UNIVERSITI PUTRA MALAYSIA

SECOND ORDER SHEAR DEFORMATION THEORY FOR RESPONSE ANALYSIS ON TEMPERATURE-DEPENDENT FUNCTIONALLY GRADED PLATES DUE TO VIBRATION AND MECHANICAL LOADING

ALI SHAHRJERDI

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By

ALI SHAHRJERDI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in fulfilment of the Requirement for the Degree of Doctor of Philosophy

August 2011

To My Family Members Especially My Parents

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman Faizal Mustapha, PhD

Faculty Engineering

The Second-order Shear Deformation Theory (SSDT) is applied to evaluate the displacement and stress fields included in a functionally graded plate (FGP) by thermo-mechanical loadings. Uniformity, linearity, nonlinearity, heat-flux, and sinusoidal thermal conditions are imposed at the upper and lower surfaces of the FGPs. The SSDT is also employed to analyze the free vibration of temperature dependent and independent FGP's. Equilibrium equations and equations of motion of FG square and rectangular plates are derived by employing second order shear deformation theory (SSDT). Navier's method is applied to find the analytical results

for the derived equations using an energy method for the case of simply supported boundary conditions. The power law material properties and linear steady-state thermal loads are asswned to be graded between full ceramic at the upper and full metal at the lower surface. In the nwnerical study, different types of FGPs such as Zr02fi-6AI-4V and Si_3N_4/SUS304 are considered. A comparison is made of the non-dimensional results for the temperature-dependent and temperature-independent FGPs and validated using the results published in the literature. By comparing the results with some nwnerical results, a quantitative agreement is exhibited. This research study used nwnerical results to quantify the effects of material composition, plate geometry, and temperature fields on vibration characteristics and mode shapes. The effects of the material grading index of a plate on stresses and displacements were investigated to reveal that, the longitudinal stresses in the FGP lie between full-metal and full-ceramic plates. It was found that, the neutral axes for FGP move to the upper surface not to the mid-surface as predicted in homogeneous plates. The SSDT has computed results for in-plane stresses, free vibration and displacement fields, which are acceptable and exhibit very close qualitative behavior and quantitative agreement to other shear deformation theories in existing literature, thus demonstrating its robustness.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

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Oleh

ALI SHAHRJERDI

Ogos 2011

Pcngcrusi Faizal Mustapha, PhD

Fakulti Kejuruteraan

Kedua-Kumpulan Deformasi Luncurkan Teori (SSDT) dilaksanakan untuk menilai perpindahan sesaran dan tekanan diambil kira pada satu *Functional Graded Plate* (FGP) melalui beban termo-mekanikal. Keseragaman, kelelurusan, ketaklelurusan, fluks haba, dan keadaan terma sinusoidal yang dikenakan pada permukaan atas dan bawah FGPs. SSDT ini juga digunakan untuk menganalisis subu getaran bebas bagi FGP's yang bergantung dan bebas. Kaedah Navier adalah digunakan untuk mencari hasil analisis untuk persamaan yang telah diperoleh dengan menggunakan kaedah tenaga untuk kes keadaan batas sederhana disokong. Sifat eiektrik bahan undang-undang dan linier mapan beban terma diandaikan mengikut gred antara logam

keramik penuh di atas dan penuh pada perrnukaan yang lebih rendall. Dalam kajian berangka, pelbagai jenis FGPs seperti Zr02/Ti-6AI-4V dan *Si3N4/SUS304* dipertimbangkan. Kajian perbandingan hasil dijalankan bagi ketidak-dimensi untuk FGPs pada suhu bergantung dan suhu bebas dan seterusnya validasi menggunakan hasil yang telah diterbitkan dalam kajian bacaan. Penyelidikan ini menggunakan hasil berangka untuk mengukur kesan daripada komposisi bahan, geometri plat, dan suhu terhadap ciri-ciri getaran dan mod bentuk. Kesan gred indeks bahan plat pada tegasan dan sesaran disiasat bertujuan mengetahui bahawa longitudinal stres dalam FGP diantara logam and plat ceramik. Didapati bahawa paksi neutral untuk pemindahan FGP ke permukaan alas dan tidak ke perrnukaan pertengahan seperti yang dijangkakan didalam plat homogen. SSDT telah mengira keputusan untuk tegasan di perrnukaan, getaran bebas dan kawasan sesaran yang boleh diterima pakai dan menghampiri teori deforrnasi luncur didalam kajian bacaan semasa dan ianya menunjukkan *"robuslnesss"*.

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I certify that a Thesis Examination Committee has met on 19 August 2011 to conduct the final examination of Ali Shahrjerdi on his thesis entitled "Second Order Shear Deformation Theory for Response Analysis on Temperature-Dependent Functionally Graded Plates Due to Vibration and Mechanical Loading" in accordance with the Universities and University College 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 Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Harijono Djojodihardjo, **PhD**
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Shahnor bin Basri, PhD, P.Eng, F.A.Sc
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Tang Sai Hong, **PhD**
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Mohammed Sarwar Jang Hashmi, **PhD**
Professor
Dublin City University
Ireland
(External Examiner)

NORITAH OMAR, **PhD**
Associate Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 29 September 2011

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted in fulfillment of the requirements for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Faizal Mustapha, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

MOHD SAPUAN **SALIT, PhD, P.Eng**
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Rizal Zahari, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

HASANAH MOHD GHAZALI, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I declare that the thesis is my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any institution.

ALI SHAHRJERDI

Date: 19 August 2011

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