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Buckling behavior of 1 × 1 rib knitting laminated plates with cutouts

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ABSTRACT

The purpose of this study is to investigate the cutout shape effects on the buckling behavior of 1 × 1 rib knitting glass/epoxy laminated plates in three different knitting tightness levels as low, medium and high. The composite plate is produced five plies as $[0°]_{5\mathrm{Course}}$ by using hand lay-up technique. In order to investigate the shape effects, five different plates are used such as, without cutout (W-C), central circular/elliptical cutout (C/E-C), central square/rectangular cutout (S/R-C), edge semi-circular/semi-elliptical cutout (SC/SE-C), and edge semi-square/semi-rectangular cutout (SS/SR-C). In addition, circular/elliptical diameter-to-plate width ratio and square/rectangular length-to-plate width ratio effects on buckling load of 1 × 1 rib knitting glass/epoxy plates are also investigated. The experimental buckling loads of plates are obtained by clamping from two edges and then these results are compared with the results calculated from the numerical analysis. ANSYS 10 commercial software is used for numerical study. A good agreement was obtained between finite element method and experimental measurements. Results are showed that the buckling loads depend on the cutout area and the level of tightness.

1. Introduction

The textile reinforced composite materials have wide application areas in marine, automobile, aerospace and aircraft industries. Among the textile composites, knitted fabric preforms have been gaining importance because of their versatile structures and acceptable mechanical features. Compared to the other conventional textile composites knitted fabric composites are of excellent properties. For instance, the strength and stiffness of knitted composites are higher than fiber mats composites but lower than woven composites [1]. However knitted composites are more isotropic than woven composites. The increasing use of knitted composite materials in a lot of engineering applications has motivated the researchers to investigate their properties. One of the areas of interest has been examined of the buckling behavior of knitted composite plates. During operation the composite plates are usually subjected to compression loads that may cause buckling if overloaded. Therefore their buckling behaviors are significant in reliability and safety of these components. On the other hand, cutouts that often found in composite structures have an important effect on the buckling behavior. These are located in structural parts to ventilate or to lighten the structure. For instance, cut outs are necessary for inspection, access, electric lines and fuel lines or to reduce the all weight of the aircraft [2].

The knitted fabric composites and buckling of composite plates have received the attention of many researchers over the past years. Gommers et al. [3,4] have analyzed the influence of the stiffness and strength of glass warp knitted fabric epoxy composites in tensile and shear loading. Leong et al. [5] have analyzed the mechanical performance of resin transfer molded composites comprising a weft-knit glass fabric of milano rib architecture. They found that the knitted composites have relatively poor tension and compression properties but comparable bearing performance with respect to conventional composites. Ramakrishna [6] has determined the tensile properties of plain weft-knit glass/epoxy composites experimentally in the wale and course directions and predicted the elastic properties using a cross-over model and laminated plate theory. Baba [7] has investigated the influence of boundary conditions, length/thickness ratio and ply orientation on the buckling load for rectangular plates with various cutout shapes. She has conducted the tests on laminated composites with circular and semicircular cutouts under various boundary conditions and she stated that the results showed a complex interaction between plate orthotropy and boundary conditions. Yazıcı [8] has examined the influence of square cutout upon the buckling stability of steel woven fiber-reinforced polypropylene thermoplastic matrix composite plates using numerical and experimental methods. The results revealed that the critical buckling loads were more affected by square holes under clamped boundary conditions than the simple supported case and the biggest decreases in the critical buckling loads were observed between 0° and 15° fiber orientations.

Pekbey and Sayman [9] have performed the experimental and numerical study on glass/epoxy composite plates to investigate the buckling behavior of single-delamination size. They have also

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considered the variation in structural configurations, such as ply stacking sequence, width of the delamination and specimen geometry. Compression tests were performed on EP GC 203 glass/epoxy woven composites with built-in single embedded delamination in order to evaluate the critical buckling load. They found a good agreement between finite element predictions and experimental measurements for the delamination geometries that were tested. Guo [10] has investigated the effect of reinforcements around cutouts on the stress concentration and buckling behavior of a carbon/epoxy composite panel under in-plane shear load. In the analysis, finite element method and an analytical method based on the laminate theory were employed to perform parametric studies on the various reinforcement designs. Four test panels were produced and tested to validate the analysis results. At the end of the paper, it is reported that there was a good agreement between the analytical and test results.

Jain and Kumar [11] have analyzed the post buckling response of symmetric square laminates with a central circular/elliptical cutout. They have used the finite element method to study the post buckling response of symmetric square laminates with a central cutout under uniaxial compression and solved the governing equations using the Newton–Raphson method. For the analysis, the effect of cutout shape, size and the alignment of elliptical cutout on the buckling and first-ply failure loads of laminates with circular and elliptical cutouts were examined. They found that these parameters have a significant effect on the reserve strength. Ungbhakorn and Singhatanadgid [12] have employed an extended Kantorovich method to investigate the buckling problem of rectangular laminated composite plates with various edge supports. They have determined the buckling load and mode from iterative calculations of the governing equations. Results showed that the presented semi-analytical approach could be used to analyze the buckling of laminated unidirectional and cross-ply symmetric plates with any combinations of simple, clamped, and free supports. Ambur et al. [13] have investigated the progressive failure analysis of compression-loaded composite curved panels with and without cutouts. Damage modes such as matrix cracking and fiber failure were modeled by degrading the material properties. They have observed good agreement between experimental data and numerical results for most part of the loading range for the structural configurations considered.

Although there has been considerable investigation dedicated to mechanical features of knitted fabric composites and buckling behavior of composite laminates in the literature, the influence of knitting tightness on the buckling behavior of weft-knitted fabric composites is not thoroughly understood. Therefore, in this study, the buckling behavior of the weft-knitted 1×1 rib glass fabric reinforced epoxy composites plates with various cutout shapes (C/E-C, S/R-C, SC/SE-C and SS/SR-C), which are manufactured from different knitting tightness levels are investigated.

2. Materials and methods

This investigation has three sub steps. Firstly, 1×1 rib knitting glass/epoxy materials are manufactured and then the mechanical properties of this material are determined according to ASTM standards. Secondly, the experimental buckling study is carried out. And finally, the numerical buckling analysis is performed by using ANSYS 10 commercial software.

2.1. Material production and determination of the mechanical properties

In this study; weft-knitted 1×1 rib fabric is used as the reinforcement material, and it is produced in three different tightness levels as low, medium and high. The illustration and photograph of the knitted fabrics of three different tightness levels are indicated in Fig. 1. In order to manufacture the fabric, 200 tex glass yarn with a slight twisting is used and it is knitted on a five gauge flat bed knitting machine. The samples used for the experimental study are produced from the five layers of the glass fabric and CY225 epoxy resin. To obtain the flat composite laminates, the knitted fabric layers are put into a mold whose course directions are parallel to each other and resin is impregnated. After the impregnation, the laminated plates are retained at a constant pressure (15 MPa) and 130 °C during 3.5 h for curing process. The fiber weight fraction of the low, medium and high tightness plates are fabricated as 59%, 61% and 65%, respectively. At the end of the process, the complete set-up is cooled to room temperature. The weight, course and wale density of the fabrics are given in Table 1.

The mechanical properties of glass/epoxy laminated plates are determined under static loading conditions according to the ASTM standards. The mechanical tests are carried out in the Department of Mechanical Engineering of Usak University by using UTEST Tensile Testing Machine of 50 kN load capacity at a ratio of 1 mm/min.

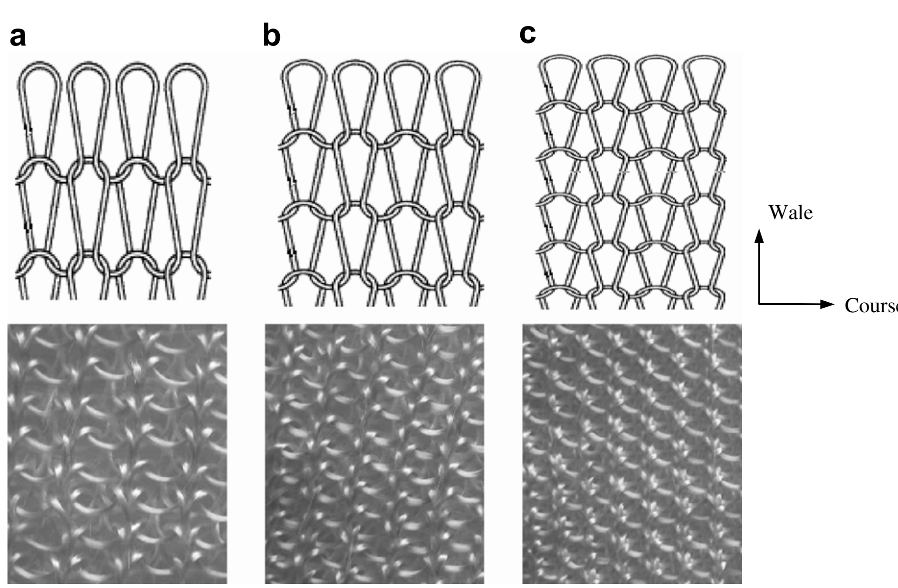

Fig. 1. The illustration and photographs of knitted fabrics (a) low, (b) medium and (c) high tightness.