Chapter 8

Design and Optimization of Defense Hole System for Shear Loaded Laminates

Mohammad Al-Husban
Civil Aviation Regulatory Commission, Jordan

Salih N. Akour
Sultan Qaboos University, Oman

Jamal F. Nayfeh
Prince Mohammad Bin Fahd University, Kingdom of Saudi Arabia

ABSTRACT

Reducing stress and weight of structures are most important to structural designers. Most engineering structures are an assembly of different parts. On most of these structures, parts are assembled by bolts, rivets, et cetera; this riveted and bolted structure is highly used in aerospace industry. Defense hole theory deals with introducing auxiliary holes beside the main hole to reduce the stress concentration by smoothing the stress trajectories in the vicinity of the main hole. These holes are introduced in the areas of low stresses that appear near the main circular hole. Defense hole system under shear loading is investigated. The optimum defense hole system parameters for a circular hole in an infinite laminated composite plate are unveiled. This study is conducted using finite element method by utilizing commercial software package. The finite element model is verified experimentally using RGB-Photoelasticity. Digital Image Processing is utilized to analyze the photoelastic images.

Stress concentrations associated with circular holes in pure biaxial shear-loaded laminates can be reduced by up to 20.56%. This significant reduction is made possible by introducing elliptical auxiliary holes along the principal stress direction. The effect of the stacking sequence, the fiber orientation, and the stiffness of both the fiber and the matrix are investigated.

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INTRODUCTION

Composite materials offer many advantages over metals such as: high strength and high stiffness-to-weight ratio, good fatigue strength, corrosion resistance and low thermal expansion. Composite materials such as glass fiber, aramide fiber, boron fiber and carbon-fiber-reinforced plastics have been used for a few decades, especially in aircraft industry. Aircraft structures include large number of open holes and cut-outs e.g. holes for electric wires and hydraulic pipes or holes required for assembly or maintenance where a laminate containing open holes is subjected to shear loading i.e. biaxial loading case. Joining by mechanical fasteners is one of the common practices in the assembly of structural components. Improper design of the joints may lead to structural problems. Conservative design may lead indirectly to overweight structures and high life-cycle cost of aircraft. Typical examples of mechanically fastened joints in composite aircraft structures are: the skin-to-spar/rib connections, the wing structure, the wing-to-fuselage connection etc. Since the failure of the joints can lead to the catastrophic failure of the structures, an accurate design methodology is essential for adequate design of the joints.

Introducing auxiliary holes in the neighborhood of a main hole to reduce the stress concentration is called defense hole (DH) theory which has been known since the early years of last century. Most of the work that has been done so far deals with defense hole system (DHS) under uniaxial loading on sheet metals (isotropic material). Some efforts are done for shear loading.

Numerical and experimental studies for reducing stress levels in structures by introducing other geometric discontinuities are very few. Erickson and Riley (1978) investigated the effect of the DHs on the stress concentration around the original hole using two- dimensional photoelasticity. Jindal (1983) examined the reduction of stress concentration around circular and oblong holes using the FE Method and photo-elasticity analysis. Meguid (1986 & 1989) studied the reduction of stress concentration in a uniaxially-loaded plate with two co axial holes using the Finite Element Analysis (FEA). Rajaq and Naik (1986) investigated hole – shape optimization in a finite plate in the presence of auxiliary holes using the two dimensional photoelastic methods. Ulrich and Moslehy (1995) used boundary element methods to reduce stress concentration in plates by introducing optimal auxiliary holes. Durelli (1978) investigated the optimization geometric discontinuities in stress field under uniaxial loading. Dhir (1981) studied the hole shape optimization in plate structure under tension and shear loading. Summary of the previous work is presented in Figure 1. Akour et. al (2003) studied the design of a DHS for pure shear-loaded plate. Mittal and Jain (2008) investigated the effect of fiber orientation on stress concentration factor in a laminated composite plate with central hole under in-plane static loading.

Most of the previous work in DH design has been done for sheet metal plates (isotropic material). Some attempts are made for composite plate under uniaxial loading. In the current research, design and optimization of stress relief system for composite laminate is investigated and unveiled the optimum design parameters of the DHS.

This research has investigated the optimum design of the DHS by utilizing univariate and pattern search optimization technique (Chapra and Canal, 2006). This technique is multi-dimensional numerical optimization technique. DHS under general in-plane biaxial shear loading is investigated. The optimum size, shape and position of the defense holes, the effect of thickness the laminate with different types of laminates such as cross-ply and angle ply laminate are obtained. The Experimental verification for selected cases is conducted using RGB photoelasticity techniques (Ajovalastit et al, 1995, Akour et al, 2003).
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