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Enhancement of flow in VARTM using localized induction heating

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Abstract

A critical step in the vacuum assisted resin transfer molding (VARTM) process is the permeation of a porous preform by the reactive resin. A real time flow control is often imperative to achieve complete preform saturation and void-free fill. Local permeability variations in the preform, however, challenge the flow control endeavor. Control strategies that use manipulation of the inlet port parameters are shown in the literature to be limited in the controllability of flow in regions of localized preform variability, particularly at locations away from the controlled injection ports. This paper explores an innovative scheme of using induction heating as a method of locally reducing the resin viscosity to counteract the effects of such localized low permeability regions within the preform. Toward this end, the paper presents a process model for nonisothermal flow during the VARTM process, in the presence of induction heating. The process model, validated with experiments, is used to conduct process simulations to investigate the effects of processing parameters such as induction heating location, induction heating power level, and vacuum level on three heterogeneous preform geometries with varying permeability ratios between the low permeability and high permeability regions. Results of these studies are presented in the form of processing windows and processing maps, which show that induction heating is capable of reducing void and dry spot formation during the VARTM process.

Keywords: Induction heating

1. Introduction

The vacuum assisted resin transfer molding process, VARTM, is a cost-effective method of producing lightweight composite parts. In this process, a stack of fibrous reinforcement materials, called a preform, is sandwiched between a net shaped solid mold on one side and a vacuum bag on the other side. Vacuum is applied to the preform-mold assembly that serves two purposes: First, it reduces the pressure within the mold, which causes atmospheric pressure to compress the preform and yield the high fiber volume fractions required for high performance composites. Second, it draws catalyzed thermosetting resin from strategically placed inlet ports into the mold and through the preform. Once the resin-saturated preform undergoes a cure temperature cycle, which hardens the fiber resin mixture to create the final composite part, the process is completed by removal of the composite product from the mold.

Mold filling is a critical step in the process, and is often the step that leads to part defects. Resin flow during the filling step is described by Darcy's law, which states that the flow velocity is related to the local pressure gradient, the fluid viscosity, and the permeability of the porous medium [1], where the permeability is a measure of the resistance to the flow provided by the preform. Determination of the permeability tensor for realistic preform structures is a challenge, and has been the subject of many theoretical and experimental studies. Elegant theoretical models and empirical fits for various preform structures have also been reported in the literature [2–5].

A fundamental challenge in the filling step is achieving adequate fiber wet-out, thereby eliminating the occurrence of dry spots and voids in the final composite part. Non-uniformity in the preform permeability can lead to variability of the flow progression from that determined by theory. This non-uniformity is primarily

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