Microgravity Impregnation of Fiber Preforms

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Introduction

It is now well-known that the spreading of liquids and wetting of solid surfaces in space exhibit a number of significant fluid management challenges as well as numerous interesting phenomena. Many of these phenomena are also technologically important in fabricating high-performance parts in space such as the structural components needed to build the Space Station or medium-to-large panels needed for repair in space. The ability to manufacture geometrically complex, lightweight and high performance composite parts in space primarily depends on understanding and subsequent controlling of flow processes such as filling a mold cavity, spreading or coating a solid surface, and impregnation of a porous fiber preform. For example, most high-performance molding operations involve impregnation of a fibrous preform where the balance between viscous and surface forces as well as nonisothermal effects significantly affect the fluid behavior. It is believed that microgravity provides the necessary means to mold much stronger/stiffer composite materials due to achieving higher volume content of the reinforcing preform. In addition, the complete process can be accomplished with much simpler, lighter, and inexpensive tooling and molding equipment.

The objective of the current research is to contribute to the understanding of microgravity impregnation and wetting of porous media, and to develop low-pressure molding methodologies to fabricate high-performance composite materials. Investigating the effects of capillary forces and gravity on mold filling will be among the primary objectives. The flow through porous media induced during the filling of a center-gated mold cavity will be studied under 1-g and microgravity conditions. The proposed experiments aim at understanding the effects of fluid viscosity, external pressure (i.e., impregnation pressure), surface tension, and microstructure of the wetted porous media on the flow kinematics.

Experimental Mold Filling Studies

An experimental molding setup for observing and characterizing flow during the filling of a disk shaped cavity has been constructed. The previous mold design has been improved and fluid front probes have been implemented. The experimental setup consists of the following components: an assembled mold cavity, a peristaltic pump and tubing system for fluid transfer, and a data acquisition system. The disk shaped cavity is fabricated by placing a spacer plate between two transparent acrylic sheets. Spacer plates are cut from 20x20 inch aluminum or acrylic sheets with

an 18 inch diameter disk shaped cut from its center. Several spacer plates with thicknesses ranging from 1/16 to 1/2 inch are fabricated and tested. The top and bottom acrylic mold walls are chosen to be one-inch thick to minimize possible wall deformation during filling experiments. Fluid front sensors are mounted at three radial locations in the disk at 2, 4, and 6 inches away from the inlet gate, each consisting of two small pairs of terminals mounted on the top and bottom mold walls. A sensing circuit in conjunction with the data acquisition system detects when the front contacts three of the sensing terminals in each probe by measuring a resistance drop. The three consecutive sudden voltage readings at each radial probe location represent the fluid contacting these three terminals at that radius. In addition to these sensors, pressure transducers are flush mounted on the top and bottom mold surfaces to obtain accurate transient pressure distribution during mold filling.

Effects of Gravity on Mold Filling

In the absence of gravity, or in filling operation in which gravity can be neglected, the shape of the free surface in a planar mold cavity would be symmetric with respect to the midplane. The presence of gravity deforms the fluid front causing it to sag towards the bottom wall. Due to this spreading, the bottom of the free surface advances ahead of the top. The difference between the radial location of the bottom and top of the free surface contact lines is defined as spreading. Initial experiments showed that spreading can be quite significant under certain conditions. With low viscosity fluids or for low filling rates, significant spreading up to 2 to 6 times the gap thickness is observed. The pressure distribution on the top and bottom mold walls can differ markedly in flows with considerable spreading. Filling experiments have been conducted with 0 to 35% chopped glass fiber mats placed in the cavity. Based on the fiber volume fraction, fluid viscosity, mold gap width, and the inlet velocity, channeling and gravity are measured to have notable effects on the flow kinematics and spreading during filling.

In the absence of a preform, spreading at a radial location in a center-gated disk can be characterized by four nondimensional parameters. The dependence of spreading on Reynolds, Bond, Capillary numbers and contact angle needs to be fully understood through carefully designed experiments. Towards this end, the following physical parameters can be changed in filling experiments: gap-width, H; volume flow rate, Q; viscosity of the fluid, μ. For a given fluid and the mold surface the contact angle can be determined. Then two of the remaining three nondimensional parameters need to be kept constant while changing the third one. This requires the adjustment of all the physical parameters (i.e., L, Q, and μ) in a unique manner. We have designed and are currently performing experiments to identify the effects of Reynolds, Bond, and Capillary numbers on spreading.

Contact Angle and Wetting Studies

In order to improve wetting and fiber-matrix adhesion, contact angle measurements have been made to understand the surface effects induced by the fiber-fluid interface. The effects of surface treatments of glass fibers on contact angles are studied with the Cahn fiber tensiometer. These surface treatments allow the manipulation of contact angle to facilitate favorable wetting and

adhesion conditions. Contact angles for a Dow epoxy vinyl ester resin, Derakane 411-C-50, was also measured with all the different treated glass fibers. The epoxy, chosen for its low viscosity and quick gel times, is found to have a zero contact angle with all fibers. Other epoxy resins with less diluent than Derakane 411-C-50 will be tested to differentiate wetting behavior of different fibers.