NUMERICAL SIMULATION OF THE CARBONIZATION PROCESS IN THE MANUFACTURING OF CARBON-CARBON COMPOSITES: I. MATERIAL CHARACTERIZATION

Jungin Kim, Khalid Lafdi and Woo Il Lee**

Center for Advanced Friction Studies, Southern Illinois Univ. at Carbondale, Carbondale, IL 62901, USA

** Dept. of Mech. Eng., Seoul Nat'l Univ., 151-742, Seoul, Rep. of Korea*

Introduction

This study focuses on development of a method for numerical simulation of the carbonization for an arbitrary 2-dimensional geometry. To illustrate the methodology, simplification to a homogeneous, single phase, isotropic material is adapted as a beginning. Phenolic foam is adapted as the sample material to serve the purpose. The first part of this study introduces material characterization necessary for the simulation, followed by detail numerical analysis and discussion in the second part.

Experimental

Weight Loss Characteristics

TGA experiments were performed with Universal TA Instruments at CytecFiberite. The typical weight loss curve is plotted in Fig.1. Degree of conversion (α) was modeled with two different mechanisms, using methodology proposed by Nam and Seferis [1].

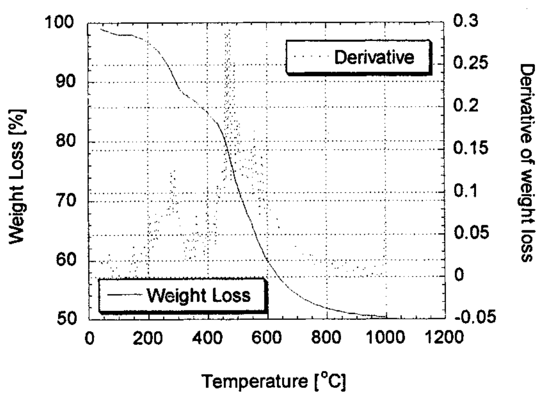


Fig.1. Weight loss curve of phenolic foam from TGA

Gas Permeability

An experimental apparatus was built to measure the gas permeability of the foam. The permeability values are plotted versus sample porosity in Fig.2. Since the classic Kozeny-Carman equation is not valid in this case due to high porosity, a linear relation was assumed between porosity and permeability.

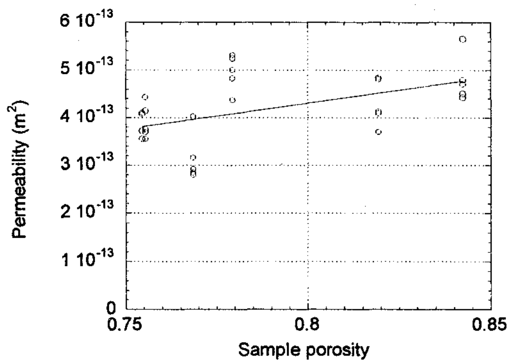


Fig.2. Results of permeability measurements

Density and Porosity

The density and porosity of the foam was measured using a pyconometer for several samples with different degrees of carbonization. The results are given in Fig.3, and were assumed as functions of α.

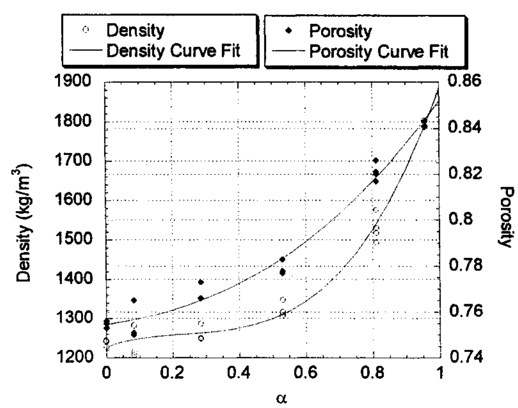
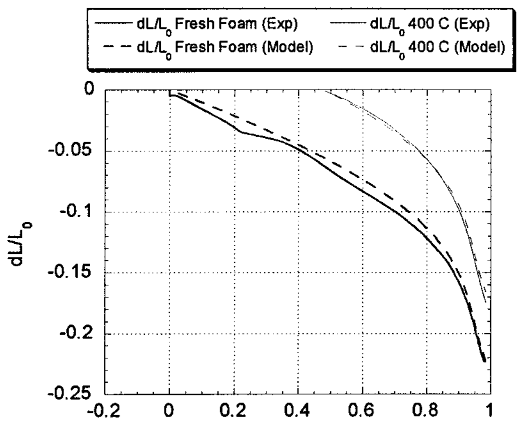


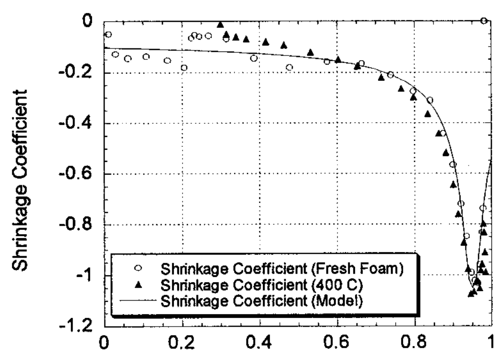
Fig.3. Density and porosity plotted versus α

Shrinkage Modeling

Shrinkage is assumed as a function of α, and the shrinkage of fresh foam and the sample carbonized to 400 °C are plotted against α in Fig.4 (a). The coefficient of shrinkage shows the same trend with α for both cases, as can be seen in Fig.4 (b). The curve fit model for the coefficient of shrinkage is used to evaluate actual shrinkage, as plotted in Fig.4 (a), which shows close agreements with experimental data.



(a) Amount of shrinkage vs. α



(b) Shrinkage coefficient vs. α

Fig.4. Shrinkage characteristics plotted versus α

Thermal Expansion

Thermal expansion of carbonized foam was measured. Expansion coefficient of phenolic foam was substituted with the data given by Mottram et al [2].

Heat capacity

DSC was performed at CytecFiberite to measure the heat capacity of carbonized foam for the temperature range from 30 to 400 °C. The data showed an asymptotic behavior to a linear function of temperature with slight deviations at lower temperatures. The data by Mottram et al. were used as fresh foam properties [3].

Thermal conductivity

The thermal diffusivity of carbonized foam was measured using Flash Diffusivity Technique. The measurement was performed for the temperature range of 12 to 427 °C since errors were magnified at higher temperatures. Measurements for phenolic resin given by Mottram et al. [3] were used as the thermal conductivity of fresh foam.

Elastic Modulus

Tensile tests using an Instron machine were performed on fresh and carbonized foam. An equation by Gibson et al was used to predict the solid modulus and to relate modulus and porosity [4].

Properties of Volatile Gases during Carbonization

The ratio of gas components in the volatile gas was modeled as a function of α using data given by Serio et al [5]. The properties of each gas components are gathered from various references and were mixed using the weight ratio and molecular weight.

Conclusions

Phenolic foam is introduced as an ideal isotropic, homogeneous material and material properties are modeled in appropriate functional forms to serve the purpose of numerical simulation.

References

[1] Nam J, Seferis JC. Generalized Composite Degradation Kinetics for Polymeric Systems Under Isothermal and Nonisothermal Conditions. J Polym Sci: Part B 1992;30:455-463.

[2] Mottram JT, Geary B, Taylor R. Thermal Expansion of Phenolic Resin and Phenolic-Fibre Composites. J Mater Sci 1992:27:5015-5026

[3] Mottram JT, Taylor R. Thermal Conductivity of Fibre-Phenolic Resin Composites. Part I: Thermal Diffusivity Measurements. Comp Sci Tech 1987: 29:189-210

[4] Gibson LJ, Ashby MF. Cellular Solids: Structure & Properties. Pergamon Press.UK.1988

[5] Serio MA, Charpenay S, Bassilakis R, Solomon PR. Pyrolysis of Phenol-Formaldehyde Resin: Experiments and Modeling. ACS Div Fuel Chem 1991:36(2):664-