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Design criteria of multilayer fibers reinforced composite in bulky 3D loaded applications

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ABSTRACT

In this research paper the design criteria of 3D loaded bulky shapes made from multilayer short carbon fibers reinforced epoxy using compression molding is studied. Five different design criteria are discussed with different limiting stress and strain values. The first criterion is based on the fibers local stresses; the second criterion depends on the interfacial bonding strength; the third criterion is the conventional failure one derived from the composite average strength. In addition to this the Hashin damage criteria are applied on the fiber and matrix of the composite. The mathematical models of the short fibers reinforced composites strength and interfacial bonding strength are reviewed. A finite element model is introduced to estimate the local stresses on the fibers, interfacial bonding stresses between the fibers and matrix, and the average composite stresses. The finite element model is checked on a representative volume element (RVE) of the composite with general fibers orientation and loading direction. The results obtained from the FEA analysis is used to check the design with the five design criteria, and compared with the tensile specimen from the experimental work as well. Finally, the finite element analysis and design criteria are applied on a 3D loaded bulky shape used in plumbing inspection chambers made from short fiberglass filled calcium carbonate reinforced polyester. The validated model and design criteria are checked on the results of the inspection chamber results.

1. Introduction

Short fibers reinforced thermoplastic or thermoset composites are widely used in 3D loaded bulky materials to provide higher strength and rigidity to weight ratios. The majority of the available micromechanical models are only valid for laminates and in-plane loaded structures. There is a need to have a model that describes the design limiting criteria for 3D loaded bulky composites. In many applications the design of short fiber reinforced composites is dependent on tensile strength or impact strength, although there is other design criteria that should be studied. The available literature studies the elastic or brittle behavior of the composite constituents and their effect on the composite produced. In this research new five design criteria are introduced to enable the designer understand his most conservative loading limits and conditions. The study also shows different design aspects, according to which, the designer can select the most suitable design criteria for his application. This will enable the designers of products made from composite materials to design more optimized and reliable products made from short fibers reinforced composites.

K. Hamza et al. [1] presented a mathematical model based on the finite element method in order to predict the stresses and deflection in random or aligned 3D short fibers reinforced composite. The FEA showed the results on each fiber and on the interfacial bonding between the fibers and the matrix. The model was also experimentally validated and tuned for manufacturing and fibers defects values. This model will be used here to get the limiting design criteria for any 3D loaded representative volume element of the composite. K. Zhu et al. [2] used the combined cell model to simulate the mechanical behavior of short fibers reinforced composites with a metal or plastic matrix with small strains. He also presented the statistical combined cell model to predict the failure properties of short fibers reinforced composites, where he concluded that the combined cell model doesn't provide the enough accuracy for the failure condition [2]. Some researchers studied the effect of the particle size and interface adhesion with the matrix on the mechanical properties of the particulate-polymer composites, while others analyzed the progressive failure of short glass fiber reinforced thermoplastics on different levels [3and4]. S. Kammoun et al. [4] started the study from a representative volume element, then a homogenization to the fibers properties and the grain modeling. Finally, the damage modeling and the final homogenization is performed to represent a representative volume element with homogenous mechanical and failure properties [4].

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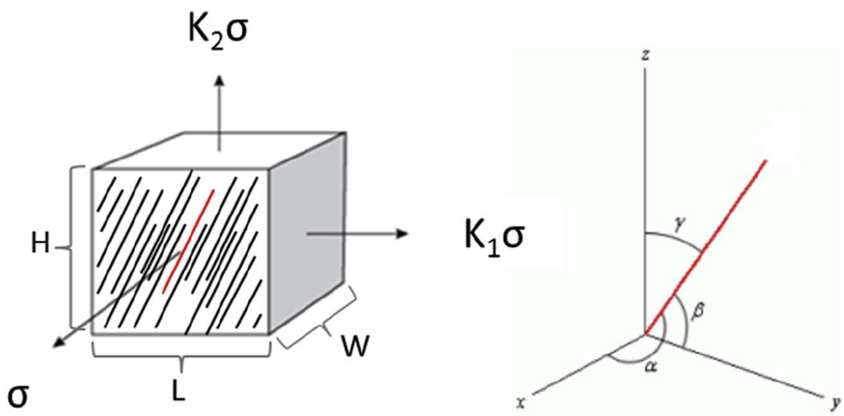

Fig. 1. Fibers embedded in the matrix representative volume element 3D orientation with loading directions.

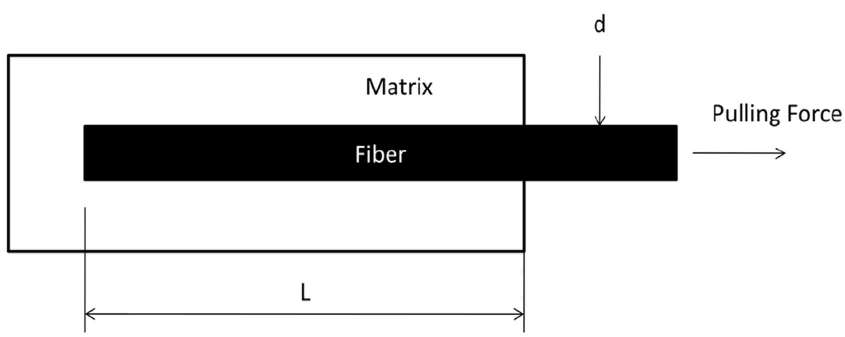

Fig. 2. Pulling force of fibers within the matrix.

Table 1
Carbon fibers and Epoxy mechanical properties.

	Carbon Fibers Torayca T300	Epoxy Epolam 2017	
Tensile Strength	3530	78	MPa
Tensile Modulus	230	3.6	GPa
Maximum Strain	0.015	–	
Density	1.76	1.13	g/cm^3

M. Eftekhari et al. [5] presented a fatigue modeling technique of filled short glass fiber reinforced Polypropylene and polymaide-66 composites, in which the study included the effect of the temperature and the mean stress on the fatigue life time of the composite. The effect of the mean stress showed a significant effect on the fatigue life on the studied materials at various temperatures. Although a general fatigue life prediction was predicted by Eftekhari's model, an average homogenous material was estimated [5]. In this research we are applying a micro-modeling on the composites where each fiber will be simulated independently. This enables us to better understand and use the model of fatigue life cycle and how to optimize and enhance our design. Janis Sliseris et al. [6] introduced a numerical modeling of a flax short fiber reinforced and flax fiber fabric reinforced polymer composites, where they could model the microstructure of short fibers and its length to diameter ratio using a predefined algorithm, then the fibers were simulated using a tetrahedron 4-node finite elements. The simulation could capture the main damage mechanisms such as fiber breakage, depending on using the representative volume elements, without proceeding to 3D loaded bulky parts [6].

Marika Eik et al. [7] introduced an experimental approximation for the fibers orientation distribution function, in which they also studied the effect of the approximation accuracy on the elastic properties of the composite, where they concluded that the effect of the orientation distribution accuracy on the stiffness matrix should be taken into consideration in the finite element modeling of fibers reinforced composites. Thus, a detailed modeling of the fibers length and also distribution is needed for a reliable simulation results. On the other side a model for the viscous behavior of short fibers reinforced composites was proposed by M. Ncin et al. [8], in which the composite was modeled as an

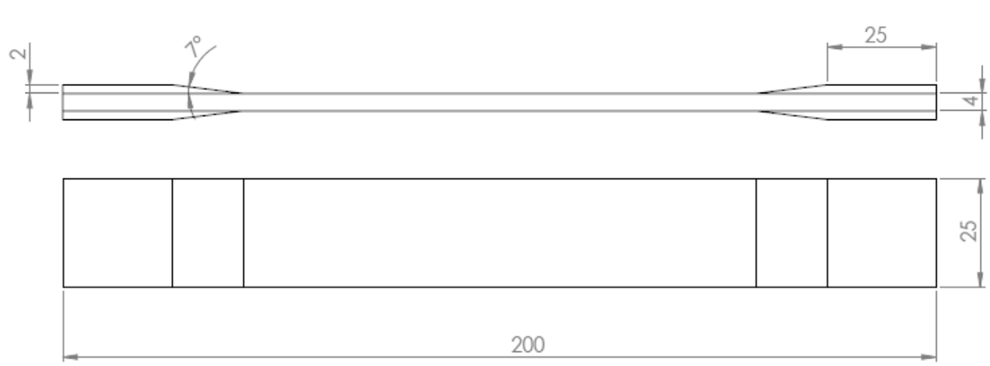

Fig. 3. Tensile test specimen according to ASTM D3039.