

# Theoretical analysis of capillary-driven nanoparticulate slurry flow during a micromold filling process

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## Abstract

The microcasting technique for the fabrication of microstructures mainly involves two consecutive steps, namely, the capillary-driven flow of nanoparticulate slurry in micromolds and sintering of the resulting preform. During the mold-filling step, particle settling leads to a spatial particle distribution in the preform, which affects the subsequent sintering kinetics, and in turn, causes a shape distortion in the final sintered product. This paper presents a comprehensive theoretical model which is adopted to account for the capillary-driven flow and simultaneous particle settling behavior during the filling step. Numerical simulations are performed over a wide range of parameters to illustrate the effects of four nondimensional groups on the fill time and particle distribution, and to develop design windows, which may serve as guidelines in the design of particle properties, slurry composition, and mold dimensions to maintain a desired level of homogeneity in particle distribution.

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## 1. Introduction

Fabrication of microstructures has emerged as an important issue in modern technologies, and techniques such as LIGA (a German acronym for lithography, electro-deposition, and molding) and silicon surface micromachining, have been developed to produce the microstructures that are widely used in microelectronics, micro optical devices, and microfluidic systems (Piotter et al., 2002; Hormes et al., 2003). However, these fabrication techniques are suited to only a limited set of materials such as electroformable metals or polymers (Garino et al., 2002, 2004; Morales et al., 2005), and the wear resistance and strength of the parts are generally low (Gietzelt et al., 2002). A novel technique based on microcasting has been developed for the fabrication of microparts with high aspect ratio and straight side walls from a broader material suite of metals,

alloys, and ceramics, improving the micropart properties (Morales et al., 2001, 2002, 2005; Garino et al., 2002, 2003, 2004; Allan et al., 2003; Merz et al., 2004).

The steps involved in the microcasting process are illustrated schematically in Fig. 1, and consist of the following: capillary-driven flow of a slurry composed of catalyzed epoxy resin and solid nanoparticles of metal or ceramic into a sacrificial micromold made of polymethylmethacrylate (PMMA); curing of the slurry in the mold to yield a nanoparticulate composite with sufficient structural integrity to be demolded, planarized, and handled without damage; exposing the preform to a high temperature cycle to burn off the organic phase and to sinter the porous nanoparticulate green body to a monolithic final micropart. During the filling process, depending upon the slurry composition and design, sedimentation or floating (referred to, generally, as settling in this paper) of the nanoparticles may occur causing inhomogeneous nanoparticulate distribution and, in turn, nonuniform porosity in the green preform. Sintering of the preform with inhomogeneous

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