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Experimental and numerical analysis of low velocity impact on a preloaded composite plate

Ali Kurşun[a,*], Mehmet Şenel[b], Halil M. Enginsoy[c]

[a] Department of Mechanical Engineering, Hitit University, Çorum, Turkey
[b] Department of Mechanical Engineering, Dumlupinar University, Kutahya, Turkey
[c] Department of Mechanical Engineering, Uşak University, Uşak, Turkey

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ABSTRACT

An experimental and numerical study on the influence of biaxial preloading on the low velocity impact performance of E-glass/epoxy-laminated composite plates was conducted. For this aim, an experimental device was developed to apply the load in two perpendicular directions. Three preload cases, representative of actual structures were selected, biaxially tension, compression and, tension-compression (shear) loading cases. The samples were produced from unidirectional reinforced E-glass and epoxy, by using a hand lay-up technique. Laminated E-glass/epoxy with stacking sequence $[0/90]_{2s}$, dimensions were 140 × 140 mm^2 and a thickness of 2 mm for the samples used. Finite element analysis (FEA) was developed, using Hashin failure criteria for the composite material, and material models implemented by a User Material Subroutine into ABAQUS®/explicit software, in order to simulate the failure mechanisms and force–time histories. Force–time and energy–time data were obtained by means of user material subroutine from the finite element model. The finite element results showed a good correlation to the experimental data in terms of force–time, energy–time graph or failure in composite plate, although these numerical results strongly depended on simulation parameters like mesh size or the number of element.

1. Introduction

Laminated composite materials are known for their high weight-specific mechanical properties, which make them a preferred candidate in the material selection for modern lightweight structures in the transportation engineering industries such as automotive, aerospace and for marine use. In those applications, laminated composites can be subjected to low-velocity impact from foreign objects, such as the dropping of tools during their life-time of service or operations of assembly and maintenance. These impacts can cause internal damage like delamination's, matrix cracking, fiber breakage, plastic deformations due to contact and large displacements which can significantly reduce mechanical performance and damages are expanded during their life-time of service. However, damage from low-velocity impacts are difficult to be detected from routine inspection like visual inspection but may reduce the residual strength and stiffness of the material, as a result they are considered critical for structures. Therefore, it is necessary to determine their response under low velocity impact.

Recently, numerous researchers have been studying the impact response of laminated composites. Most of these researchers focus on laminated composites that are unloaded before low velocity impact [1–5]. But with regard to applications industry, it is rather unlikely that the impacted structures are unloaded. The composite structure may be subject to tensile, compressive or shear loads during their life-time of service. Therefore, it is necessary to determine the effect of preloading on the impact response of composite laminates. In the literature, there is a scarcity of information on the effect of preloading on the impact response of composite laminates.

A relatively small number of researchers have analyzed the behavior of preloaded structures subjected to low-velocity impact, the researchers studied experimental [6–11], numerical [12–14] both experimental and numerical [15–17] which discuss the impact response of different composite laminates. Some of these researchers focus on plates forced uniaxial or biaxial in-plane load, uniaxial tensile [7–9], biaxial tensile [11], uniaxial tensile and biaxial tensile–compressive (shear) [10] subjected to low velocity impacts.

Saghafi et al.[8] investigated the effect of preloading on the impact behavior of GFRP curved laminates. The result of the study is that the compression preload reduces the propagation of cracks, while in a tension preload field cracks propagate easily. The effects of impactor shape and biaxial preload on the impact behavior of the glass

* Corresponding author. Tel.: +90 5442524519.
E-mail address: alikursun@hitit.edu.tr (A. Kurşun).

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Nomenclature

Symbol	definition
σ_1	Component stress acting at fiber direction
σ_2	Component stress acting at normal to the fiber
σ_3	Component stress acting at normal to the ply plane
σ_{12}	Shear stress acting at the ply plane
σ_{13}	Shear stress acting transverse to the ply plane
σ_{23}	Shear stress acting transverse to the ply plane
X_T	Strength value parallel to the fiber under tension
X_c	Strength value parallel to the fiber under compression
Y_T	Strength value normal to the fiber under tension
Y_c	Strength value normal to the fiber under compression
e_F	Failure index for the fiber
e_M	Failure index for the matrix
E_{11}	Young modulus at fiber direction
E_{22}	Young modulus at normal to the fiber
υ_{12}	Poisson's ratio
d_f	Modulus degradeted after fiber damage
d_m	Modulus degradeted after matrix damage
d_{ela}	Modulus degradeted after delamination

fiber reinforced polyester laminates were studied by Mitrevski et al. [11]. They obtained results that under tensile preloading the contact force and time are increased as well as the deflection are reduced compared to the impacted unloaded plate. Kurşun and Şenel [6] performed the effects preloaded on low-velocity impact of the E-glass/epoxy-laminated composites. The samples were loaded biaxial tension, compression and shear loading. A finite element model was developed by Tita et al. [17], using Hill's model and material, models implemented by UMAT (User Material Subroutine) into ABAQUS™ software, in order to simulate the failure mechanisms under the indentation tests.

In the literature, there is a scarcity of information on the effect of preloading on the impact response of composite laminates, and thus better data on the response to low-velocity impacts of preloaded structures are needed.

In the present work, an experimental and numerical study of the influence of an in-plane biaxial load on the impact behavior of E-glass/epoxy-laminated composites plates was analyzed. Finite element analysis (FEA) was developed, using Hashin failure criteria for

Table 1
The mechanical properties of a unidirectional layer.

Property	Value
Fiber volume fraction (V_f)	57%
Longitudinal modulus (E_1)	45 GPa
Transverse modulus (E_2)	11 GPa
In-plane shear modulus (G_{12})	3.75 GPa
Major poisson's ratio (υ_{12})	0.33
Longitudinal tensile strength (X_t)	820 MPa
Transverse tensile strength (Y_t)	48 MPa
Longitudinal compressive strength (X_c)	365 MPa
Transverse compressive strength (Y_c)	127 MPa
Interlaminar shear strength (S_i)	38 MPa
In-plane shear strength (S)	57 MPa

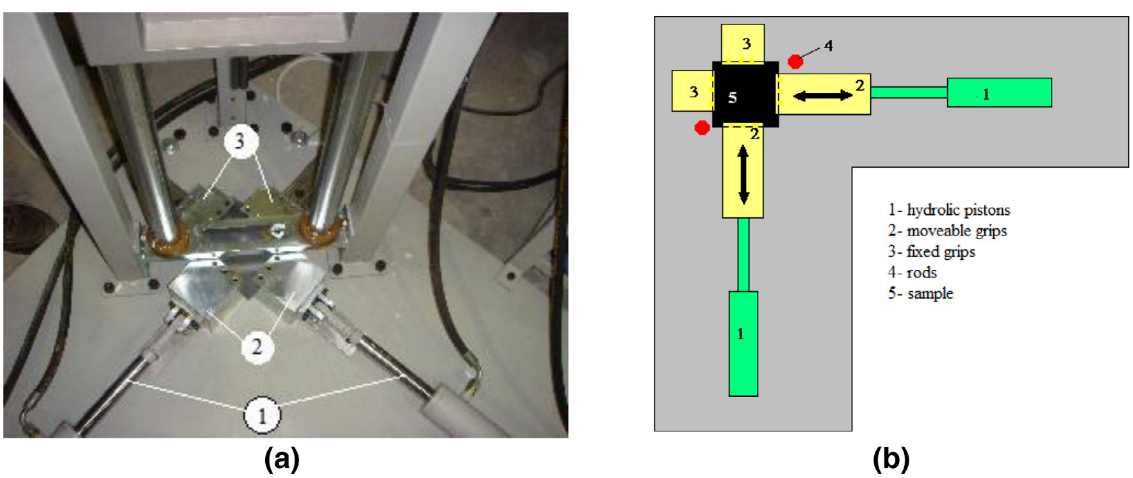

Fig. 1. (a) Preloading system; 1-hydrolic pistons, 2-moveable grips, 3-fixed grips and (b) schematic drawing.

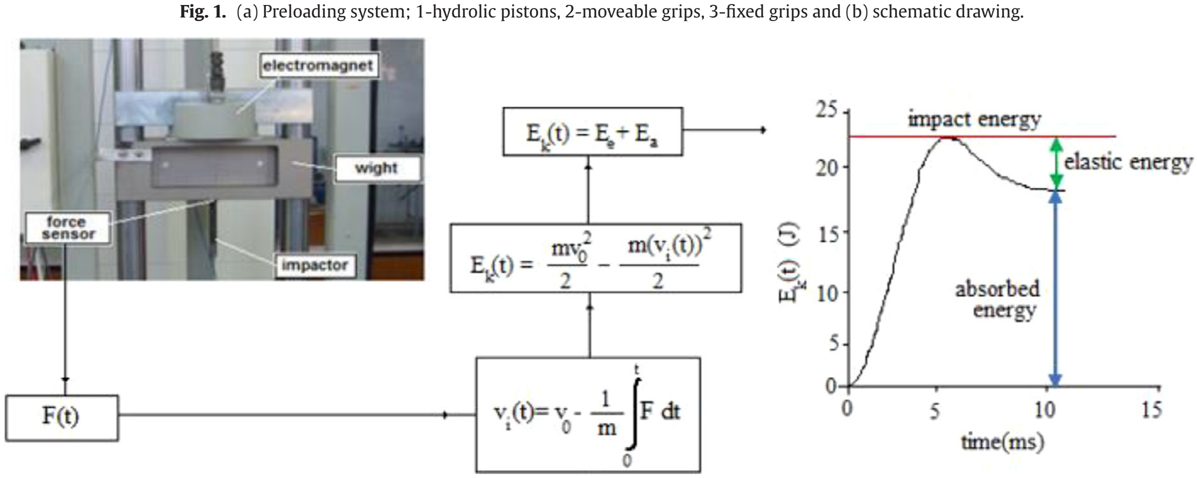

Fig. 2. Impact energy level, absorbed energy, and elastic energy [6].