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Using dragonfly algorithm for optimization of orthotropic infinite plates with a quasi-triangular cut-out

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ABSTRACT

This paper aims at optimizing the parameters involved in the stress analysis of perforated orthotropic plates, to achieve the lowest value of stress around the quasi-triangular cut-out located in an infinite orthotropic plate by using the Dragonfly Algorithm (DA) method. This method is used to calculate the stress distribution based on Lekhnitskii's analytical solution. The study design variables include fiber angle, load angle, bluntness, orientation angle of cut-out and the material properties. In addition, the performance of the DA algorithm is compared with the Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). The comparison of these methods indicates the appropriateness of the DA algorithm in optimizing the perforated plates. The finite element method has been used to verify the accuracy of the analytical results. The results indicate that by selecting the aforementioned parameters properly, we can increase the structural load-bearing capacity.

1. Introduction

The recent years have seen an increase in the use of composite materials in the manufacture of mechanical, space and marine structures as well as in the automotive industry. At the same time, perforated plates can be observed in many industrial applications. These cut-outs are mostly created in plates to reduce the weight of a structure or to create points of entry and exit. These cut-outs change the plate geometry and lead to severe local stresses (this is called stress concentration) around the cut-outs. Stress concentration reduces the strength and causes premature failures in structures and plastic deformations at the point of stress concentration. Experience has shown that most failures created in aerial structures originate from the presence of stress concentration in the structural fittings and fasteners. Knowing the stress concentration values is crucial towards achieving optimal design. Therefore, given the wide use of these materials and their complex behaviour against external loads in comparison with isotropic materials, the effective parameters that lead to a reduction in stress concentration in different structures should be carefully monitored.

2. Literature review

Determining the stress concentration factor in different structures for different geometric discontinuities has been widely studied by investigators such as Howlland and Heywood (Howland, 1929; Heywood, 1952). Howlland (Howland, 1929) presented some relations for long plates with circular cut-outs and finite widths. Heywood extracted relations for the correction of the stress concentration factor in finite widths using stress concentration factors in infinite plates. Heywood (1952) presented these relations using the resultant balance of forces for perforated plates that were subjected to unidirectional tensile load, where the effect of finite width was applied alone. The complex variable method for solving boundary value problems in two-dimensional elasticity was first applied by Muskhelishvili (1962) for isotropic elastic plates. Shortly afterwards, applying a similar method, Savin (1961) performed some investigations on infinite isotropic plates with different cut-outs and anisotropic plates with only elliptical and circular cut-outs using the complex variable method. These solutions were mainly based on the classical laminate theory and on the fundamental works of Lekhnitskii (1968). Lekhnitskii used the analytical solutions to investigate boundary value problems by the complex variable method based on the Kolosov-Muskhelishvili formulas for anisotropic plates with circular and elliptical cut-out. An accumulation of all the previous researches on plates containing cut-outs was conducted by Sternberg (1958), Neuber (1968), Peterson

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(1974), and Pilkey (1997). Theocaris and Petrou (1986) used the Schwarz–Christoffel transformation to evaluate the stress concentration factor for an infinite plate with a central triangular cut-out. Rezaeepazhand and Jafari (2010) also studied the stress concentration around several non-circular cut-outs in isotropic plates. They investigated the effects of the rotation angle and the bluntness of the square and triangular cut-outs on stress concentration. Daoust and Hoa (1991) analysed the triangular cut-out in infinite isotropic and anisotropic plates under uniaxial loading. Apart from the equilateral triangle, they investigated other triangular cut-outs with different aspect ratios. They also studied the effect of the curvature of the cut-out corner on the stress distribution around the triangular cut-out. Abuelfoutouh (1993) formulated a relation for tangential stress around different cut-outs such as circular, elliptical, triangular, and rectangular by a single equation. Asmar and Jabbour (2007) also applied the same theory to investigate the stress distribution around the cut-out in an anisotropic plate with a quasi-square cut-out that was subjected to a uniaxial load. This research, however, only studied only the effect of bluntness and rotation angle for very special cases. Ukadgaonker and Rao (1999) presented solutions for stress distribution around triangular cut-outs with blunt corners in composite plates. Sharma et al. (2010) discovered a general solution to calculate the stress distribution around polygonal cut-outs in infinite isotropic plates that were subjected to biaxial loading. He also studied the effect of cut-out geometry and the pattern of loading on the stress analysis of the plates.

One of the main concerns of industrial designers is the choice of optimal values of the design variables. The selection of an appropriate method among different methods of optimization depends on the type of problem. Recently, a number of researchers attempted to apply these methods to different problems in diverse fields such as Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Genetic Algorithm (GA) etc. to design composite structures. These algorithms are SI-based algorithms. The successful application of these algorithms in science and industry provides evidence of the merits of swarm intelligence (SI) based techniques in practice. Sivakumar et al. (1998) studied the optimization of laminate composites containing an elliptical cut-out by the genetic algorithm method. In this research, the design variables were the stacking sequence of laminates, the thickness of each layer, the relative size of cut-out, the cut-out orientation, and the ellipse diameters. The first and second natural frequencies were considered as the cost function. Liu et al. (2006) investigated the optimization of composite plates with multiple cut-outs. At first, they considered the effect of the number of cut-outs and cut-out spacing in relation to each other. Kradinov et al. (2007) showed the application of the genetic algorithm in the optimal design of bolted composite lap joints. In this research, the laminate thickness, the laminate lay-up, the bolt location, bolt flexibility, and the bolt size were considered the optimization variables for maximizing the strength of the joint. Jafari and Rohani (2015) studied the optimization of perforated composite plates under tensile stress using the genetic algorithm method. They used an analytical solution to determine the stress distribution around different cut-outs in perforated composite plates. Moreover, Suresh et al. (2007) investigated the particle swarm optimization approach for the multi-objective composite box-beam design. The usage of the particle swarm optimization algorithm based on the flocking behaviour of birds in an appropriate form to optimize composite structures performed by Alonso et al. (Alonso and Duysinx, 2013), is an example of work performed on the optimization of structures using meta-heuristic algorithms. Jianqiao et al. (2013) developed a method for optimum designing (based on reliability) of a composite structure based on the combination of the PSO and the Finite Element Analysis (FEA) methods. Omkar et al. (2009) studied quantum behaved particle swarm optimization (QPSO) for the multi-objective design optimization of composite structures. Kathiravan and Ganguli (2007) showed the application of particle swarm optimization and the gradient method in the strength design of composite beams. Barbosa et al. (Ines Barbosa and Maria Amélia, 2014) designed a composite lattice structure under the torsion and the investigated effects of many materials and the geometric parameters on the optimized mechanical behaviour of the structure. The PSO technique was employed in order to maximize the torsion constant of the structure in this work. Nature has always been source of inspiration for scientists. Mirjalili (2015) conceived the idea of imitating from the static and dynamic swarming behaviours of dragonflies in nature and called the resulting technique the dragonfly algorithm.

Different parameters affecting stress distribution around the cut-out located in the plate under tension include the cut-out geometry, the cut-out orientation, the load angle, the fiber angle, and the cut-out bluntness. Due to the complexity of present problems the ambiguity of the cost function, and multiple local minima, the use of non-gradient algorithms is essential. In this study, relying on Lekhnitskii's analytical solution and generalizing it to a quasi-triangular cut-out, we have attempted to use the dragonfly algorithm to determine the optimal values of these parameters that lead to the lowest possible stress value around the quasi-triangular cut-out. It should be noted that Lekhnitskii has just investigated anisotropic plates with circular and elliptical cut-outs using the complex variable method. The other purpose of this paper is to show that the DA is an algorithm with suitable performance in solving the problem of stress concentration around a quasi-triangular cut-out. It should be noted that the optimal value of stress around the cut-out has been considered as the Cost Function (C.F.). Furthermore, the minimum normalized stress is defined as the ratio of the maximum stress created around the cut-out to the applied stress.

3. Description of methods

The problem to be investigated in this article is the perforated plate containing the quasi-triangular cut-out. It is assumed that an infinite perforated plate with a central cut-out is subjected to a uniformly distributed tensile load at a large distance from the cut-out (as shown in Fig. 1). The cut-out size is small enough with respect to the plate dimensions. Therefore, its effect will be negligible at a distance of a few diameters from the edge. The load is applied at angle with respect to X-axis (α). The major axis of the cut-out is directed at an angle with respect to X-axis (β). As shown in Fig. 1, γ is the fiber angle for composite plates. The cost function is to obtain the optimal design variables that minimize the maximum stress around the quasi-triangular cut-outs. As shown in Fig. 1, the design variables are the load angle (α), the cut-out orientation (β), the fiber angle (γ) and the curvature of the cut-out corner (w). The cut-out size is small in comparision to the size of the plate (infinite plate). This investigation is conducted by considering the plane stress state and the absence of body forces. In addition, the plate material is in its linear elastic region. The normal and tangential coordinates (ρ,θ) are shown in this figure. Due to the traction-free boundary conditions at the edge of the cut-out, the stresses σ_ρ and $\tau_{\rho\theta}$ at the cut-out edge are zero and the circumferential stress σ_θ is the only remaining stress.

Analytical method used in this study is retrieved from the