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AN INTERFACE-BASED GENERALIZED FINITE ELEMENT METHOD FOR THE MESO-SCALE DESIGN OF MICROVASCULAR HIGH-TEMPERATURE COMPOSITES

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ABSTRACT

This work is motivated by recent advances in the manufacturing of 3D microvascular fiber-reinforced high-temperature composites, in which microchannels with diameters comparable to that of the fiber tows are embedded directly into the composite microstructure using a technique based on a sacrificial fiber (Figure 1).

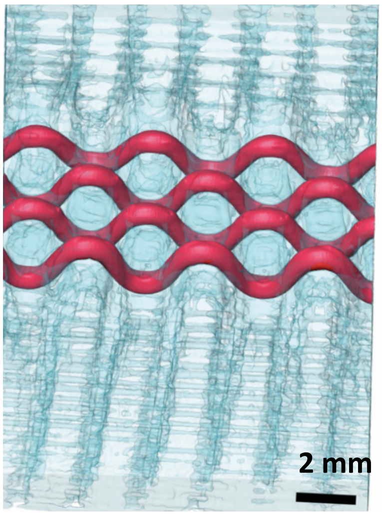

Figure 1. MicroCT image of a 3D woven glass fiber composites with four embedded microchannels (shown in red). The glass fibers are shown in light blue. The microchannels have a diameter of about 500 microns.

The similarity in scales between the microchannels and the composite microstructure, and the complexity of the network geometry whose topology is constraint by the presence of the fiber tows, necessitate the development of a special numerical tool to model accurately and efficiently the impact of the embedded microchannels on the thermal field in the composite. To that effect, we introduce an interface-based generalized finite element method (GFEM) specially design to solve the coupled fluid/solid thermal problem using a finite element grid that does not conform to the geometry of the microchannels and/or the fiber tows. Unlike "conventional" GFEM that are based on nodal enrichment degrees of freedom, the proposed scheme relies on interfacial degrees of freedom and enrichments. This approach presents various advantages in terms of reducing the number of additional degrees of freedom, applying Dirichlet boundary conditions and computing the enrichment functions.

Figure 2 presents the thermal field in a polymeric fin with a 500-micron diameter sinusoidal microchannel, obtained with the interface-based GFEM.

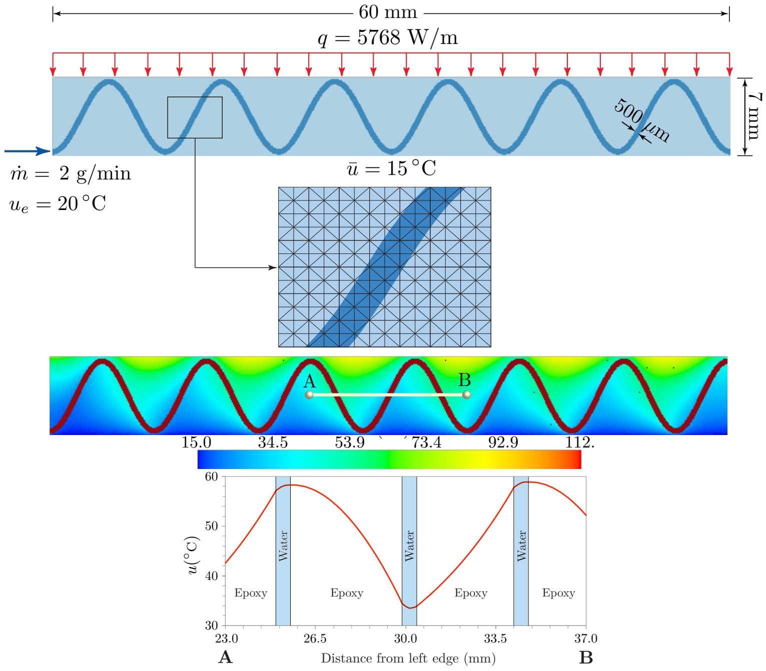

Figure 2. Thermal field in an epoxy fin with a sinusoidal microchannel filled with water (with a mass flow rate of 2 g/min). The applied heat flux on the top edge of the domain is chosen so that that edge would be at 100°C in the absence of active cooling. The inset of the top figure shows the non-conforming nature of the mesh. The bottom figure presents the temperature distribution along the line AB, showing the ability of the GFEM solution to capture the temperature gradient discontinuity at the boundaries of the microchannels (corresponding to the blue vertical lines).

The efficiency and accuracy of the method are compared with conventional FEM and GFEM, and we present the results of a validation study based on experimental measurement of the thermal response of a fin specimen similar to that shown in Figure 2, and of a panel made of 3D microvascular glass fiber/epoxy matrix composite.

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