Strain Concentration Analysis of Biaxialy Loaded Countersunk Hole in an Orthotropic Plate

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Abstract

This research investigates the strain concentration factors (SCFε's) around a centered countersunk hole in an infinite orthotropic laminate subjected to a biaxial static load. ANSYS - finite element software is used to build the finite element (FE) model and to perform the analysis. The effect of the biaxial remote strain ratio, the geometric parameters of the hole, and the material orthotropy represented by the ply angle of the laminate on the maximum SCFε's at the hole is studied. Based on the FE results, it is found that the SCFε's are directly proportional to the parametric dimensions of the hole and also dependent of the biaxial remote strain ratio and the ply angle of the laminate. It is found that a compromised minimum SCFε's can be attained by selecting a ply angle between 70 and 80-degrees for remote strain ratios less than 1.0 and a ply of 45^{o} for a remote strain ratio of 1.0.In this paper we show the basic formatting required for papers submitted to the CM13 conference to be held in March 2013 at Durham University. Please use this file as the initial template for your own submission and follow the guidelines included. This will allow the rapid inclusion of your work within the conference and associated proceedings.

Keywords: Strain concentration, Biaxial load, Orthotropic material

1. Introduction

Flush rivets are commonly used in joining thin structural components such as the fuselage and the external surfaces of airplanes and marine vessels. Upon their application, flush rivets form countersunk holes through the thickness of the joint and act like stress and strain risers. Therefore, stress and strain analyses around such holes must be carefully considered in the design of the joint to avoid any structural failures at low load levels.

Numerous results for the stress concentration factor (SCF) around holes of different geometries and under different types of loading conditions are reported in the literature [1]. Experimental failure results of riveted fuselage specimens under uniaxial and biaxial loading conditions were reported by the FAA [2]. The failure due to biaxial tensile loading of a quasi-isotropic composite plate with a circular hole was experimentally investigated [3, 4]. The limit load of plates with different hole shapes under different loading conditions was analytically estimated and compared with the FE results [5]. Analytical stress solutions were obtained for the SCF around cutouts in infinite composite laminates subjected to biaxial loading [6]. A finite element investigation was carried out on a stiffened plate with a square cutout under various combinations of biaxial loading conditions [7]. A general analytical solution was also obtained for the stresses and deformations around a traction free elliptic hole in an infinite plate subjected to a biaxial load [8]. The size effect of a countersunk hole on the SCF of infinite plates subjected to different loading conditions was investigated through finite element analysis (FEA) [9]. Parametric equations for the stress and strain concentration factors around a countersunk hole in an isotropic plate under uniaxial tension were formulated [10, 11]. A modified equation for the uniaxial SCF around a countersunk hole was reported as well [12]. A new equation for the SCF around countersunk rivet holes in orthotropic laminates under uniaxial tension was expressed as a function of the hole geometry and the material orthotropy [13]. The effect of the plate thickness and the notch geometry on the SCF, the stress constraint factor and the strain energy density was investigated through an analytical solution of the stress domain around the notch [14].

The main objective of this study is to examine through FEA the effect of the remote strain ratio ($R = \varepsilon_{xo}/\varepsilon_{yo}$), the dimensions of the countersunk hole and the material orthotropy of the laminated plate on the in-plane strain concentration factors in the x- and y-directions, $Kt_{\varepsilon,x}$ and $Kt_{\varepsilon,y}$ respectively, which are defined as the ratio between the maximum local strain at the hole and the applied remote strain at the edge of the plate as expressed in equations (1).

$$Kt_{\varepsilon,x} = \frac{\varepsilon_{x,\max}}{\varepsilon_{xo}} \quad , \quad Kt_{\varepsilon,y} = \frac{\varepsilon_{y,\max}}{\varepsilon_{yo}} \tag{1}$$

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