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Short Communication

Evaluation of transverse thermal conductivity of Manila hemp fiber in solid region using theoretical method and finite element method

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ABSTRACT

The transverse thermal conductivity of Manila hemp fiber in solid region K_{sf} was evaluated using theoretical method (Hasselman–Johnson's model) and finite element method (FEM). It was found that the results of them are similar to each other: 0.1847 W/(mK) from Hasselman–Johnson's model and 0.1849 W/(mK) from FEM. The evaluated data of K_{sf} was used to estimate the transverse thermal conductivity of Manila hemp fiber composites compared with the experimental data showing good agreement.

1. Introduction

From last two decades, natural fiber has been a subject of interest in the composites due to their specific properties such as good biodegradability, low density, and high specific properties [1–3]. Transverse thermal conductivity is of great importance in the natural fiber reinforced composites that has been studied widely by many researchers [4–6]. However, it is quite difficult to study the transverse thermal conductivity as compared to longitude because of radially arranged crystalline cellulose lattice, large number of fiber walls and lumens in transverse direction [7], which leads to the difficulty in designing the natural fiber composite materials. On the other hand, if the microstructure of natural fiber is considered and the parameters in transverse direction are obtained, it is feasible to understand the mechanism of thermal conduction across the natural fiber in detail and design composite with desirable thermal conductivity.

One of the important parameters is the transverse thermal conductivity of natural fiber in solid region (K_{sf}) (see Fig. 1a). Because natural fiber is hollow and different from conventional solid fiber, it is over simplified to consider the transverse thermal conductivity of the natural fiber bundle as a whole [7], and one cannot directly apply the existing models [8–10] about conventional fiber composite to the transverse thermal conductivity of natural fiber composite. Otherwise, some avoidable error may generate and exhibit adverse effect on the study of thermal conduction of composites. Therefore, it is necessary to evaluate the value of K_{sf}. If K_{sf} is obtained, it is possible for analysis tools (FEM [11,12], the finite difference method (FDM) [13], and so on) to study the transverse thermal conduction behavior of natural fiber composite thoroughly. However, according to our best knowledge, the systematical analysis of this problem is not reported in literatures and present paper is aimed to provide the report of K_{sf} of Manila hemp fiber based on theoretical and numerical analysis.

2. Method

2.1. Method I: theoretical method

The theoretical method is based on Hasselman–Johnson's model [14], derived from the interface interaction between the matrix and inclusion. In this model, n cylinders as fibers with radius a are dispersed unidirectionally in a circular area with radius b as composite ($a/b \ll 1$) perpendicular to heat flow. The effective transverse thermal conductivity K_{eff} of composite is shown in Eq. (1).

$$K_{eff} = K_m\left[\left(\frac{K_d}{K_m} - 1 - \frac{K_d}{ah_c}\right)V_d + \left(1 + \frac{K_d}{K_m} + \frac{K_d}{ah_c}\right)\right] \times \left[\left(1 - \frac{K_d}{K_m} - \frac{K_d}{ah_c}\right)V_d + \left(1 + \frac{K_d}{K_m} + \frac{K_d}{ah_c}\right)\right]^{-1} \quad (1)$$

where K_m, K_d are the thermal conductivity of matrix and dispersed fiber [W/(mK)], h_c is the thermal barrier resistance [W/(m^{2}K)]. If $h_c \to +\infty$, Eq. (1) becomes Eq. (2) agreeing the solution of Rayleigh's model [15].

$$K_{eff} = K_m\left[\left(\frac{K_d}{K_m} - 1\right)V_d + \left(1 + \frac{K_d}{K_m}\right)\right]\left[\left(1 - \frac{K_d}{K_m}\right)V_d + \left(1 + \frac{K_d}{K_m}\right)\right]^{-1} \quad (2)$$

This model has been originally developed for the thermal conduction analysis of unidirectional fiber composite similar to other models [9,10]. However, it reasonable to employ this model to

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