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FINITE ELEMENT ANALYSIS OF BUCKLING OF COMPOSITE-STIFFENED PANELS

ARASH ZAIGHAMI

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FINITE ELEMENT ANALYSIS OF BUCKLING OF COMPOSITE-STIFFENED PANELS

By

ARASH ZAIGHAMI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

November 2014

DEDICATIONS

In the name of the creator of Science

This thesis is dedicated to:

My

Parents

&

Siblings

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

FINITE ELEMENT ANALYSIS OF BUCKLING OF COMPOSITE-STIFFENED PANELS

By

ARASH ZAIGHAMI

November 2014

Chairman: Rizal Zahari, PhD
Faculty: Engineering

Buckling of laminated composite plates can be improved by introducing stiffeners to the plate. Majority of the researches concentrate on the buckling response of unstiffened and stiffened panels subjected to in-plane compressive loadings. Some contributions in the form of design charts and guidelines have been developed for unstiffened panels subjected to in-plane compression and shear loadings, but still there is a relative lack of investigation into this area of research. This study considers the effects of radius of the fillet of stiffener-and-plate joint under compression loading and to investigate the effects of stiffener depth and pitch length under combined in-plane compression and shear loading using Finite Element Method (FEM). In total, 46 panels were modeled using ABAQUS software. In the first study, the effects of a filleted joint on the local and global buckling loads of the panels were investigated. The results show that increasing the radius of the fillet results in an increase in the buckling load. It had been found that 2.18% and 43.7% stability improvements are obtained for the panel with a 5-mm fillet radius in the global and local buckling, respectively. In the next study, the effects of the stiffener pitch length under combined compression and shear loading on the buckling of the panels with various plate aspect ratios were investigated numerically. The results indicate that increasing the number of stiffeners (reducing stiffener pitch length) results in an increase in the buckling load. In the last study, the effects of the height of the stiffener (stiffener depth) on the stability of the panels with different plate aspect ratios were investigated. The results show that increasing the height of the stiffeners results in the improvement of the stability of the panels. Although the improvement is significant in the panels with shorter stiffeners, this value is not noticeable after a certain value of stiffener depth.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

ANALIS UNSUR TERHINGGA BAGI LENGKOKAN PANEL KOMPOSIT-TERKUKUH

Oleh

ARASH ZAIGHAMI

November 2014

Pengerusi: Rizal Zahari, PhD
Fakulti: Kejuruteraan

Lengkokan plat komposit berlapis boleh diperbaiki dengan memperkenalkan pengukuh kepada plat. Sebahagian besar penyelidikan menumpukan perhatian kepada lengkokan panel penyambut tidak terkukuh dan panel yang terkukuh tertakluk kepada dalam-satah beban mampatan. Beberapa sumbangan dalam bentuk carta reka bentuk dan garis panduan yang telah dirumus untuk panel penyambut tidak terkukuh tertakluk kepada mampatan dalam sotoh dan beban ricih, tetapi masih terdapat kekurangan relatif penyiasatan bidang ini penyelidikan. Kajian ini cenderung untuk mempertimbangkan kesan jejari filet daripada penyambut-dan-plat bersama di bawah beban mampatan, dan untuk menyiasat kesan mendalam bagi penyambut dan panjang pic di bawah gabungan mampatan dalam-satah ricih dan beban menggunakan Kaedah Unsur Terhingga (FEM). Secara keseluruhan, 46 panel telah dimodelkan menggunakan perisian ABAQUS. Dalam kajian pertama, kesan sendi filet pada beban lengkokan tempatan dan global panel telah disiasat. Keputusan menunjukkan bahawa peningkatan jejari filet telah menyebabkan peningkatan dalam beban lengkokan. Hasil daripada penemuan, didapati bahawa 2.18% dan 43.7% peningkatan kestabilan diperolehi dengan panel 5 mm filet jejari dalam lengkokan global dan tempatan, masing-masing. Dalam kajian seterusnya, kesan panjang pic penyambut bawah gabungan mampatan dan beban ricih pada lengkokan panel dengan pelbagai nisbah aspek plat, disiasat secara berangka. Keputusan menunjukkan bahawa peningkatan bilangan pengukuh (mengurangkan panjang pic penyambut) menyebabkan peningkatan dalam beban lengkokan. Dalam kajian yang lalu, kesan ketinggian penyambut (kedalaman penyambut) terhadap kestabilan panel dengan nisbah aspek plat yang berbeza telah disiasat. Keputusan menunjukkan bahawa peningkatan ketinggian pengukuh meningkatan kestabilan panel. Walaupun peningkatan adalah ketara dalam panel dengan pengukuh lebih pendek, nilai ini tidak ketara selepas mencapai nilai tertentu kedalaman penyambut.

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I also place on record, my sense of gratitude to one and all who, directly and indirectly, have lent their helping hand in this expedition.

I certify that a Thesis Examination Committee has met on 14 November 2014 to conduct the final examination of Arash Zaighami on his thesis entitled "Finite Element Analysis of the Buckling of Composite Stiffened Panels" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

C	Clamped
CAE	Computer Aided Engineering
CE	Constrained Equations
CLPT	Classical Laminate Plate Theory
CNT	Carbon Nanotube
CPT	Classical Plate Theory
DoF	Degree of Freedom
ESL	Equivalent Single Layer
F	Fixed
FEA	Finite Element Analysis
FEM	Finite Element Method
FSDT	First-order Shear Deformation Theory
HSDT	Highest-order Shear deformation Theory
IGA	Isogeometric Approach
LCPAS	Large Composite Primary Aircraft Structure
LLT	Layer-wise Lamination Theory
LSS	Laminate Stacking Sequence
NASA	National Aeronautics and Space Administration
NURBS	Non-Uniform Rational B-Splines
RPT	Refined Plate Theory
S	Simply Supported
SCF	Shear Correction Factor
SWCNT	Single-Walled Carbon Nanotube

CHAPTER 1

INTRODUCTION

1.1 Overview

For many years, metals have been largely used as structural material mostly because of their strength and ductility. With the growing demand for stronger and lighter materials, composites have become very important for structural applications. A composite material is a combination of a discontinuous phase called reinforcement embedded in a continuous phase called matrix. The reinforcement is responsible for carrying the load. The matrix keeps the reinforcement together, transfers the load to the reinforcement, and provides environmental protection. The constituents keep their properties and identities, i.e. they do not dissolve or merge completely into one another whilst performing in harmony. This allows the newly formed material to exhibit better engineering behavior and properties than its constituents.

Environmental moisture, chemical corrosion and oxidation are prevented by matrix material. Also, matrix holds together the fibers and keeps fibers in the proper orientation and position. Matrix materials can be polymers, metals, and ceramics. Polymeric Matrices are divided into two categories. These are Thermosets such as Epoxy and Thermoplastics such as Polyethylen [1].

Reinforcement materials, which are used in the composite industry, can be written as Fiberglass, Kevlar, Polyethylene, Carbon/Graphite, Ceramic fibers. Carbon fibers have high strength and stiffness properties. Carbon fiber reinforced composites are stronger and stiffer than the metallic parts which have same weight with carbon fibers [1].

1.1.1 Plates

A thin plate is, by definition, a two-dimensional flexural element of which the thickness is much smaller than its other two dimensions. A plane that divide the plate into two identical part is known as the middle plane.

Thin plate elements are utilized in different structures; these elements can be part of a complex structure or they can themselves form the main part of a structure. Walls of containers, silos, and reservoirs, flat roofs, flat elements of vehicles and aircraft, and sheet piles are some instances of plate elements. Plate elements may be homogeneous and isotropic or they may be stiffened and/or have a composite construction.

1.1.2 Buckling of Structures

Buckling is loss of stability due to geometric effects rather than material failure. But it can cause failure of material and collapse if the ensuing deformation are not restrained. Most structures can operate in a linear elastic range. That is, they return to the undeformed configuration upon removal of the load. Permanent deformations result if the elastic range is exceeded, as when matrix cracking occurs in a composite.

Consider a simply supported column of area A, length L, and moment of inertia I, made of homogeneous material with modulus E and strength F along the length of the column. the column is loaded by a compressive load P acting on the centroid of the cross section [2]. If the column geometry, loading, and material have no imperfections, the axial deformation is

$$u = PL/EA \tag{1.1}$$

With no lateral deformation ($w = 0$). The deformation of the structure (u, v, w) before buckling occurs is called the *Primary path*, which u, v and w represent the displacements in x, y and z directions, respectively. The slightest imperfection will make the column buckle when

$$P_{cr} = \pi^2(EI)/L^2 \tag{1.2}$$

What happens after the column reaches its critical load depends largely on the boundary conditions. The behavior of the structure after buckling has occurred is called *post buckling.*

Depending on the mode of application, a plate can be subjected to various lateral as well as in-plane forces. Under certain circumstances, applied in-plane loading may cause global or local buckling. Concerning thin plates, buckling is a phenomenon that can affect the load-bearing capacity of plate elements. Therefore, it should be taken into consideration in the design of plate elements.

1.1.3 Buckling of Stiffened Panels

There are several ways to improve the stability of the plates such as increasing the thickness of the plate. An efficient and creative approach to improve the buckling load of the plate is to introduce stiffeners to the plate. The stiffeners can be located longitudinally or in a grid form. The shape of the stiffeners can be blade, I-, J- or T-shaped.

1.2 Problem Statement

An important criterion typically used in structural design is the prevention against buckling. However, it is known that a rectangular plate supported at its boundaries can carry considerable load beyond its critical buckling load. Therefore, a design based on the buckling strength results in lighter structures. The possibility of saving weight makes the study of buckling in plates important. It also helps in understanding of failure mechanisms.

Numerical methods, that are adequately accurate, are utilized by researchers for the analysis of laminated composite stiffened panels. Due to the advent of super computers and the versatility of finite element method as an indispensable tool, different attempts have been done worldwide to understand the buckling behavior of laminated composites. The reports include parametric results for various plate aspect ratios, plate thickness to length ratios, degree of layer orthotropy, ply orientations, and stiffener depth to plate thickness ratios [3, 4].

Considering the fact that buckling phenomenon of laminated composite stiffened panels occurs under various types of loading in nature, conceive the idea of study the buckling behavior of laminated composite stiffened panels under combined loading. Majority of the researches concentrate on the buckling behavior of the stiffened and unstiffened panels which are subjected to the in-plane compression loadings [5].

Some contributions in the form of design charts and guidelines have been developed for unstiffened panels subjected to in-plane compression and shear loadings [6], but still there is a relative lack of investigation into this area of research such as the effects of the stiffener depth and the pitch length under combined in-plane compression and shear loading. Also, there is no report on the effect of the radius of fillet of the stiffener and plate joint using laminated composite stiffened panels.

1.3 Objectives of the study

The objectives of this study are:

1. Investigate the effect of radius of fillet of stiffener-and-plate joint on the buckling of composite stiffened panels under in-plane compression loading.

2. Investigate the effects of pitch length and stiffener depth on the buckling of composite stiffened panels under combined in-plane compression and shear loading.

1.4 Scope of the study

Regarding aforementioned facts, in the present study a database is developed by using finite element investigations and based on the results a number of effective parameters and their effects on buckling behavior of simply supported laminated composite stiffened panels is discussed. This study is divided into two main sections i.e., the panels which are subjected to the pure compression loading and the ones which are exposed to the combined in-plane compression and shear loading. Stiffener depth and pitch length are the parameters that are investigated under combined loading and the radius of filleted joints is investigated under compression loading. This guidelines will be helpful for the designers.

A number of 46 samples using ABAQUS (v6.10) are modeled and a database is prepared for the effects of different geometrical parameters including pitch length of stiffeners, depth of stiffeners and the radius of the fillet of stiffener and plate joint based on the various plate aspect ratios.

1.5 Significance of the Study

Aerospace and automotive industry demand cost efficiency for development and operating. Reducing cost can be achieved by utilizing lightweight structures or employing new materials with a high strength-to-weight ratio. Composite structures can satisfy mentioned demands. To increase the stability of composite panels, the thickness should be increased. But the increase in thickness results in heavier structure. So the economic way to increase the stability while keeping weight as low as possible is to introduce stiffeners. Now the question is "how to employ stiffeners?" The most efficient state of the structure will achieve by knowing the effect of height and number of stiffeners on the structure. In manufacturing process, a fillet may apply to the jointing area between stiffeners and plate. How sensitive is the stability of the plate to the radius of the filleted area?

This study answers the above questions and prepare a database which can help designers in terms of needless to do time consuming simulations to figure out the trends.

1.6 Outlines of Thesis

Chapter 1 presents the introductory words including a brief background of composite structures which continues with stating the problem and the objectives that is set in this study. This chapter also discuss about the significance of this thesis and come to end with an outline of this study.

Chapter 2 presents a literature review of previous researches related to this study including composite definition and its types, buckling of plates and its solutions using Finite Element Method (FEM), buckling of stiffened panels subjected to various loads and boundary conditions.

Chapter 3 describes the procedure of getting the results from the initial steps of modeling to simulation of the panels and also represents the employed methods and formula to achieve the results. Chapter 4 gives a complete description of the attained results in details and conclusions based on the results are presented in chapter 5 which is followed by some recommendations for future work in chapter 6.

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