The 8th European Congress on Computational Methods in Applied Sciences and Engineering
ECCOMAS Congress 2022
5-9 June 2022, Oslo, Norway

Evaporative front kinetics in random 3D topologies. Application to the Lost Foam casting process

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Keywords: *Metal casting, Heat transfer, Phase change, Multiphysics interaction, Porous media, Metric tensor*

The lost foam casting process is a form of evaporative-pattern casting selected to manufacture automotive parts, where a polymeric foam pattern, covered by a refractory material permeable to gas and surrounded by sand is replaced by a flowing hot liquid metal. The basic model consists in pouring the liquid aluminium into the mold cavity, that decomposes the foam into liquid polymer and gaseous byproducts, and forming, according to literature [1][2], a so-called decomposition layer between the advancing metal and the receding foam pattern casting.

By performing a dimensional analysis on an acceptable regime of the process (defined as a steady and flat front flow of both the advancing liquid metal and the degradation front of the polymeric pattern), we have validated our estimates of the front flow velocity ranging usually between 1-2 cm/s, and the decomposition layer thickness presenting an approximate order of magnitude of 10^{-4} m [3], which is insignificant compared to the pattern width (order of 10^{-3} m). The complexity of the problem lies in the high coupling between the physics involved and in the wide ranges of scales to consider, and most importantly the multiphase interactions. Modeling such a multiscale problem can lead to undesirable computational cost.

According to that, we propose in this paper an advanced flow modelling technique, with the least computational cost, developed for an accurate estimate of the evaporative front kinetics in random 3D topology. This new technique consists mainly in treating the advection of the liquid metal front, captured using a levelset method, along a unitary vector field, similarly to a neutral line direction in structural dynamics, that follows any arbitrary part curvature.

The advection velocity is expressed in terms of the process parameters and geometric variation.

First, the directional vector field oriented in the neutral line direction is extracted by performing a projection of the metal interface levelset gradient onto a tangent metric tensor T induced by the natural anisotropic topology of the domain (eigenvectors of T associated to non zero eigenvalues are tangent to the domain boundaries).

Second, the filling velocity magnitude was derived by coupling multiple phenomena: (i) heat transfer through the vapor layer in the flow direction, (ii) foam phase change into residues (melting, degradation, vaporization), (iii) mass transfer of the gaseous residues through porous media in the flow transverse direction. The net result is that the filling velocity depends on the square root of the local (in each channel/compartment of the part) interface perimeter to surface ratio.

It is then important to take into account this geometric variation as it alters the mold filling speed at each time step.

Moreover, in the case of multiple fronts, a front flagging method was adopted, where an indicator function defined on each local interface is built using coloring, spreading and diffusing operators.

This model was solved numerically, using our finite element library, and tested on several test cases. We will show that it can quantitatively predict experimental front kinetics as well as complex phenomena such as fronts merging in 3D highly curved industrial parts.

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