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THEORETICAL MODELS FOR THE ANISOTROPIC CONDUCTIVITIES OF TWO-PHASE AND THREE-PHASE METAL-MATRIX COMPOSITES

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Abstract—Simplified analytical models are developed for predicting the anisotropic conductivities of particulate-reinforced metal-matrix composites fabricated using the powder metallurgy process. First, a two-phase model accounting for the effects of the matrix and the reinforcement phases only, is described. The model exploits the microstructural information available from metallographic analysis, and is based on the concept of a unit cell. The effects of the intermetallic phases formed during the processing stage are accounted for in a three-phase model, where the three-phase matrix-reinforcement-intermetallics composite is modeled as being composed of a "modified"-matrix reinforced with a third phase. The "modified"-matrix is, in turn, formed of the pure matrix reinforced with either the intermetallics, if the reinforcement particles are considered to be the third phase, or the reinforcement particles, if the intermetallics are regarded as the third phase. Good agreement is demonstrated between the theoretical predictions and the experimental data on Al/SiC_p composites, obtained using eddy current techniques, for a wide range of phase compositions and volume fractions. The two-phase and three-phase models are shown to be more effective in estimating the anisotropic conductivities, in comparison to the models available in the literature, which yield only the isotropic properties. The methodology underlying the three-phase model development may be used to characterize multi-phase composites, in general.

1. INTRODUCTION

Metal-matrix composites are rapidly becoming one of the strongest candidates as structural materials for many applications such as automobile and turbine engine components, in the aerospace industry, and in the electronic and magnetic packaging industries. Metal-matrix composites offer an increased service temperature and improved specific mechanical properties over the existing alloys. However, usage of the state-of-the-art composites is often limited by the relatively few reliable material qualification techniques currently available.

Nondestructive evaluation (NDE) methods using eddy currents or ultrasonics offer a practical means of characterizing metal-matrix composites and their properties [1–7]. Additionally, NDE technqiues also provide a viable means for process-interactive, product quality assessment in a manufacturing environment. For example, an on-line eddy current measurement of electrical conductivities may be used to evaluate the volume fractions of the reinforcements, intermetallic compounds and voids at various locations on the product [7]. The variations in the measurements can provide valuable information concerning the uniformity of reinforcement dispersion, clustering phenomena etc.

A vital link in the use of NDE methods for metal-matrix composite applications is the correlation of the nondestructive property measurements to the microstructural features. A few experimental investigations [1–4] have been performed in this regard, on extruded Al/SiC_p systems comprising of Al2124, Al6061 and Al7091 alloy matrices. Experimental measurements of the electrical conductivities of Al/SiC_p composites were reported in Ref. [1]. While experimental studies focus on specific composite systems, a theoretical analysis, especially in a dimensionless form, presents the advantage of a generalized treatment, and will hence be of enhanced practical value. With this objective, we consider the problem of estimating the anisotropic conductvities of extruded particulate reinforced metal-matrix composite systems.

The conductivities of composite systems have been studied in the literature by considering well-defined reinforcement geometries ranging from unidirectional continuous fibers [8–10] to short fibers [11] and spherical dispersions [12]. A summary of the various studies may be found in Refs [12, 13], and is not repeated here for the sake of brevity. However, as explained below, none of these analyses can be directly used for estimating the conductivities of extruded metal-matrix composites.