Influence of Fabric Weave Pattern on Buckling Behavior of Fabric Reinforced Composite Plates with Through the Width Delamination

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Abstract

Delamination is one of the most common failure modes in composite materials which affects the overall stiffness of the structure. In present study, the compressive buckling behavior of E-glass/epoxy composite laminates with artificial through the width delamination is investigated experimentally. Glass fabrics with two most basic weave patterns, i.e. plain and twill(2/2) were used as reinforcement of composite samples. Each laminate consists of 8 layers with same fabric weave type. Compression tests were carried out on specimens in order to compare the buckling load-carrying capacity of the two different types of fabric reinforced composites with each other. Results showed that the reinforcement weave type has a considerable effect on compressive behavior of laminated composites.

1. INTRODUCTION

Fibrous composite materials, due to their high potential in terms of stiffness/strength to weight ratio, are widely used in applications where low weight and high stiffness/strength conditions for structures have to be reached. Designing structures with optimum stiffness and strength in particular directions is attainable owing to the inherent heterogeneity of composite materials. However, the heterogeneity is also the source of weakness in such materials, regardless of the nature of the constituents. For instance, in fiber reinforced laminated composites the interface between reinforcing fibers and the matrix is prone to the onset and growth of damages. In this case, one of the most prevalent damages is the delamination between adjacent layers. Delamination has been a subject of major concern in engineering applications of composite laminates because of the problems associated with structural stability, reduction in load-bearing capacity, stiffness degradation and fracture. The presence of the delamination in a flat laminar structure may lead to local buckling when subjected to compressive loads and, in consequence, it will affect the overall stiffness and strength of the structure [1,2]. Numerous studies have been carried out to investigate the buckling behavior of composites with delaminations [3-12]. Chai et al. have established an analytical one-dimensional model for the analysis of delamination buckling of beam-plate using fracture mechanics-based energy release rate criterion [3]. Shivakumar and Withcomb have studied the buckling behavior of thin elliptical delamination using the Rayleigh–Ritz and finite element method [4]. Nilsson et al. have performed an experimental investigation of buckling induced delamination growth [5]. Gu and Chattopadhyay have used higher order shear deformation theory to study the buckling behavior of delaminated composite plates [6]. The effects of delamination and ply-arrangement on the compressive failure of multi-layered structures were identified by Nakamura and Wu using the energy release rate and mixed-mode stress intensity factors [7]. Shu analyzed the buckling behavior of the laminated composites with two centrally through-the-width delaminations [8]. In his study, the classical laminate theory was employed, and the effects of the constraint imposed by the sublaminates to each other and to the base laminate on the buckling behavior of the plate were investigated. Ovesy et al. have investigated post-buckling analysis of composite plates containing embedded delaminations by using higher order shear deformation theory [9]. They have analyzed plates with square or circle delaminated regions and their formulation are developed specifically for these shapes of delaminations. In their work, which is based on the Rayleigh-Ritz approximation technique, the shape of the delaminated region has an important role in defining the corresponding shape functions.

Although many researchers have investigated the effect of ply orientation, delamination shape, size, and location on the buckling behavior of laminated composites, there is a lack of information in the literature about making a comparison among the buckling behavior of laminates reinforced by different woven fabrics. Thus this paper aims to investigate the influence of two most basic weave patterns of woven fabrics, i.e. plain and twill (2/2) on the buckling of delamination-inserted composite plates subjected to in-plane compressive loads.

2. Material and Method

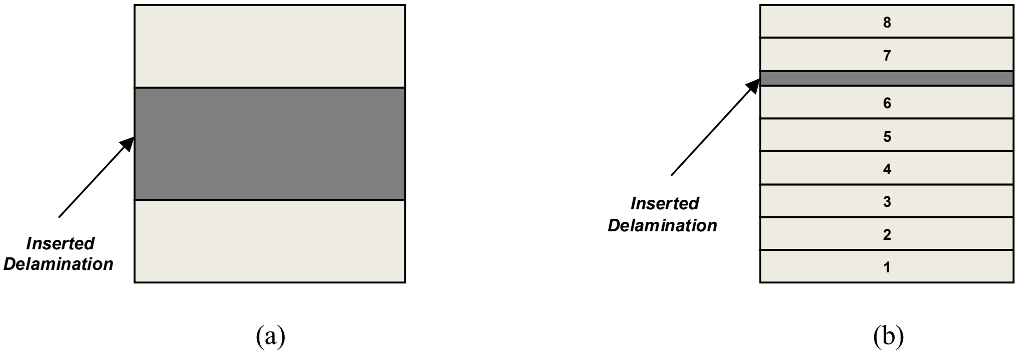
2.1. Manufacturing of Laminated Composites

Laminated composites with eight layers were produced using hand lay-up technique. E-glass woven fabrics with two basic weave patterns, i.e. plain and twill(2/2) were used as the reinforcements of composite samples. The characteristics of woven fabrics are shown in Table 1. A cold-curing epoxy system based on Araldite® LY 5052 (resin) and Aradur® 5052 (hardener) was used as the matrix constituent with a mixing ratio of 100:38 (resin to hardener) by weight.

Weave Type	Weight per Unit Area (g/m^2)	Warp Density (ends/cm)	Weft Density (picks/cm)
Plain	353.25	6.3	6.3
Twill(2/2)	346.61	6.8	6.8

Table 1. Properties of E-glass fabrics.

The mixture of resin and hardener was deposited on the surface of each layer one by one, and then brushed to spread evenly over each layer. In order to create an artificial through-the-width delamination area, a very thin aluminum film in the shape of rectangle with the dimensions 19 cm * 13 cm and the thickness of approximately 12 μm was inserted between 6th and 7th layers and right in the center of plate. Hence layers from the 1st to the 6th form the 'base laminate' and the layers 7th and 8th are referred to as 'sub-laminate' of laminated composites. Figure 1 shows the schematic diagram of layers and the inserted delamination. Curing process was done in room temperature and 31% relative humidity for 24 hours. The cured laminates were cut into the shape of square with the dimensions of 19 cm * 19 cm. The laminated composites consist of eight layers with two different configurations, $(p/p/p/p)_s$ and $(t/t/t/t)_s$ which respectively represent laminates made up of plain weave fabrics in all eight layers and twill (2/2) weave ones in all. The properties of two different configured laminates are shown in Table 2.



(a) (b)

Figure 1. Schematic diagram of laminate with inserted through-the-width delamination: (a) Top view (b) Side view.

Laminate Configuration	Number of layers	Thickness (mm)	Fiber Volume Fraction (%)	Void Content (%)
$(p/p/p/p)_s$	8	2.38	46	2.3
$(t/t/t/t)_s$	8	2.32	49.6	3.3

Table 2. Properties of two different configured laminates.

2.2 Buckling Tests

Buckling tests under uniaxial compressive load were carried out in order to determine buckling behavior of laminated composites using DARTEC Tensile Testing Machine with 50 kN load capacity in the Fracture Laboratory of Aerospace Engineering Department, Amirkabir University of Technology. Composite specimens were located in a particular frame to provide desired boundary conditions (Figure 2). Uniaxial compressive load was acted to the specimens longitudinally while the loaded edges were simply supported and the remaining edges were completely free. Three samples of each configuration were tested with a constant head displacement rate of 0.01 mm/s in room temperature and 31% relative humidity.

During the tests, specimens initially sustain the applied load (stage 1) and then under a critical load the sub-laminate started to buckle in the mode of local buckling (stage 2). After a while base laminate also buckled in the same direction of sub-laminate buckling due to the increasing acted load (stage 3). It continued until the whole structure reached the point in the mode of global buckling where there was no longer increase in load carrying amount, while the deflection of buckled specimen persisted (stage 4). Figure 3 shows the diagram of above-mentioned stages.

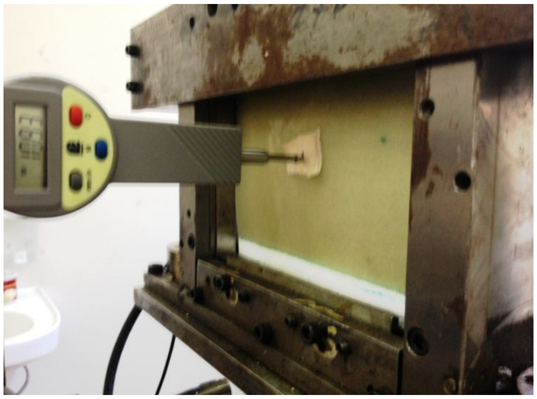


Figure 2. laminated composite specimen located in the frame and subjected to uniaxial compressive load.

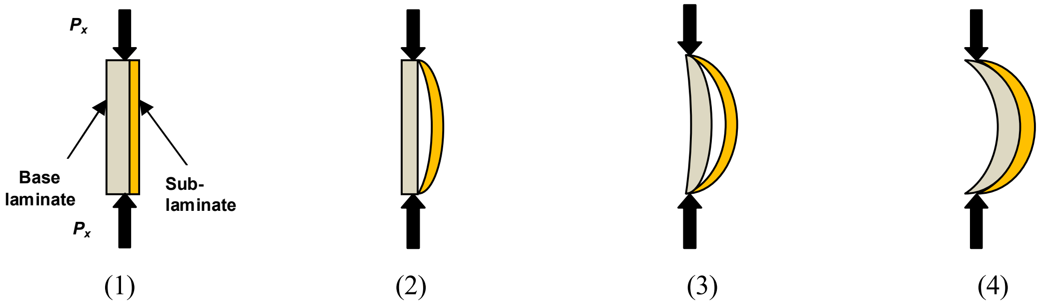


Figure 3. Stages of compression behavior of specimens.

3. Results and Discussion

Results of buckling tests for the specimens are plotted in the form of edge load (P_x) versus the end shortening (u) as shown in Figures 4 and 5. Furthermore, critical buckling loads obtained from experiments are given in Table 3. In order to draw a comparison between two different types of laminates, results of buckling tests were normalized by eliminating the effect of the difference in fiber volume fractions of specimens on the experimental data.

Results show that critical buckling load in laminated composites with the $(p/p/p/p)_s$ configuration is higher than the critical load in the $(t/t/t/t)_s$ ones. Considering the results in Figures 3 and 4, the load-carrying capacity in $(p/p/p/p)_s$ specimens is also more. It attributed to the difference between the structures of reinforcements. As shown in Figure 6 which illustrates the cross-sections of an equal repeat of two weave patterns, i.e. plain and twill 2/2, the number of resisting elements in the direction of applied load, i.e. weft threads and sections of warp thread interlaced by weft threads with the diameter of D which resisting the deformation viscoelastically under the compression in a 4-thread repeat plain weave structure is more than that in twill 2/2. Hence the compressive resistance of $(p/p/p/p)_s$ samples are higher than $(t/t/t/t)_s$ ones.

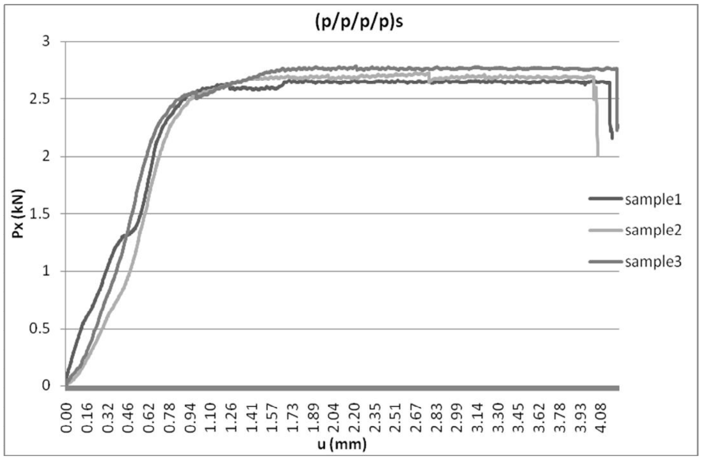


Figure 4. Load-end shortening curves of $(p/p/p/p)_s$ samples.

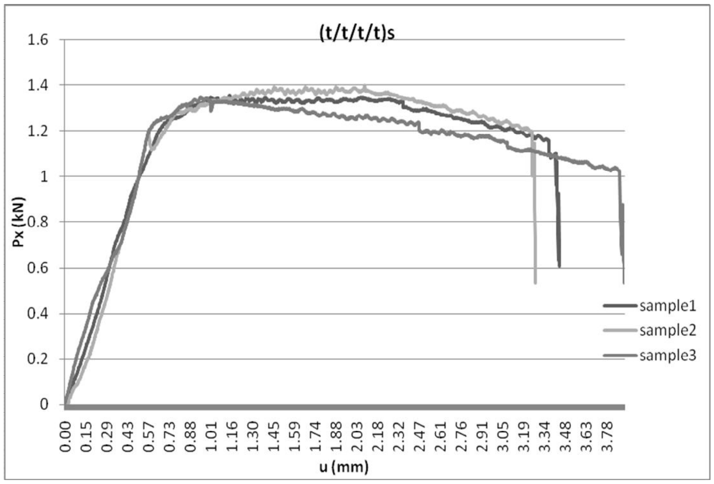


Figure 5. Load-end shortening curves of $(t/t/t/t)_s$ samples.

In order to verify the significance of differences in the critical buckling loads of $(p/p/p/p)_s$ and $(t/t/t/t)_s$ samples statistically, Mean Comparison Test was done. For this aim, the statistical software package SPSS 19 was used to interpret the experimental data. All test results were assessed at significance level of $\alpha \leq 0.05$. Mean Comparison Test results showed significant differences between the critical buckling loads of two different types of laminated composites (Sig<0.05).

Laminate Configuration	Critical Buckling Load (kN)			Mean	CV%
	Sample 1	Sample 2	Sample 3		
$(p/p/p/p)_s$	0.139	0.117	0.124	0.127	8.87
$(t/t/t/t)_s$	0.083	0.076	0.092	0.084	9.58

Table 3. Critical buckling loads of laminates.

(a) (b)

Figure 6. Cross-section of 4-thread repeat of (a) twill 2/2 (b) plain weaves.

4. Conclusions

In this study, the effect of fabric weave pattern on the buckling behavior of woven E-glass/epoxy laminated composite plates with through-the-width delamination was investigated experimentally. It was found that the critical buckling load of composite laminates with $(p/p/p/p)_s$ configuration is higher than the critical load of those with $(t/t/t/t)_s$ configuration. Buckling test results also indicated that the load-bearing capacity of $(p/p/p/p)_s$ laminates is more than that of $(t/t/t/t)_s$ laminates. Results of statistical tests also confirmed that there is a significant difference between critical buckling loads of two different types of laminates.

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