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Investigation of stress distributions in the resin rich region and failure behavior in glass fiber composites with microvascular channels under tensile loading

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ABSTRACT

Microvascular channels in fiber-reinforced composites offer various functional enhancements such as damage monitoring and self healing. As an adverse effect, presence of such channels can harm the mechanical behavior of composites. In the present study, 3D models are generated to investigate the stress concentrations in the resin-rich pocket and failure behavior considering different stacking configuration and vascule sizes. Similar results were obtained for $[0/90]_{4s}$ and $[90/0]_{4s}$ stacking configuration in spite of having different layer just above the channel and different resin pocket dimensions. The effect of changing the vascule diameter is mostly observed in UD 0 configuration. Utilizing elliptical channels results in reduced stress concentrations compared to the circular ones with the same diameter. While the staking configuration affect the failure in the resin rich zone, it does not affect the failure from the laminate region.

1. Introduction

Composite materials have been used extensively in many industries such as aerospace and automotive. Rapid developments in this industry brings the necessity of enhancement of production methodologies of the composites. Introduction of microvascular channels is one of those where from 1 μm to 1 mm diameter channels are generated inside the composite with various productions techniques. These channels can function for many applications such as provide active cooling [1,2] self-healing [3,4] and damage monitoring [5,6].

While providing these functions, the micro-vascular channels also introduce a modification in the structure of the composites. The effect of these channels on the mechanical behavior of composites is investigated in quite a few studies. In Ref. [7], the effect of these channels on the tensile and compressive behavior of a composite is investigated. The results showed that the modulus and strength properties decrease with increasing vascular diameter and determined that higher mechanical properties are obtained when the channels are aligned in the longitudinal (0) direction to the applied load compared to the transverse (90) direction. Zhou et al. [8] and Jensen et al. [9,10] detected 2%–9% decrease in the in-plane strength when a certain diameter is reached in the composite. Trask et al. [11] found that the compressive strength of a carbon/epoxy material containing 0.6 mm diameter microvascular hollow is reduced by 16% while Williams et al. [12] detected a small reduction in flexural strength for the same vascule diameter. Kousourakis et al. [13] studied the inter-laminar properties of carbon/epoxy laminates with these channels and detected a reduction in the inter-laminar shear strength of the laminates. Walker et al. [14] and Norris et al. [15] have detected an increase in the mode I delamination toughness when microvascular channels are introduced as crack tips are blunted due to the microvascular channels.

Parallel to the experimental studies, very few studies have focused on the numerical modeling methods to investigate the mechanical behavior of composites employing vascular channels. Huang et al. [16] performed finite element analysis using a plain strain model to study the crack initiation and failure for the composite layers all oriented 90° and validated their FEA results with experimental results by high-speed photography. They also presented a few stress concentration results near the vascular channels. Alex et al. [17] applied a damage analysis method for the models presented in Ref. [7]. Liu et al. [18] studied the progressive failure and strain localization using a 3D FE model. Intra-laminar and inter-laminar damage evolution were predicted simultaneously using special subrotines. Hartl et al. [19] studied the impact of the channel spacing and laminate thickness on the failure behavior

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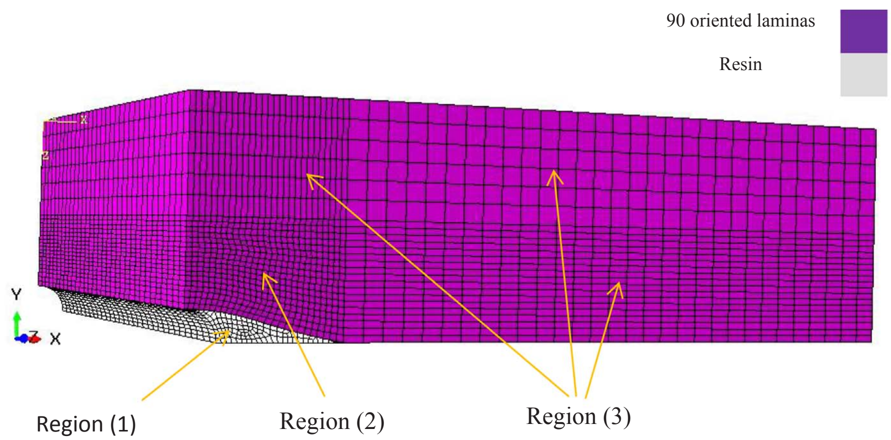

Fig. 1. Quarter section of the 3D FEA model (the readers are referred to colored version for clarity). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

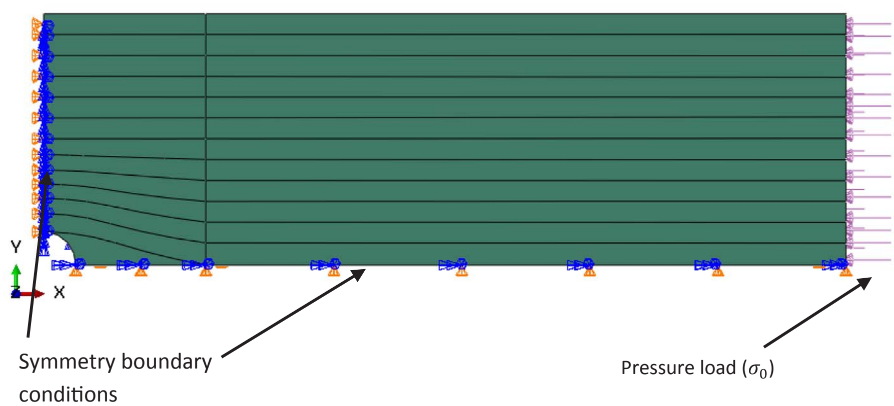

Fig. 2. Boundary conditions and load for the validation model.

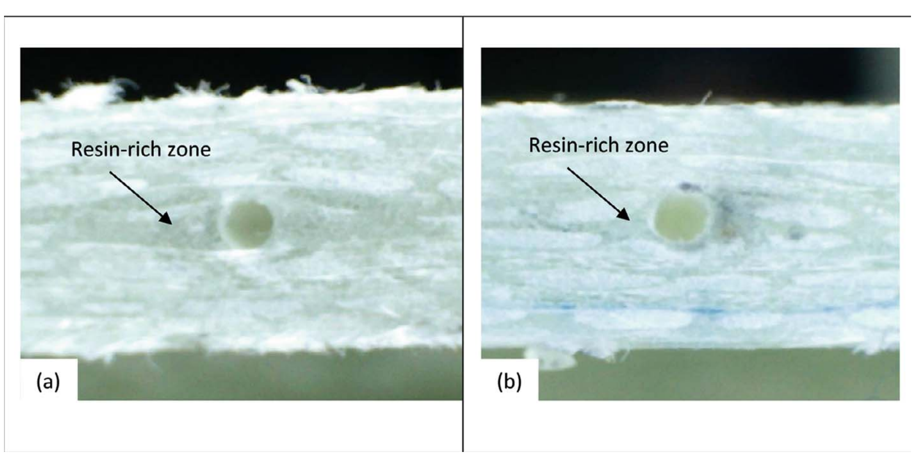

Fig. 3. Micro-pictures vascularized glass fiber reinforced composites with vascular channel diameter of 1 mm for stacking configurations (a) $[0/90]_{4s}$; (b) $[90/0]_{4s}$.

under various loading conditions. They reported that, the channel orientation to the local fiber direction has no noticeable effect on the strength under combined load. Apart from these, the effect of these channels on the temperature field was studied by Soghrati et al. [36] using a novel Interface-enriched Generalized Finite Element Method.

When the literature related to microvascular channels is investigated, it was observed that except [16], none of the computational studies investigated the stress concentrations which can explain the stress re-distribution and failure behaviors due to channels. In Huang [16], results for only a specific channel and composite stacking configuration is given, which is difficult to come up with a scientific conclusion. In addition, only transverse loading is considered. In this work, stress concentrations generated around microvascular channels for various channel configurations are investigated and compared with each other by a three dimensional finite element model under tensile load. It was mentioned in many studies that when such channels are introduced into the composite, a relatively weaker resin reach zones are generated around vascular channel. These resin reach zones are