Modeling of Transport Phenomena in Metal Foaming

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Abstract

Metal foams are interesting materials with many potential applications in engineering. Foamed metals or alloys include gas voids in the material structure with the real possibility to modify ad hoc their physical properties. Therefore, a wide range of possibilities arise in the automotive, aerospace, nautical, railway, building, civil engineering and medical industries. For industrial applications, metal foams offer attractive combinations of fundamental physical properties, like mechanical, thermal, acoustical, etc.

During the foaming process of a metal in a mold, simultaneous mass, momentum and energy transport mechanisms arise between three different phases, the solid one (mold walls and the solidified metal), the liquid metal and the gas one (gas bubbles and the surrounded air). Furthermore, other physical phenomena like complex interface processes, bubble motion, coexistence, coalescence and collapse of bubbles, have place. Experimental works carried out by observation techniques cannot be sometimes applied owing to the specific properties of liquid metals, since they are hot, opaque and very reactive with oxygen. Therefore, to investigate these mechanisms the computational techniques could represent a useful tool, although the computational work is very challenging, because the phenomena are not independent among them and are simultaneous.

Following our previous efforts aimed to simulate and study the foaming process of a metal, we propose in this work a model, by COMSOL Multiphysics® version 4.3b, which considers heat and mass transfer phenomena, coupled to the growth and movement of hydrogen gas bubbles in liquid aluminium. The aim of the work is to simulate the expansion of a metal foam in a horizontal 2D mold, by taking more mechanisms into account. To model and numerically solve the governing equations of the problem, we use the Heat Transfer and the Chemical Engineering Reaction Modules. These tools have been coupled to the level set interface and the weakly-compressible flow, both available in the CFD Module. We assume time dependent conditions, simplifying the flow regime to a Stokes flow. Due to its low concentration, the diffusion of hydrogen gas in the liquid aluminum is studied by applying the Fick's law, available in the Transport of Diluted Species User Interface of COMSOL Multiphysics®. A source term accounts for the hydrogen releasing mechanism which delivers gas in the system and is responsible for the bubbles expansion in the metal foams. The gas in the bubble is considered as an ideal gas and the equilibrium concentration at the gas-liquid interface is modeled by the Sievert's law. Furthermore, surface tension effects are considered and repulsive forces between

neighboring bubbles are expressed through the disjoining pressure.

The numerical results of the simulation show that the computational model, based on a level set technique for capturing the phase interface, can be effective. The computations, carried out for different cases, simulate satisfactorily heat and mass transfer, bubble expansion, interface movement and fluid flow. In this way other physical mechanisms as heating and cooling rates, drainage, etc. could be included in the future for a more comprehensive model.

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