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Performance of composite I-beams under axial compression and bending load modes

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Abstract

An experimental and finite-element analyses for glass/epoxy composite I-beams have been carried out. Four, six, eight and ten layers of woven fabric glass/epoxy composite I-beams were fabricated by a hand lay-up (molding) process. Quasi-static axial crushing and bending loading modes were used for this investigation. The load–displacement response was obtained and the energy absorption values were calculated for all the composite I-beams. Three tests were done for each composite I-beams type and each loading case for the results conformation. The second part of this study includes the elastic behavior of composite I-beams of the same dimensions and materials using finite-element analysis. The woven fabric glass/epoxy composite I-beams mechanical properties have been obtained from tensile tests. Results from this investigation show that the load required and the specific energy absorption for composite I-beams under axial compression load were higher than those for three and four point bending. On the other hand, the loads required for composite I-beams under four point bending were higher than those for three point bending, while the specific energy absorption for composite I-beams under three point bending were higher than those for four point bending. The first crushing loads difference between the experimental and finite-element results fell in the 3.6–10.92% range for axial compression tests, while fell in the 1.44–12.99% and 4.94–22.0% range for three and four point bending, respectively.

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1. Introduction

Composite materials are being proposed for applications to aircraft and automotive structures to meet stringent weight and manufacturing cost constraints. Composite materials can exhibit crushing modes, which are significantly different from the crushing modes of metallic materials. Composite structures have a wide range of applications because of their high stiffness and strength with respect to the weight. In addition, composite materials have high corrosion resistance, thermal expansion, thermally resistive and considered as non-conductive materials.

The numerical simulation on the pultrusion of fiber glass–vinyl ester composite I-beams using a numerical procedure based on general purpose FE packages has been described [1]. The procedure is verified by good agreement between the predicted temperature profiles and the experimental ones. The effect of various process parameters and/or heating configurations on the temperature and curing profiles in the composite I-beams were also investigated. His results are used to determine preferred process conditions and/or heating configurations for the pultrusion of the composite I-beams.

An extensive study on crushing behavior of fiber-reinforced composite material has been carried out [2]. He found that composite materials absorb high energy, despite that the mechanism is fracture surface energy rather than plastic deformation.

The effect of section shape on the specific energy absorption of composite tubes has been investigated [3].

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Nomenclature

AX	Axial compression	W_d	Work done (total energy)
FCL	First crushing load	H	Specimen height
TPB	Three point bending	W	Specimen width
FPB	Four point bending	ρ	Material density
ICBM	Initial crushing bending moment	A	Cross-section area
L_c	Crushed length of specimen	V	Crushed volume of specimen
M	Bending moment	L	Specimen span
S_s	Specific crushing energy absorption	t	Specimen thickness
S_b	Bending energy absorption	θ	Rotation angle

They concluded that for a given fiber lay-up and tube geometry, the specific energy absorption increased in the order, rectangle square circular.

The flexural–torsional buckling behavior of pultruded E-glass FRP I-beams has been experimentally investigated [3], and the observed results compared well with numerical predictions using a finite-difference method. There is potential danger in analysis and design of FRP beams without including shear deformation [4].

Furthermore, a comprehensive experimental and analytical approach to study flexural–torsional buckling behavior of pultruded two full-size FRP wide-flange I-beams with two different material architectures have been carried [5]. The equilibrium equation in terms of the total potential energy was solved [5] by the Rayleigh–Ritz method, and simplified engineering equations for predicting the critical flexural–torsional buckling loads. A good agreement is obtained between the experimental results, proposed analytical solutions and finite-element analyses. They found that the testing set-up used can be efficiently implemented in the characterization of flexural–torsional buckling of FRP shapes and the proposed analytical design equations can be adopted to predict flexural–torsional buckling loads.

On the other hand, simplified the general governing equations given [6], for a special case, has been simplified [7], to obtain static deformation response of composite I-beams subjected to torsional loads. They developed appropriate solution procedures for estimating rotation and warping deformations. They found also that the numerical results for a cross-ply laminated graphite-epoxy cantilever I-beam subjected to a torsional load at the free-end show good correlations with the available experimental and theoretical results. The restraining of warping deformation amounts to a significant increase in the torsional stiffness of the beam. Some additional results for cross-ply glass/epoxy and steel beams are also consistently good.

In addition, more general asymptotically correct theory of composite I-beams applied to the lateral–torsional stability of cantilevered beams at the same time giving heed to the effects of prebuckling deflections [8], offset of the applied load away from the centroid, and elastic coupling to obtain an approximate, closed-form solution for the buckling load taking into account all of these phenomena. They found that using comparison function, a formula for the buckling load as a function of the small parameters of the problem is found and validated.

Ceramic matrix composite (CMC) I-sections has been tested experimentally [9]. Axial loads and moments have been applied to activate delamination mechanisms. They found that the delamination propagates primarily through the matrix, which has a relatively low toughness. The consequence is that the peak load bearing capacity exhibits considerable variability, governed by the size distribution of manufacturing flaws.

Analytical solutions for the static response of composite I-beams loaded at their free-ends have been analyzed within the circumferentially uniform stiffness (CUS) and circumferentially asymmetric stiffness (CAS) ply-angle configurations [10]. They found that, in the CAS case, the warping restraint plays a much stronger effect than in the CUS case, while, in the CUS case, for the warping restraint twist model the ply-angles have a more distinct effect on twist distribution as compared to the CAS case, where the influence of the ply-angles is almost immaterial. They also found that the increase of the ply-angle yields a decrease of the extensional displacement.

Moreover the application of micro/macro mechanics models and optimization techniques for the optimum design of pultruded glass fiber-reinforced plastic composite I-beams with respect to material architecture: fiber orientations and fiber percentages have been studied [11,12]. The design objectives include minimization of beam mid-span deflections and maximization of buckling loads and FPF loads. The beams are subjected to transverse loading, and beam deflection, buckling resistance and material failure is considered as multiple objectives in the optimization process. They used the Tsai–Hill failure criterion to determine first-ply-failure loads. They also evaluated the critical buckling loads by using Rayleigh–Ritz solution for pultruded I-beams, and the results are verified with finite-element analyses.

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