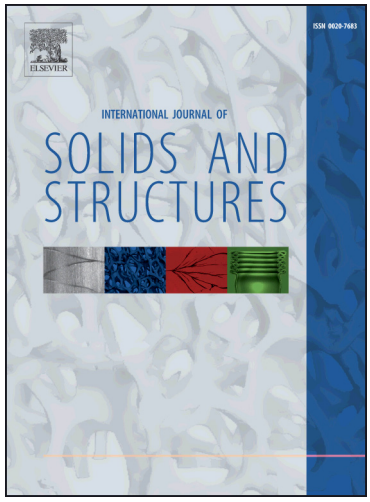

A stiffness degradation model for cracked multidirectional laminates with cracks in multiple layers

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A stiffness degradation model for cracked multidirectional laminates with cracks in multiple layers

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Abstract

In the present work the problem of the stiffness degradation of multidirectional symmetric laminates in the presence of off-axis cracks is studied. A new analytical model is presented, capable of estimating the elastic properties of a multidirectional symmetric laminate with an arbitrary lay-up and cracks in one or more plies. The model is based on the so called "optimal" shear lag analysis of a laminate with cracks in one layer (and its symmetric), coupled with an analytical procedure to account for the presence of cracks in multiple plies, considering also their mutual interaction. The model requires, as inputs, the geometric and elastic properties of the layers and the crack density only. A very satisfactory agreement is found between the present predictions and experimental and numerical results from the literature. It is also shown that accounting for the mutual interaction between cracks in different plies is fundamental for a reliable estimation of the stiffness drop.

1. Introduction

The increasing use of composite materials in the aerospace, automotive and wind energy industries is due to their high specific mechanical properties, and of course the stiffness is a property of great interest. During their service life, composite laminates undergo several damage mechanisms, which cause the degradation of the laminate elastic properties, even if they are not critical for catastrophic failure. For a multidirectional laminate made of unidirectional (UD) plies, the first damage mode responsible for stiffness degradation, both under static or fatigue loading, is the onset and propagation of matrix cracks in the off-axis layers. This phenomenon is documented in several researches in the literature for static (Tong et al. 1997a; Varna et al. 1999a) and fatigue (Tong et al. 1997a; Bartley-Cho et al, 1998; Wharmby and Ellyin, 2002; Thogo et al. 2006; Adden and Horst, 2010; Quaresimin and Carraro, 2014; Quaresimin et al. 2014) loading. An increasing trend of the crack density (meant as the number of cracks per unit length normal to the crack faces) as the static applied load or the number of cycles increases is usually reported. In the literature, many efforts have been devoted to the correlation of the laminate elastic properties to the density of off-axis