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Review

On the free vibration analysis of laminated composite and sandwich plates: A review of recent literature with some numerical results

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ABSTRACT

The present article reviews the recent research done on the free vibration analysis of multilayered laminated composite and sandwich plates using various methods available for the analysis of plates. Displacement fields of various displacement based shear deformation theories have been presented and compared. Also, some numerical results related to fundamental flexural mode frequencies of laminated composite and sandwich plates are presented using a trigonometric shear and normal deformation theory. The theory involves six unknown variables and does not require problem dependent shear correction factor. Governing differential equations and associated boundary conditions of the theory are derived by employing the dynamic version of the principle of virtual work. Navier-type closed-form solutions are obtained for simply supported laminated composite and sandwich plates. The present results are compared with exact elasticity solution and other higher order shear deformation theories wherever applicable. This article cites 391 references.

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1. Introduction

Structures composed of composite materials are among the most important structures used in modern engineering and, especially, in the aerospace industry. Such lightweight structures are also being increasingly used in civil, mechanical and transportation engineering applications. The rapid increase of the industrial use of these structures has necessitated the development of new analytical and numerical tools that suitable for the analysis and study of mechanical behavior of such structures. The behavior of structures composed of advanced composite materials is considerably more complicated than for isotropic ones. Review of various properties of composite material is presented by Hashin [1]. Recent applications of fibre reinforced polymer composites to naval ships and submarines are reviewed by Mouritz et al. [2]. Review of polymer composites also presented by Chamis [3]. Pendhari et al. [4] reviewed the applications of polymer composites in civil engineering constructions, whereas a historical review of mechanics of composites is presented by Herakovich [5].

The classical plate theory (CPT) [6] and first order shear deformation theory (FSDT) [7] are commonly used theory for the analysis of laminated composite plates. However, CPT predicts good results for thin plates only, because, the transverse shear deformation is omitted in CPT. FSDT does not satisfy shear stress free conditions at top and bottom surfaces of plates. The shear correction factor is needed to appropriately take into account the strain energy of shear deformation. Its value depends on the material coefficients, geometry, stacking scheme, boundary conditions and loading conditions, which cannot be easily determined for practical problems. Further, FSDT is not capable of properly constraining all the displacements at the clamped supports of beams and plates. Higher order shear deformation theories are therefore developed to overcome these limitations of classical laminated plate theory and first order shear deformation theories for the better representation of the bending, buckling and vibration of the laminated composite and sandwich plates.

Several review articles on laminated composite and sandwich plates have been reported in the literature by various researchers, such as Leissa [8], Reissner [9], Reddy [10,11], Kapania and Raciti [12], Noor and Burton [13], Noor et al. [14], Bert [15], Vasil'eV [16], Mallikarjuna and Kant [17], Reddy and Robbins [18], Liew et al. [19,20], Liu and Li [21], Carvelli and Savoia [22], Altenbach [23], Bose and Reddy [24,25], Carrera [26–29], Kant and Swaminathan [30], Chao and Chern [31], Ferreira and Fernandes [32], Kulikov [33], Ambartsumian [34], Piskunov and Rasskazov [35], Carrera and Demasi [36,37], Ghugal and Shimpi [38], Alhazza and Alhazza [39], Reddy and Arciniega [40], Rohwer et al. [41], Wanji and Zhen [42], Demasi [43–48], Carrera and Brischetto [49], Sharma and Mittal [50] and Kreja [51]. Several books are also available on vibration of plates such as, Leissa [52], Reddy [53], Liew et al. [54], Qatu [55], Soedel [56], Szilard [57], Yang [58] and Chakraverty [59].

Various methods for the analysis of plates are available in the literature. This article reviews the application of these methods for the vibration analysis of laminated composite and sandwich plates. The research reported from year 2000 to 2013 is reviewed with some classical references.

1.1. Navier's method

Navier's solution technique is used only for simply supported boundary conditions. Many higher order shear deformation theories have been reported in the literature for the free vibration analysis of simply supported plates using Navier's method. Theories of Ambartsumian [60] Kruszewski [61], Panc [62] and Reissner [63] are not accurate while predicting the vibration response of laminated and sandwich plates. Therefore, Reddy [64] has developed a well known third order shear deformation theory which is further used by many researchers for their research. Recently, Aghababaei and Reddy [65] reformulated the third-order shear deformation plate theory of Reddy [64] using the nonlocal linear elasticity theory and applied for the bending and vibration of plates. Ray [66] has developed Zeroth order shear deformation theory and applied for the free vibration analysis of laminated composite plates. However, Kapuria and Dumir [67] showed that, Zeroth order shear deformation theory developed by Ray [66] is mathematically equivalent to Reddy's third order shear deformation theory [64]. Matsunaga [68–72] studied vibration analysis of laminated composite and sandwich plates using global higher-order plate theory. Levy [73], Stein [74], Touratier [75], Shimpi et al. [76], Shimpi and Ainapure [77], Zenkour [78,79], Ghugal and Sayyad [80–84], Neves et al. [85,86], Ferreira et al. [87], Thai and Vo [88] and Mantari et al. [89–92] developed some trigonometric shear deformation theories for the free vibration analysis of isotropic, orthotropic, laminated composite, sandwich and functionally graded plates. Soldatos [93] has developed hyperbolic shear deformation theory for the analysis of laminated composite and sandwich plates. Ghugal and Pawar [94] applied theory of Soldatos [93] for the free vibration analysis of orthotropic plates. Recently, several new hyperbolic shear deformation theories are developed by Akavci [95,96], Akavci and Tanrikulu [97], Meiche et al. [98], Bessaim et al. [99], Daouadji et al. [100–102], Grover et al. [103], Neves et al. [104] and Zenkour [105]. Karama et al. [106] have developed an exponential shear deformation theory for the free vibration analysis of laminated and composite plates which is further used by Sayyad and Ghugal [107]. Aydogdu [108] has carried out comparison of various shear deformation theories for the free vibration analysis of laminated composite plates. Aydogdu [109] also developed a new shear deformation theory for the free vibration analysis of laminated composite plates. Shimpi et al. [110] developed new first order shear deformation theories which are further discussed by Simmonds [111] and Shimpi et al. [112]. This theory is extended by Thai and Choi [113] for the free vibration analysis of laminated composite plates. Shimpi and Patel [114] developed two variable plate theory for the free vibration analysis of isotropic and orthotropic plates, which is extended for the laminated composite plates by Thai and Kim [115], Alibakhshi [116], Thai and Choi [117] and Thai et al. [118]. Xiang