures⁽³⁾. During the centrifugal process, the particle fraction at a certain location in the mixture spatiotemporally varies from almost zero to several tens percent. Consequently, η in the mixture, which is a function of the particle fraction, varies spatiotemporally.

In this contribution, we proposed a modification of the conventional method (i.e., Farris equation) to obtain better estimation of η for bimodal mixtures with high particle fraction.

2. Materials and Experimental Method

Spherical alumina particles with nominal diameters of 35 μ m and 80 μ m were employed as fine and coarse particles, respectively, and they were mixed with an epoxy resin. Description of both particle property and method of measurement can be seen in our previous papers⁽⁴⁾⁽⁵⁾.

3. Results and Discussions

When the fine and coarse particles by the volume of V_f and V_c , respectively, were mixed with an epoxy resin by the volume of V_e , two kinds of the volume fraction of particles can be defined: one is ratio of the volume of all particles to the volume of the mixture

$\nu_p = (V_f + V_c)/(V_f + V_c + V_e)$, and the other is ratio of the volume of the coarse particles to the volume of all particles $\nu_{coarse} = V_c/(V_f + V_c)$.

3.1 Experimental results Symbols in Fig. 1 show measured values of η_b as a function of ν_c obtained for various ν_p ⁽⁵⁾. ν_p varied between 0 to 45%, and ν_{coarse} varied between 0 to 100% for each ν_p . It is noted that the bimodal mixtures with $\nu_{coarse} = 0\%$ and 100% correspond to the unimodal mixtures with the fine and coarse particles only, respectively.

3.2 Discussions A procedure proposed by Farris⁽⁶⁾ can be applied to approximate η_b of the bimodal mixture from two η_u 's, each of them is corresponding to the unimodal mixture each component contained in the bimodal mixture, and is given by the following expression.

$$\eta_b(\nu_p, \nu_{coarse}) = \eta_0 \cdot \frac{\eta_f(\nu_f)}{\eta_0} \cdot \frac{\eta_c(\nu_c)}{\eta_0} \dots \dots \dots (1)$$

Fig. 1. η_b of bimodal mixtures as a function of ν_{coarse} for various ν_p ; Symbols: Measured, Solid lines: Estimated

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Here, $\eta_f(\nu_f)$ and $\eta_c(\nu_c)$ are η of the unimodal mixtures involving the fine and coarse particles, respectively, and are estimated by using the following Brinkman equation⁽⁷⁾:

$$\eta_i(\nu_i) = \eta_0 / \left(1 - \frac{\nu_i}{\nu_{i,max}}\right)^n \dots\dots\dots (2)$$

where, suffix $i = f$ and c for the fine and coarse particles, respectively, η_0 is the coefficient of viscosity of the epoxy resin, $\nu_{i,max}$ is the maximum packing fraction obtainable for the mixtures under consideration, and n is a constant. In general cases, $n = 2.5$ can be used with reasonable accuracy.

For the bimodal mixture under consideration, dependency of η_b on ν_{coarse} were calculated using Eq. 1 for $\nu_p = 5, 20, 35, 45\%$, and the results are plotted by solid lines in Fig. 1. In this calculation, ν_f and ν_c are calculated by the following equations, respectively:

$$\nu_f = \frac{V_f}{V_e + V_f} \dots\dots\dots (3)$$

$$\nu_c = \frac{V_c}{V_e + V_f + V_c} \dots\dots\dots (4)$$

It is obvious from comparison between the measured and estimated values shown in Fig. 1 that the approximation procedure yields reasonable estimation of η_b for ν_p smaller than 35%, while it underestimates η_b for ν_p larger than 45%.

To improve the accuracy of estimation of η_b for large ν_p , a modification to the definition of the coarse particle fraction given by Eq. 4 was carried out. Dotted lines in Fig. 1 are obtained by applying the same Eq. 1 as the solid lines, except that a new definition of the packing fraction ν'_c of coarse particles given by Eq. 5 is introduced instead.

$$\nu'_c = \frac{V_c}{V_e + V_c} \dots\dots\dots (5)$$

Comparison between the measured and estimated values shown in Fig. 1 indicates that the new method based on Eq. 1 using the new definition of ν'_c given by Eq. 5 gives reasonable estimation of η_b for ν_p larger than 45%.

4. Conclusions

The modification of Farris method proposed in this contribution enables better approximation of η_b of the bimodal mixture for higher packing fraction larger than 45%. The combination of this modification and the original Farris method enables the approximation of the spatiotemporally varying η_b during the centrifugal process.

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