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Stress Concentrations in Composites with Microvascular Channels

Hamed Tanabi[a]*, Ahmed Al Shawk[b], Baris Sabuncuoglu[c]

[a]*Mechanical Engineering Department, University of Turkish Aeronautical Association, Ankara, Turkey*
[b]*Graduate School of Natural and Applied Sciences, University of Turkish Aeronautical Association, Ankara, Turkey*
[c]*Mechatronic Engineering Department, University of Turkish Aeronautical Association, Ankara, Turkey*

Abstract

Microvascular channels in fiber-reinforced composites offer various functionalities ranging from self-healing and damage monitoring, to active thermal management. However, the tradeoff between extended functionalities and mechanical performance at vascularized composites is still an issue. In this study, a three dimensional finite element model is developed to investigate the stress concentrations generated around macro-vascular channels for various channel configurations and lamination sequences. Results indicate that the stress distribution around vascular channel is same for symmetric stacking configurations 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.

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Keywords: Finite element; vascular channel; fiber reinforced composites

1. Introduction

Introduction of microvascular channels embedded within fiber reinforced composites offers the potential for significant developments in functionality. For instance, these channels can be used for thermal management and active cooling of composite laminates (Aragón et al., 2007; Kozola et al., 2010). Patrick *et al.* (Patrick et al., 2014)

* Corresponding author. Tel.:+90-553-222-3813; fax: +90-312-342-8460.
E-mail address: htanabi@thk.edu.tr

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and Norris *et al.* (Christopher J. Norris et al., 2011) conducted in situ self-healing in fiber reinforced composites using microvascular networks. While providing these functions, the microvascular channels also introduce a modification in the structure of the composites. The effect of micro channels on the structural behaviour of composites is investigated experimentally and numerically in quite a few studies. The studies on tensile and compressive properties of vascularized composites show that the loss of elastic moduli is negligible when size of micro channel is less than a critical diameter (Coppola et al., 2014; Kousourakis et al., 2008). However, the modulus of elasticity decreased with channel diameters greater than a threshold. Also it was reported that the loss in modulus was much greater for the case at which channels are in the transverse direction. The reported results in (Jensen et al., 1992a, 1992b; Zhou et al., 2004) show 2% - 9% decrease in the in-plane strength of vascularized composites when a certain vascular diameter is reached. In (Trask and Bond, 2006), authors reported a 16% reduction in compressive strength of a carbon/epoxy composite laminate containing 0.6 mm diameter channel and a small reduction in flexural strength of the composite laminate with the same vascular diameter. Parallel to the experimental studies, very few studies have focused on the numerical modelling methods to investigate the mechanical behaviour of composites employing micro-vascular channels. Huang et al. (Huang et al., 2010) performed finite element analysis (FEA) using a plain strain model to study the crack initiation and compression strength in vascularized composites under transverse loading. This model was used by (Nguyen and Orifici, 2012) for a damage analysis. They (Nguyen and Orifici, 2012) studied the effect of the channel spacing and laminate thickness on the failure behaviour under various loading conditions. The reported results in (Nguyen and Orifici, 2012)show that, the channel orientation respect to the fiber direction does not have noticeable effect on the strength of the composite laminate under combined load. Surveying the available literature related to microvascular channels shows that except the study by (Huang et al., 2010), none of the computational studies investigated the stress concentrations which can explain the stress re-distribution and failure behaviors due to exist of micro channels. In (Huang et al., 2010), results for only a specific channel and composite stacking configuration is given. 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. Furthermore, this study considers one of the issues that have never been considered in the previous studies: the effect of lamination sequence on the stress concentrations.

2. Sample preparation

In this study, Vaporization of Sacrificial Components (VaSCs), was introduced by (Esser-kahn et al., 2011), is used to create hollow micro channels in continuous glass fiber reinforced composites. In this process, unidirectional glass fabrics are laid inside the mold together with a catalyst-saturated polylactic acid (PLA) sacrificial filament. Then fabrics are impregnated with a low - viscosity resin using Vacuum Assisted Resin Transfer Molding (VARTM). Composites were cured in an oven at 80 ºC for one hour then at 160 ºC for 4 hours. Following the cure, composite plates were trimmed around the edges and then samples are put in a vacuum oven at 200 ºC for 24 hours to vaporize the sacrificial component (PLA filament).

In the present case, glass fiber reinforced composites are prepared with a fiber volume fraction of 55% containing vascular channel of 1 mm diameter along the laminate mid-plane. The fabricated laminates contain 16 plies with stacking orders $[90/0]_{4s}$ or $[0/90]_{4s}$.

3. Finite Element Model

3.1. Geometrical Configuration

Micro scale images are taken from cross section of the vascularized laminates. These images are then used to extract the dimensions of the model (Fig. 1). As it is seen in Fig. 1, there is a resin-rich region around vascular channel. Also, it was found that there is a significant geometrical difference in the resin-rich region between [90/0] and [0/90] stacking orders. The resin-rich pocket in [0/90] is much larger than the one in [90/0]. These dimensional differences are also confirmed by the reported results with (Nguyen and Orifici, 2012; C J Norris et al., 2011). The