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Strain rate effects on the intralaminar fracture toughness of composite laminates subjected to compressive load

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Abstract

This paper presents an experimental and numerical study focused on the mode-I intralaminar toughness characterization of a woven carbon/epoxy composite loaded in compression and subjected to high strain rates. Simulations for non-standardized Single Edge Notch Bending (SENB) and Double Edge Notch (DEN) specimens were carried out using a continuum damage mechanics based failure model implemented as an user defined material model within ABAQUS software. A Finite Element Model was used in order to produce an optimal specimen for intralaminar fracture toughness tests. A new data reduction scheme based on the numerical evaluation of the strain energy release rate using the J-integral method is proposed to determine the stress intensity factor for composites. The proposed methodology accounts for finite geometry and material anisotropy effects. The dynamic tests were carried out at strain rates of $560s^{-1}$, $690s^{-1}$, $770s^{-1}$ using an adapted version of the Split Hopkinson Pressure Bar. A high-speed camera was used for monitoring the crack propagation. A Scanning Electron Microscope (SEM) was used to aid the fractographic analyses on the damaged surface of the tested samples searching for the possible failures mechanisms within the material. The experimental results indicated that the composite laminates studied herein are very sensitive to the strain rate effects.

Keywords: Composite materials, fracture mechanics, dynamic analysis, failure analysis, fracture toughness

1. Introduction

Composite structures made of carbon fiber are commonly applied in high performance structures due to their improved specific properties such as high strength and stiffness per unit of mass. However, almost in its totality, these properties published in text books and articles refer to static loading regime only. When the material is subjected to extreme loading, many questions may arise.

The applications of composites in dynamically loaded structures requires experimental knowledge and understanding of the response of the composites to high strain-rates. Very few studies on the mechanical properties of composites at high strain-rates have been published when compared with isotropic materials. Therefore, there is a clear need to investigate the behavior of composites at high strain rates in order to better understand the structural response and failure mechanisms induced in this class of materials and develop physically based failure models capable of predicting the structural response of composite laminates in the dynamic regime. This characterization, is far more complex due to the anisotropic nature of the composites, where there are two or more constituents present, and interaction between different failure modes. Another essential information to set-up the experiments are the reinforcement configuration (cross-ply or woven),

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