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A Micro-Structure Dependent Buckling Analysis of Partially-Cracked Generally Orthotropic Plate under Thermal Domain

Ankur Gupta*, Shashank Soni and N. K. Jain

Department of Mechanical Engineering, National Institute of Technology, Raipur, Chhattisgarh 492010, India

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Abstract. In this work, a non-classical analytical approach for buckling analysis of partially cracked generally orthotropic plate is proposed under the thermal domain. The derivation for the governing equation is based on the non-classical approach using Kirchhoff's thin plate theory and the modified couple stress theory. The effect of fibre orientation on critical buckling temperature is incorporated by considering the coefficients of mutual influence. Line spring model is applied with some modifications to formulate all the crack terms while the thermal effects are introduced in form of thermal in-plane moments and forces. The final governing equation is solved using Galerkin's method and the relation for critical buckling temperature as affected by fibre orientation is obtained. The variation of critical buckling temperature as affected by fibre orientation for different values of crack length, crack location and length scale parameter is presented. Also, the effect of fibre orientation on fundamental frequency under the thermal domain is analysed.

AMS subject classifications: 74K20

Key words: Orthotropic plate, fibre orientation, crack, microstructure, thermal domain.

1 Introduction

The orthotropic plate being an elementary structural unit is vastly used to obtain desired mechanical properties, especially in automobile, aerospace and naval applications. The application of orthotropic materials in micro-sized structure is evident from the literature [5, 11, 45]. It is seen that as the dimensions of general structures such as plates and shells reduce, the mechanical properties of such a micro-sized structure becomes size-dependent. For example, classical theories like Kirchhoff's thin plate theory and classical

*Corresponding author.
Emails: ankurgupta1729@gmail.com (A. Gupta), shashanksoninitr@gmail.com (S. Soni), nkjain.me@nitrr.ac.in (N. K. Jain)

shell theory underpredict the stiffness of micro-sized plates and shells. The micro-sized plates find their usage in various engineering applications such as micro-resonators, sensors and actuators, atomic force microscopes (AFMs), and micro-switches etc. At various instances, these micro-sized structures have to operate under the thermal domain which affects their stability, as well as mechanical properties, e.g. micro-sized computer elements in the form of plates and shells, are operated at wide range of temperature. Owing to its wide application, the mechanical properties of micro-sized structures has to be accurately determined including the external factor such as temperature or flaws in the form of cracks and holes.

In literature, it has been also observed that the presence of defects in form of cracks or holes in these structural units makes the dynamic behaviour severely different from that of an intact plate. Mostly numerical techniques are used for static solutions for the cracked plate, but an approximate analytical approach has been presented employing the simplified Line Spring Model (LSM). This model (LSM) was firstly proposed by Rice and Levy [37] and their concept of the line spring model was based on Kirchhoff's classical plate theory. They developed the line spring model for cracked plate considering bending and stretching compliances to determine the stress intensity factors at crack tips. King [29] established a pair of linear algebraic equations to analyze parameters of fracture by doing simplification of integral equations of LSM given in [37]. Later, Zeng and Dai [38] used this model [29] and calculated the stress intensity factors of a plate having angled surface crack subjected to a biaxial state of stresses. Bose and Mohanty [6] developed a model for vibration problems of a cracked thin isotropic plate having arbitrary crack position and orientation of crack and concluded that the crack orientation affects the frequency of the plate. Stahl and Keer [44] used the Fredholm integral equation of the second kind to investigate the natural frequency of the plate containing a centrally located internal crack and a side crack. Recently Xu et al. [49] have established an accurate and efficient solution method for free vibration and buckling of cracked NFRC rectangular thin plate using a symplectic approach and the line spring model. In their work, they concluded that both length and crack location are important factors that affect the vibration response and hygrothermal ageing of NFRC plates.

Solecki [39] analyzed the flexural vibration of a plate having an arbitrarily located crack for simply supported boundary condition by using the Fourier transformation functions and green gauss theorem. Liew et al. [31] has given the frequency response of cracked plates by employing the virtual principle with the Ritz method. Khadem and Rezaee [23] given a technique to detect the crack using modified comparison functions in a simply supported plate. The deviation of frequencies of a rectangular plate with arbitrary orientation of narrow slits is experimentally performed by Maruyama and Ichinomiya [47]. Using the application of the Ritz method Huang et al. [13] developed the new function for vibration response of plate with through internal crack of various orientations. Wu and Law [48] found that if the orientation of the crack is changed then it affects the vibration response of the plate having a moderate thickness. Jha et al. [20] thoroughly reviewed the literature on FGM plate and performed stability and dynamic