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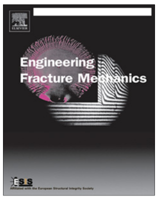

Influence of tows waviness and anisotropy on effective Mode I fracture toughness of triaxially woven fabric composites

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ABSTRACT

Tows waviness and anisotropy effects on effective Mode I fracture toughness, K_{IC}, of triaxially woven fabric (TWF) composite were numerically and experimentally investigated. 2D isotropic Kagome, wavy isotropic, and wavy anisotropic TWF were modeled for various relative densities, crack lengths, and cell sizes, verification of which was ensured with experimental results. In general, K_{IC} increases with relative density, the inverse of cell size, and crack length. Both waviness and anisotropy cause a drop in K_{IC}, with a remarkable 76% of maximum knockdown in comparison to those without these effects. K_{IC} reduction is observed to be highly sensitive to tows waviness. The influence of tows anisotropy on K_{IC} reduction of TWF composites is somewhat minor, compared to TWF with wavy isotropic members.

1. Introduction

To date, there exists a paramount interest in the development and usage of triaxially woven fabric (TWF) composite in numerous applications, such as inflatable, active, and morphing aerospace structures [1–3]. This is because a single-ply TWF takes load distribution uniformly in tension, bending, and shear [4,5], has good stiffness and strength properties [5,6], lightweight but highly flexible especially in the out-of-plane direction [7,8], as well as has good impact behavior and low thermal sensitivity [9,10].

Fig. 1 shows a piece of cured TWF composite, in which an even distribution of hexagonally-shaped voids can be seen. As a result, these voids decrease the mass of the material significantly, a useful feature for lightweight structure applications. Highlighted in the same figure is the unit cell of TWF with t and l defined as the cell wall thickness and cell size, respectively. Basically, the fabric is formed by three sets of tows, each of which interlaces at a repetitive 60° angles. Hence, on a macroscopic scale, this material possesses a set of mechanically quasi-isotropic properties. This makes it attractive for constructing ultra-thin structural element for spacecraft antennas and deployable structures [11]. In the orbital environment, TWF composite structures for the aforementioned applications are however exposed to various mechanical loads and severe thermal shock, which could subsequently produce cracking of the material. Thus, their damage tolerance becomes a weighty matter that requires an in-depth attention. In view of this, the fracture toughness of single-ply TWF composite, which is defined as the ability of a material to resist the propagation of the crack, is an important property for its comprehensive designs and applications. It is of importance to realize that although the topology of the single-ply TWF composite follows a direct

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Nomenclature

a	edge notch length
A, B	coefficients for reduction factor
d	fitting parameter from the fracture toughness curve
E_i	extensional modulus, $i = 1, 2, 3$
G_{ij}	shear modulus, $i, j = 1, 2, 3$
h	specimen thickness
K_{IC}	effective Mode I fracture toughness
l	cell size
P_c	applied tensile load that causes the first crack growth
t	cell wall thickness
V_f	volume fraction of fiber
w	specimen width
Y	shape factor
β	reduction factor
η	$\frac{E_{2f}-E_m}{E_{2f}+\xi E_m}$
ν_{ij}	Poisson's ratio, $i, j = 1, 2, 3$
σ_{IC}	applied Mode I stress that causes the first crack growth
σ_f	modulus of rupture for composite tow
ξ	curve fitting parameter, $1 \le \xi \le 2$

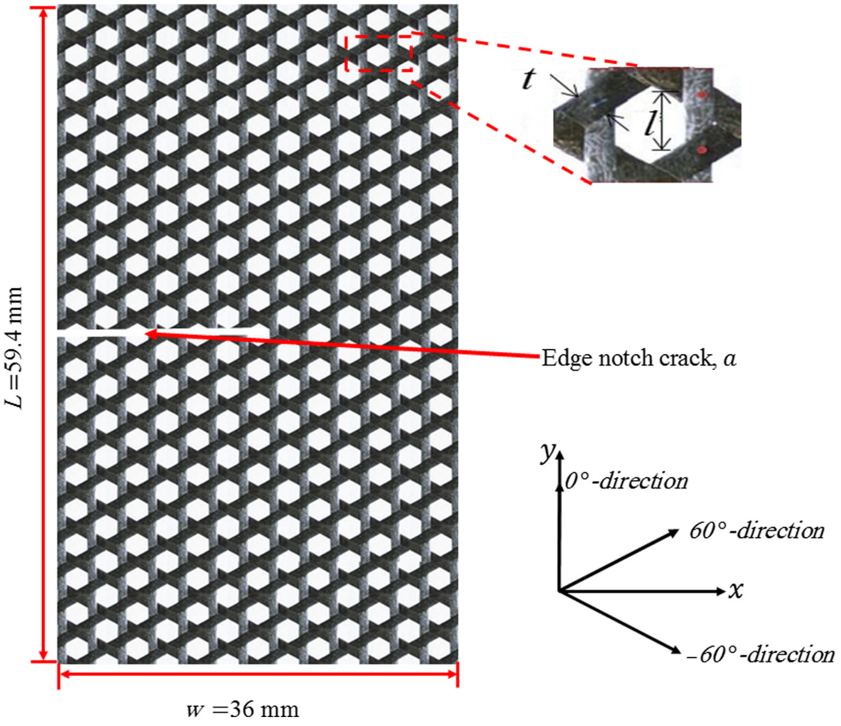

Fig. 1. Single-edge notch tension specimen of triaxially woven fabric composite and its highlighted unit cell.

transition from that of the planar Kagome lattice, many of the local, three-dimensional degrees of freedom remain unconstrained. This results in some significant differences in their behaviors.

Fracture toughness is a material characteristic for solid materials, as classically found in the pioneering works of Griffith and Irwin in the 1940s and 1950s. For lattice materials, however, it depends on the cell size and stockiness. Due to this effect, it is defined as the effective fracture toughness in this paper, to distinguish it from the classical material description, the lat-