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Thermal buckling analyses of FGM sandwich plates using the improved radial point interpolation mesh-free method

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ABSTRACT

This study reports thermal buckling analyses of functionally graded material (FGM) sandwich plates using an improved mesh-free radial point interpolation method (RPIM). The buckling formulation of FGM sandwich plates is derived from the improved RPIM which employs a new radial basis function enabling the shape functions to be built without any supporting fixing parameters based on the higher-order shear deformation plate theory. Two types of FGM sandwich plates with different composition scheme, i.e. one with FGM skins and homogenous core and the other composed of homogenous skins and FGM core are considered in the analyses. The simulated results by the improved RPIM are compared with the analytical solutions found in the literature for the verification purpose. Detailed parametric studies are then carried out to scrutinize the effects of the volume fraction, plate length-to-thickness ratio, aspect ratio, boundary condition and FGM constituents on the critical buckling temperature changes of the FGM sandwich plates under various types of temperature variation through the thickness. Results demonstrate that the improved mesh-free RPIM can effectively predict the thermal buckling behavior of the FGM sandwich plates.

1. Introduction

Sandwich structures are finding increased use in nuclear reactors, aircrafts, aerospace vehicles, offshore and marine structures, construction and shipbuilding industries and reusable transportation systems thanks to their exceptional features: high stiffness with low weight, excellent thermal and sound insulation, prolonged operational life and high energy absorption capability [1,2]. In recent years, sandwich structures have become even more attractive due to the development of advanced composite materials such as functionally graded materials (FGMs). FGMs are microscopically inhomogeneous composites and usually composed of two microstructural phases such as metal and ceramic, making them resistant to corrosion, high temperature and mechanical loading. FGMs in which material properties vary continuously and smoothly can circumvent many problems encountered in conventional laminated composites, e.g. thermally or mechanically induced stress gaps at the interfaces caused by mismatches in the properties of two different materials. The remarkable advantages of FGMs and the need for resolving the technical problems involved in thermal environments have prompted the introduction of FGMs into sandwich structures.

Responses of FGM sandwich structures in thermal environments have been a subject area of extensive research activities and quite a number of investigations have been carried out to explore the thermal behavior. Thermo-elastic analyses of FGM sandwich plates have been conducted theoretically by many researchers. Zenkour and Alghamdi [3] examined the thermo-elastic bending behavior of functionally graded (FG) ceramic-metal sandwich plates with the FGM face sheets and homogeneous ceramic core by developing a unified shear deformable plate theory. Pilipchuk et al. [4] presented an exact solution for bending of sandwich FGM plate-like beams subjected to thermal loads based on two-dimensional theory of elasticity. Houari et al. [5,6] studied the thermo-elastic bending of simply supported rectangular sandwich plates with FGM face sheets and isotropic homogeneous core based on the two-variable refined plate theory and a new higher-order shear and normal deformation theory, respectively. Tounsi et al. [7] utilized a refined trigonometric shear deformation theory to carry out the thermo-elastic bending analyses of sandwich plates with FGM core and isotropic homogeneous skins. Mantari and Granados [8,9] presented analytical solutions for the

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thermo-elastic bending analyses of FGM sandwich plates by using a new quasi-3D (three dimensional) hybrid type higher-order shear deformation theory (HSDT) with five or six unknowns. The generalized quasi-3D HSDT accounts for adequate distribution of the transverse shear stresses through the plate thickness and tangential stress-free boundary conditions on the plate boundary surface. Much work has been dedicated to scrutinize the thermo-mechanical behavior of FGM sandwich structures. Pradhan and Murmu [10] carried out thermo-mechanical vibration analyses of FGM sandwich beams with different FGM skin and homogeneous core resting on various elastic foundations by using the modified differential quadrature method. Zenkour [11] conducted bending analyses of simply supported sandwich plates with FGM face sheets and isotropic homogeneous core subjected to a transverse mechanical load and a through-the-thickness thermal load using the refined sinusoidal shear deformation plate theory. Zenkour and Alghamdi [12,13] analyzed stresses and deflections of symmetric and non-symmetric FGM sandwich plates under both the thermal and mechanical loads. Wang and Shen [14] used a two-step perturbation technique to investigate large amplitude vibration and nonlinear bending of a sandwich plate with carbon nanotube-reinforced composite (CNTRC) face sheets and isotropic homogeneous core resting on an elastic foundation in thermal environments. They [15] also investigated the nonlinear dynamic response of sandwich plates with FGM face sheets and homogeneous core layer supported by Pasternak elastic foundations in thermal environments. Their studies demonstrated that the volume fraction distribution of FGM layer has a pronounced influence on the dynamic response of a single-layered FGM plate, whilst this effect is less significant for a sandwich plate with FGM face sheets. Taibi et al. [16] proposed a simple shear deformation theory for analyzing the thermo-mechanical deformation behavior of shear deformable FGM sandwich plates resting on a two-parameter (Pasternak model) elastic foundation. By dividing the transverse displacement into bending and shear parts, the number of unknowns and governing equations of the theory is reduced. Pandey and Pradyumna [17] derived a layerwise finite element (FE) formulation for free vibration analyses of FGM sandwich plates in thermal environment. Two configurations of sandwich plate, i.e. one with homogenous face sheets and FGM core and the other with FGM face sheets and homogenous core were considered. Alibeigloo [18] presented the 3D thermo-elastic solution for a simply supported sandwich panel with FGM core by using the Fourier series expansions and the state-space technique. He [19] performed bending analysis of sandwich circular plate with FG core layer subjected to thermo-mechanical load based on the generalized differential quadrature method as well. By employing a four-variable refined plate theory, Li et al. [20,21] presented the Navier-type exact solutions for the thermo-mechanical bending of two types of FGM sandwich plates with simply supported boundary condition and carried out bending analyses of sandwich plates with both FGM face sheets and FGM core exposed to thermo-mechanical loading. Bich and Ninh [22] explored the nonlinear vibration of imperfect eccentrically stiffened FGM sandwich toroidal shell segments containing fluid under mechanical loads with external temperature. As for the thermal buckling behavior of FGM sandwich structures, limited studies have been performed. Shen and Li [23] studied the compressive postbuckling under thermal environments and the thermal postbuckling due to heat conduction for a simply supported sandwich plate with FGM face sheets and homogeneous core by employing the two-step perturbation technique. Zenkour and Sobhy [24] obtained the critical buckling temperatures of simply supported sandwich plates with metal-ceramic FGM face layers and isotropic homogeneous ceramic core subjected to various types of temperature rise based on the sinusoidal shear deformation plate theory. Kiani and Eslami [25] examined post-buckling behavior of sandwich plates with FGM face sheets and homogeneous core with a Pasternak-type elastic foundation under uniform temperature rise using the first-order shear deformation plate theory. Fazzolari and Carrera [26] carried out the thermal stability analyses of FGM sandwich plates by virtue of the refined quasi-3D equivalent single layer and Zig-Zag plate theories developed within the framework of the Carrera's unified formulation. Parametric studies were conducted in order to evaluate the effects of significant parameters which included volume fraction index, length-to-thickness ratio, boundary conditions, aspect ratio, sandwich plate type and temperature distribution through-the-thickness direction on the critical buckling temperatures. Seidi et al. [27] developed an improved high-order theory for temperature-dependent buckling analysis of sandwich conical shell with FGM face sheets and homogenous soft core submitted to axial in-plane compressive load and temperature variation. They presented an analytical solution for the static analysis of the simply supported sandwich conical shell under the thermo-mechanical load. Tung [28] investigated nonlinear bending and postbuckling behavior of FGM sandwich plates resting on Pasternak type elastic foundations with tangential edge constraints, which are subject to thermal loading and uniaxial compression in thermal environment on the basis of the first-order shear deformation theory. Sobhy [29] introduced a new four-variable shear deformation plate theory in order to illustrate the hygrothermal vibration and buckling of FGM sandwich plates resting on Winkler-Pasternak elastic foundations.

During the last decade, mesh-free methods have been extensively exploited to scrutinize the responses of FGM or FG-CNTRC plates and shells subjected to various types of loading such as bending, axial compression, vibration and thermal gradients [30]. Nevertheless, numerical analysis of a FGM sandwich structure by employing a meshless method is very scarce in the literature. Wu and Jiang [31] developed a state space differential reproducing kernel method, which is a kind of mesh-free method, for the 3D static analyses of FGM sandwich circular hollow cylinders with combinations of simply-supported and clamped edges and under sinusoidal distribution of loads. Neves et al. [32] combined a quasi-3D HSDT and a mesh-free technique based on the collocation with radial basis functions to perform the static, free vibration and buckling analyses of two types of FGM sandwich plates focusing on the thickness stretching. Nguyen et al. [33] suggested a rotation-free moving Kriging meshless method based on a refined plate theory for the static, dynamic and buckling analyses of two types of FGM sandwich plates. The formulation satisfies the tangential stress-free boundary conditions at the top and bottom surfaces. Thai et al. [34] devised a mesh-free method with a modified distribution function of moving Kriging interpolation on the basis of the HSDT for the static, dynamic and buckling analyses of FGM sandwich plates. They illustrated that the proposed method yielded more stable and accurate prediction as compared to 3D elasticity solution and other meshless methods.

According to the literature review, it seems that the buckling behavior of FGM sandwich plates under thermal loading has not been thoroughly investigated. Furthermore, very few research works have been conducted on prediction of the thermal buckling behavior of sandwich plates with FGM face sheets or core by using a mesh-free method. Motivated by this, this study aims to analyze the critical buckling temperature changes of FGM sandwich plates employing a meshless method with the HSDT. An improved radial point interpolation method (RPIM), in which a new radial basis function enabling the shape functions to be constructed without any supporting fixing coefficients is incorporated, based on the HSDT is proposed and utilized to solve the problems. Validity of the improved RPIM is first confirmed by comparing the computed results with the analytical solutions reported in the literature.