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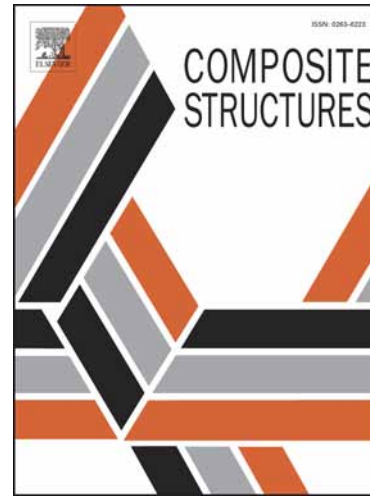

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Soheil Gohari, S. Sharifi, Zora Vrcelj

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A novel explicit solution for twisting control of smart laminated cantilever composite plates/beams using inclined piezoelectric actuators

Soheil Gohari*, S. Sharifi, Zora Vrcelj

*Tel: +61423656484

College of Engineering and Science, Victoria University, Melbourne, VIC 8001, Australia

Email Addresses: soheil.gohari@live.vu.edu.au, soheil.gohari7@gmail.com (S. Gohari), sharifi.te@gmail.com (S. Sharifi), Zora.Vrcelj@vu.edu.au (Z. Vrcelj)

Abstract. In the present work, a novel explicit solution is proposed for obtaining twisting deformation and optimal shape control of smart laminated cantilever composite plates/beams using inclined piezoelectric actuators. The linear piezoelectricity and plate theories were adapted for the analysis. A novel double integral multivariable Fourier transformation method and discretised higher order partial differential unit step function equations were employed. For the first time, an exact solution is developed to analyse electro-mechanical twisting moments in smart composite structures. Since there are no published benchmark results for verification, a series of simple, accurate and robust finite element (FE) analysis models and realistic electro-mechanical coupled FE procedures are developed for the effective prediction of the structural behaviour of the smart laminated piezo-composite structures under arbitrary loads. In addition to the novelty of the explicit solution, more comprehensive FE simulations of smart structures and step-by-step guidelines are discussed. The effect of various parameters including electro-mechanical twisting coupling, layup thickness, actuators size, placement, and inclination angle, electrical voltage, stacking sequence, and geometrical dimension was taken into account. The comparison of results showed an excellent agreement. Unlike the earlier studies, the proposed method does not require the characteristic and trial deflection function to be predetermined.

Key Words: Twisting control; Electro-mechanical twisting coupling; Explicit solution; Finite element method (FEM); Inclined piezoelectric actuators; Smart laminated cantilever composite plates/beams.

1.Introduction

Laminated and asymmetric composite structures are being used considerably in aerospace, automotive, civil, mechanical and structural engineering applications due to their high stiffness and strength to weight ratio, low density, and temperature resistance[1][2][3]. Laminated plates and beams are usually applied to achieve the desired stiffness and lightness for parts of load-bearing engineering structures[4][5]. For instance, laminated cantilever composite plates are adopted widely in various engineering applications such as airplane wings, corrugated plates, reinforced concrete slabs, decks of contemporary steel bridges, boom arms of industrial cranes, and flight control surfaces[6][7][8]. Piezoelectric materials have recently drawn much attention due to their low power consumption, high material linearity, and quick response when induced by external forces[9][10][11]. Piezoelectric materials can be integrated with laminated composite structures to provide smart-intelligent composite systems. Numerous smart engineering structures incorporated with smart devices such as piezoelectric sensors and actuators have proved to be superior to their conventional counterparts. Static analysis of advanced composite structures under axial, transverse, twisting, and torsional loads in addition to the torsional actuation due to piezoelectric materials has potential application in mechanical systems, helicopter rotor blades, and/or blades for turbomachinery[12]. Some other applications of piezoelectric materials in smart and adaptive engineering structures are acoustical noise reduction, damage identification, structural health monitoring, vibration suppression, deflection control in missile fines, and airfoil shape changes[13][14][15]. One of the great advantages of piezoelectric materials is their ability to respond to changing environment and control structural deformation, which has led to the new generation of aerospace structures like morphing airplanes[11]. Among piezoelectric materials, bounded piezo-ceramic actuators are commonly used for shape control of online monitoring systems. Piezoelectric actuators can also be embedded in