A Model for Predicting the Thermal Conductivities of Bentonite-Bonded Molding Sands at High Temperatures

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The effective thermal conductivities of bonded molding sands vary with the dry density, binder content, initial moisture content, temperature as well as the types of sand and binder clay. In this study, a theoretical model for predicting the effective thermal conductivities of bentonite-bonded molding sands was developed. The results of measurement of the effective thermal conductivities of molding sands at temperatures up to 750°C were used. The binder thermal conductivities of both western bentonite and southern bentonite were suggested as a function of dry density, binder content and initial moisture content and were assumed not to vary with temperature. The radiation model proposed by Vortmeyer was also incorporated. The model developed in this study was proved to predict well the effects of binder content, initial moisture content, dry density and temperature.

Key Words: Thermal Conductivity, Molding Sand, Bentonite Clay Binder, Theoretical Model, High Temperature.

Nomenclature

\[ a+2s \] : Constants in Eq. (4) \([m^{-1}]\]
\[ B \] : Binder content by weight
\[ k_{be} \] : Effective thermal conductivity of binder \([W/mK]\)
\[ k_c \] : Thermal conductivity due to conduction \([W/mK]\)
\[ k_e \] : Effective thermal conductivity of molding sand \([W/mK]\)
\[ k_r \] : Thermal conductivity of saturating fluid \([W/mK]\)
\[ k_{rr} \] : Thermal conductivity due to intergranular radiation \([W/mK]\)
\[ k_a \] : Thermal conductivity of sand grain \([W/mK]\)
\[ k_{se} \] : Effective thermal conductivity of sand grain \([W/mK]\)
\[ k_{sr} \] : Thermal conductivity due to transgranular radiation \([W/mK]\)

\[ M \] : Initial moisture content by weight
\[ \gamma \] : Variable in the model of Fig. 1
\[ \gamma_b \] : Variable in the model of Fig. 1
\[ R \] : Characteristic radius in the model of Fig. 1
\[ x \] : Coordinate
\[ y \] : Coordinate
\[ \rho_d \] : Dry density \([g/cm^3]\)
\[ \phi_b \] : Volume fraction of binder
\[ \phi_f \] : Volume fraction of fluid in the pore space
\[ \phi_s \] : Volume fraction of sand particles

1. Introduction

The earliest experimental investigation of the thermal properties of molding sands was carried out by Briggs and Gezelius (1933). Atterton (1953) investigated the influences of several parameters on the effective thermal conductivity of bonded sand molds.

Whitmore and Ingerson (1960) proposed an expression to predict the effective thermal conductivity of clay-bonded silica molding sands. Kubo et al. (1982) developed a heat transfer model
modified from the Kunii's theory for a packed bed. A model equation was suggested for the prediction of the effective thermal conductivity of sand molds at temperatures below 600°C. The predictions show good agreement with the measured thermal conductivities of dry molding sands bonded with western bentonite and of resin-bonded molding sands. Kubo et al. (1983) measured the thermal properties of dry and green molds of silica, olivine, zircon and chromite sands by the pouring method. The effective thermal conductivity as a function of temperature was obtained from the pouring method using a parameter optimization technique.

Hartley and Patterson (1983) investigated the effects of temperature, initial moisture content, and binder content on the effective thermal conductivity of bentonite-bonded silica and zircon sand molds. From the measurements at temperatures up to 750°C, they presented the normalized functions to account for the effects of temperature, initial moisture contents and binder content.

Park and Hartley (1992) developed a theoretical model for predicting the effective thermal conductivities of unbonded sands and sands bonded with liquid binders. This model was not applied to clay-bonded molding sands because of the different characteristics of clay binder. The difference between bentonite clay binders and liquid binders can be attributed to the complex bonding mechanism of bentonite clay in molding sands. Bentonite clay forms a film on the surface of sand particles and a porous bond at the contact points between the sand particles. The effectiveness of bentonite clay is much reduced to enhance the heat transfer through the bentonite bond between the sand particles.

The bonding structure of bentonite clay in molding sands has been investigated using a scanning electronic microscope. But no detailed analysis is available to distinguish the influence of the bentonite binder on the effective thermal conductivities of bentonite-bonded molding sands.

The effect of bentonite clay binder on the effective thermal conductivities of molding sands is included in the model for liquid binders by assuming that all of the bentonite clay coalesces at the contact points between the sand particles just as liquid binders do in the unsaturated sands. With this assumption, the effective thermal conductivity of dried bentonite bond in the molding sands could be calculated from the model using the measured effective thermal conductivity of bonded molding sands reported by Park and Hartley (1996). Thus, the model developed by Park and Hartley (1992) can be used for the bentonite-bonded molding sands also and is shown in Fig. 1.

The model is composed of three phases. The shape of sand assumed is a cylinder with a side end having spherical surface. The binder was assumed to coalesce at the contact point between the sand particles. The effective thermal conductivity of western bentonite binder determined as described above could be expressed as a function of apparent density of the bonded sand and the ratio of initial moisture content to the binder content by weight. Least-square curve fits of the calculated effective thermal conductivities of unbonded sands and sands bonded with liquid binders. This model was not applied to clay-bonded molding sands because of the different characteristics of clay binder. The difference between bentonite clay binders and liquid binders can be attributed to the complex bonding mechanism of bentonite clay in molding sands. Bentonite clay forms a film on the surface of sand particles and a porous bond at the contact points between the sand particles. The effectiveness of bentonite clay is much reduced to enhance the heat transfer through the bentonite bond between the sand particles.

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In this study, a theoretical model for predicting the effective thermal conductivities of bonded molding sands at temperatures up to 750°C was developed by modifying the model developed by Park and Hartley (1992). Also, the predicted results from the model were compared with the measured results reported by Park and Hartley (1996). The model predictions were proved to be reasonably accurate and thus it could be used to examine the effects of the dry density, binder content, initial moisture content and temperature when either western bentonite or southern bentonite was used as binder.

2. Model Development for Bonded Molding Sands

A model was developed by Park and Hartley (1992) to predict the effective thermal conductivities of unbonded sands and sands bonded with liquid binders. This model was not applied to clay-bonded molding sands because of the different characteristics of clay binder. The difference between bentonite clay binders and liquid binders can be attributed to the complex bonding mechanism of bentonite clay in molding sands. Bentonite clay forms a film on the surface of sand particles and a porous bond at the contact points between the sand particles. The effectiveness of bentonite clay is much reduced to enhance the heat transfer through the bentonite bond between the sand particles.

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