

An Overview of modeling of nano-composite materials and structures

Mohammed Ridha H .Alhakeem

Ministry of Oil, Midland Refineries company , Baghdad, Iraq

mu_1978@yahoo.com



***Corresponding Author**

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ABSTRACT

The research conducted by many scientists and engineers on nanocomposite materials and continuous systems made from such materials will be reviewed historically in this article by the writers. Nano composites are a form of well-known composite material that has been improved by adding nanoscale fibers and/or particles for reinforcement. These materials may be more appropriate for industrial applications that require material qualities that are noticeably improved. In other words, because of the improved properties of materials at the nanoscale, the material properties of nanocomposites are superior to those of macroscale composites. Designers are using these materials more frequently than traditional composite materials as constituent parts in aerospace, mechanical, and automotive applications. In order to forecast how buildings made of these materials will behave under actual operating conditions, it is crucial to be aware of the research that has been done in this field. The mechanical analyses carried out on various nanocomposite structures, such as those reinforced with carbon nanotubes (CNTR), graphene (GR), graphene platelets (GPLR), graphene oxide (GOR), and multi-scale hybrid (MSH) nanocomposite ones, will be reviewed in the sections that follow, along with the most significant aspects of the suggested scientific activities.

INTRODUCTION

In several sectors today, nanocomposite materials are being used in place of more traditional composite materials to create devices that accomplish the intended function. When comparing the mechanical, thermal, electrical, and optical properties of materials at the nanoscale to those at the usual macroscale, the cause of this tendency may be understood. In fact, compared to equivalent materials at the macroscale, nanoscale materials have different characteristics. As a result, anytime nanosize reinforcements are chosen to be used instead of macroscale ones, the major goal from the design of composite materials, which is the amplification of an initial matrix with the superior properties of the reinforcing phase, can be better satisfied. In contrast to carbon fiber (CF), which has GPa-order stiffness, carbon nanotube (CNT) stiffness can range from the order of TPa to GPa, depending on its chirality. Therefore, it is only normal to observe that the scientific community has progressed toward using CNT rather than CF when building composite materials in order to enrich a greater rigidity. This tendency led many academics to focus their scientific investigations on understanding how nanocomposite structures respond mechanically to different kinds of external loadings.

However, it must be made clear that analyzing nanosize structures like nanobeams, nanoplates, and nanoshells is a fundamentally separate topic from the examination of nanocomposite structures. To learn more about the aforementioned topic, volunteer readers are advised to examine related sources [1–6] that deal with the mechanical analysis of nanostructures. It is also important to note that a variety of nanoparticles and nanofillers can be used to enhance the material properties of nanocomposites. In order to enhance the material qualities of an original resin, carbon-based nanofillers are frequently used. Researchers have been heavily using graphene, graphene oxide (GO), and graphene platelet (GPL) to reinforce nanocomposite materials in recent years. Additionally, a suitable starting matrix will be strengthened by two-scale reinforcing components in a recently developed type of nanocomposites. In fact, a group of both macroscale and nanoscale fibers/fillers will be disseminated in a media to enhance material qualities even more than those obtained from previously created nanocomposites in such nanocomposites, which are referred to as

multi-scale hybrid (MSH) nanocomposites. It is typical to combine CF and a nanosize reinforcing phase in MSH nanocomposites. In order to achieve improved material properties either in the middle or at the upper and lower edges of the analyzed structure, it is also common practice to design the desired distribution for the nanosize reinforcement across the thickness of the nanocomposite media as opposed to the uniform-type distribution. The resultant nanocomposite is typically referred to as functionally graded (FG) nanocomposites in this type of nanocomposite material due to the dependence between thickness and the presence of nanofillers. The FG-O, FG-X, and FG-A type nanocomposites are the most well-known FG distributions. The designations stated above come from a cross-sectional view of the nanofillers injected across the thickness of the primary matrix. For instance, in the FG-O nanocomposite structures, the middle surface of the structure has the highest volume fraction of nanoparticles, while the top and bottom surfaces have the lowest volume fraction.

From this point forward, it appears that nanofillers are distributed across thickness in a pattern similar to the English "O" letter. The various designations given to other classes of FG nanocomposites can be understood by following a similar process. The numerical and analytical analyses of the constitutive behavior and mechanical responses of CNT reinforced (CNTR), graphene reinforced (GR), graphene platelet reinforced (GPLR), graphene oxide reinforced (GOR), and MSH reinforced nanocomposites will be covered in the phases that follow.

LITERATURE REVIEW

Nanocomposites (CNTR)

The first type of nanocomposite that caught the researchers' attention was CNTR nanocomposites. The mechanical performance of CNTR nanocomposite structures under various static and dynamic excitations has recently been the subject of numerous publications published in prestigious international journals and conferences. Shi, Feng, Huang, Hwang, and Gao [7] reported an analysis about the constitutive equations of such nanocomposite materials with respect to the effects of the aggregation of the nanofillers as well as their intrinsic wavy nature in one of the early studies about the CNTR nanocomposites. In this study, two significant problems that arise in the actual world were taken into account, and the elasticity tensor of CNTR nanocomposites was computed in relation to these problems. Because of their enormous length-to-radius ratio, CNTs will in fact have a sinusoidal wavy shape, and this fact was taken into account in this research via the creation of a novel continuum mechanics-based method. The influences of CNT aggregation, which occurs due to the high surface to volume ratio of the nanosize fillers, were also taken into account in this study along with the effects of waviness. Ke, Yang, and Kitipornchai [8] used a finite element (FE) based formulation in another study on the CNTR nanocomposite structures in order to investigate the natural frequency characteristics of beams made of such nanocomposites. In addition, the effects of three different boundary conditions, such as simply supported-simply supported (S-S), clamped-clamped (C-C), and clamped-simply supported (C-S) ones, were covered in the research obtained by Ke, Yang, and Kitipornchai [8]. In this paper, the obtained governing equations were solved by the well-known Ritz method regarding the influences of nonlinear strain-displacement relations in the framework of the Timosh Researchers have found a solution to the problem of thermally influenced stability of FG nanocomposite plates and shells reinforced with CNTs [9, 10].

On the basis of the well-known third-order shear deformation theory, the effects of geometric nonlinearity were taken into account in the aforementioned studies (TSDT). Shen and Xiang [11] used a similar approach to investigate the vibrational responses of CNTR nanocomposite shells in regard to the impact of nonlinear von Karman relations. Once more, this study covered the effects of various nanofiller distribution types. The effects of shear deformation were taken into account up to the third order in this investigation. Furthermore, Sobhani Aragh, Nasrollah Barati, and Hedayati [12] used the Eshelby-Mori-Tanaka micromechanical homogenization scheme to take into account the effects of nanofillers' agglomeration as well as the aligned or straight being of the CNTs on the natural frequency of FG-CNTR nanocomposite panels. They were able to use the well-known generalized differential quadrature method (GDQM), a potent numerical technique, to tackle the vibration problem. In a different analysis, Wang and Shen [13] examined the vibrational properties of FG-CNTR nanocomposite rectangular plates supported on an elastic medium within the TSDT of plates and in the presence of thermal loading to present a trustworthy thermal analysis. They also took into account the temperature-dependency of the CNTs' material properties. Yas and Samadi [14] utilized the GDQM by examining the impacts of different types of nanofillers distributed over the thickness of the beam-type element by performing static buckling and dynamic frequency assessments of CNTR nanocomposite beams within the context of the Timoshenko

beam theorem. In the framework of an elasticity-type methodology for the static assessments of CNTR nanocomposite plates and panels with smart piezoelectric controllers, Alibeigloo [15], [16] combined the increased properties of CNTR nanocomposites with the smart features of piezoelectric materials. Additionally, Alibeigloo and Liew [17] presented a thermal static stress analysis to ascertain the stress diagrams of FG-CNTR nanocomposite plates within the confines of the elasticity theorem. In this study, the analytical solution for the S-S beams was used to solve the problem's governing equations. The stability issue of FG-CNTR nanocomposite beams in the presence of inertial effects was examined by Ke, Yang, and Kitipornchai [18]. The investigation of nanocomposite structures' dynamic stability can benefit from this article's findings regarding outcomes. The linked governing equations of the problem were resolved using the DQM in this research. Lei, Liew, and Yu [19] used a FE-based kp-Ritz approach in another article to examine the free vibration responses of FG-CNTR nanocomposite plates. Two micromechanical homogenization techniques were used in this study to enhance the nanocomposite's equivalent material properties. The first is an expanded version of the well-known mixture rule, and the second is the Eshelby-Mori-Tanaka technique, which can take the agglomeration of nanofillers into account. Additionally, the effects of shear deflection were taken into account in this research up to the first order. Malekzadeh and Shojaei [20] investigated the stability issue of quadrilateral plates made up of a few CNTR nanocomposite layers while shear deformation influences were taken into account in the FSDT of plates. The edges of the examined plate were thought to be either simply supported or clamped. The molecular dynamic (MD) simulation coefficients were used to obtain the effective material properties of the CNTR nanocomposite using the rule of the mixing. Three-layered smart beams with a FG-CNTR nanocomposite core and two upper and lower smart piezoelectric facesheets were the subject of research by Rafiee, Yang, and Kitipornchai [21].

In this study, the effects of shear deformation are not considered. Following the previous research, Rafiee, Yang, and Kitipornchai [22] addressed the bifurcation-type buckling issue in smart nanocomposite beams. In this study, the von-Karman relations for Euler-Bernoulli beams were extended while assuming that the structure was built of a CNTR nanocomposite material with two piezoelectric facesheets. Shen and Xiang [23] completed a huge nonlinear large amplitude static and dynamic study on the bending, vibration, and buckling issues of CNTR nanocomposite beams using a higher-order beam hypothesis combined with von-nonlinear Karman's strain-displacement relations. Thermal gradients were present when this study was being done. When the shell is expected to be susceptible to axial and radial excitations, Shen and Xiang [24] used a perturbation-based approach to resolve the problem of thermo-elastic postbuckling analysis of CNTR nanocomposite shells. This approach also took the effects of shear deformation into consideration. On the basis of the theory of elasticity and 3D analysis, Yas, Pourasghar, Kamarian, and Heshmati [25] used the GDQM solution for the free vibration analysis of nanocomposite shells reinforced with CNTs. With a related study, Alibeigloo [26] reported a 3D elasticity solution for cylindrical CNTR nanocomposite shells wrapped in piezoelectric layers using Fourier expansions. On the other hand, an analysis obtained by Ansari, Faghih Shojaei, Mohammadi, Gholami, and Sadeghi [27] dealing with the forced vibration problem of CNTR nanocomposite beams with respect to various distributions of CNTs across the thickness of the structure included the effects of neutral surface and von-Karman type nonlinearity. This study also considered the impact of firstorder shear deflection. Later, Heydarpour, Aghdam, and Malekzadeh [28] studied the natural frequency characteristics of conical shells made from nanocomposite materials enhanced with CNTs. They did this by employing the effective numerical DQM. The FSDT's kinematic relations were used in this study to derive the problem's governing equations. Lei, Zhang, Liew, and Yu [29] used FE formulas to find the critical buckling load of CNTR nanocomposite panels and successfully resolve the problem. The utilized FE method (FEM) is known as the element-free kp-Ritz technique since it can solve the problem without dividing the structure into a significant number of elements. It is important to note that the static and dynamic responses of CNTR nanocomposite structures have been studied in numerous articles whenever it is anticipated that the continuous system will be subjected to various mechanical and thermal loadings. The mechanical study of the nanocomposite structure in these studies used a variety of beam, plate, and shell theories to either include or remove the effects of shear deformation. The fact that these issues were resolved using both analytical and numerical methods is especially intriguing. It is not intended to discuss every one of these publications here; instead, readers are strongly urged to consult Refs. [30-57].

As previously mentioned, it is crucial to take into account how the agglomeration of CNTs affects the mechanical responses of CNTR nanocomposite structures because, in the real world, this phenomenon occurs and some nanofillers will be involved in the van der Waals (vdW) potential of the others, resulting in an uneven distribution of NTs that is by

no means admirable. As a result, some scientists tried to take this problem into account when they were analyzing the mechanical properties of CNTR nanocomposite beams, plates, and shells. To enrich the governing equations of the vibration problem of CNTR nanocomposite doubly-curved shells with respect to the effects of CNTs agglomeration, Tornabene, Fantuzzi, Baccocchi, and Viola [58] developed the well-known Carrera Unified Formulation (CUF) for a higher-order shear deformation shell theory with dual curvature. This is one of the most significant articles in this field. A graded distribution for the volume percentage of the nanofillers throughout the thickness of the shell was used to represent the aggregation phenomenon. Wu, Yang, and Kitipornchai [59] explored the vibrational properties of FGCNTR nanocomposites by combining the effects of geometrical nonlinearity with geometrical imperfection for the Timoshenko beam hypothesis. They did this by utilizing the so-called Ritz method as a potent FEM. Zhang, Liew, and Reddy [60], [61] found a solution to the postbuckling issue of FG-CNTR nanocomposite shear deformable plates taking into account the effects of both axial and biaxial type compressions. Zhang, Song, and Liew [62] demonstrated the use of piezoelectric patches to control the mode forms of fluctuations in a CNTR nanocomposite plate using Reddy's TSDT. The top and bottom surfaces of the plate are where the piezoelectric actuators and sensors are situated, respectively. However, Ansari, Torabi, and Faghieh Shojaei [63] used the variational DQM (VDQM) for sector plates with different boundary conditions to explore the buckling and vibration issues of CNTR nanocomposite sector plates (BCs). Civalek [64] used the governing equations obtained from the FSDT to use the discrete singular convolution method (DSCM) to evaluate the vibrational behaviors of FGCNTR nanocomposite shells and plates. Ebrahimi and his collaborators [65, 66] investigated the thermally influenced dynamic behaviors of beams and plates composed of FG-CNTR nanocomposite layers on the basis of higher-order shear deformation beam and plate hypotheses. In a separate project, Fantuzzi, Tornabene, Baccocchi, and Dimitri [67] carried out an isogeometric analysis (IGA) to investigate the free vibration problem of FG-CNTR nanocomposite plates with arbitrary shapes with reference to the impacts of the aggregation of the nanosize reinforcements. On the basis of the FSDT, they calculated the motion equations for the plate. Garca-Macas, Rodriguez-Tembleque, CastroTriguero, and Sáez [68] obtained a numerical analysis to take into account the postbuckling issue of FG-CNTR nanocomposite panels while the structure is being compressed axially. This investigation takes into account both the aligned or straight insertion of the NTs into the matrix and the impacts of the nanofillers' aggregation. The vibration problem of FGCNTR nanocomposite beams in the presence of thermal loading was solved by Ghorbani Shenasi, Malekzadeh, and Ziaee [69] using the FE-based Ritz technique with Chebyshev shape functions. In this study, it was decided that the effects of the pre-twisting phenomena, which occurs in long CNTs, would show more trustworthy results. Additionally, Kumar and Srinivas [70] implemented layer-wise composite analysis for the static and dynamic issues of CNTR nanocomposite plates within the context of higher-order shear deformable plate theories. On the basis of higher-order shear deformation shell theories, Nejati, Asanjarani, Dimitri, and Tornabene [71] used the GDQM to enhance the natural frequency of FGCNTR nanocomposite conical shells. Shi, Yao, Pang, and Wang [72] used the Ritz technique to solve the free vibration problem of the aforementioned structure, focusing on the impact of arbitrary BCs on the change of the natural frequency of FG-CNTR nanocomposite beams. In a related article, Wang, Cui, Qin, and Liang's investigation into the impact of BCs on the dynamic behaviors of FG-CNTR nanocomposite shallow shells was discussed [73].

In order to account for the impact of shear deflection up to first-order, the shell was modelled using the FSDT in this article. Wang, Qin, Shi, and Liang [74] studied the free vibration problem of FG-CNTR nanocomposite axisymmetric shells and panels with respect to various types of BCs using the Ritz-variational energy approach. On the basis of the meshless Ritz approach, Zarei, Fallah, Bisadi, Daneshmehr, and Minak [75] presented a numerical study addressing the thermally impacted impact responses of FG-CNTR nanocomposite plates taking into account the affects of various BCs. In this investigation, the impact of temperature on the nanocomposite structure's impact reactions was taken into consideration, specifically for reference temperatures of 300, 500, and 700 Kelvin. Zhang, Song, Qiao, and Liew [76] applied the TSDT of Reddy to examine the dynamic reactions of FG-CNTR nanocomposite cylinders under the influence of an impactor. In this study, the shell was taken to be S-S, which made it simple to use the well-known Navier's method to solve the motion equations. Regarding the effects of the temperature environment on the critical buckling load of the beam, Ebrahimi and Farazmandnia [77] found a solution to the stability problem of the multilayered CNTR nanocomposite beams. In a different research endeavor, Ebrahimi, Rostami [78, [79]] used an effective exponential analytical solution method to handle the wave dispersion problem of CNTR nanocomposite beams and plates. In the context of an axisymmetric investigation pertaining to general BCs, Wang, Pang, Qin, and Liang [80]

connected the FG-CNTR nanocomposite structures to a series of springs to apply the FSDT to handle the natural vibration problem of the nanocomposite shells and panels. Using FE formulas, Zghal, Frikha, and Dammak [81] reviewed the nonlinear bending problem of FGCNTR nanocomposite doubly-curved shells. The shear deformation effects were taken into account in this study up to third-order to produce the TSDT of Reddy. Another attempt to give a numerical solution to ascertain the natural frequency of FG-CNTR nanocomposite circular and annular complete or sector plates based upon the well-known FSDT of plates in the polar coordinate system was made by Zhong, Wang, Tang, Shuai, and Qin [82].

On the other hand, Zhu, Jeong, Lim, and Yun [83] examined the constitutive behaviors of CNTR nanocomposite materials taking into account the effects of CNTs' waviness and their orientation in the media. Based on a probabilistic multi-scale modeling procedure, this simulation was run. Additionally, Ebrahimi, Hajilak, Habibi, and Safarpour [84] conducted a thermo-mechanical buckling investigation on the CNTR nanocomposite shells with regards to the affects of the viscous fluid flow in the shell. The nanocomposite structure is viewed as spinning around its axial axis in this study. Recently, a Mori-Tanaka based inquiry about the constitutive equations of CNTR nanocomposites containing wavy CNTs explored the impact of the interface between nanofillers and matrix.

Nanocomposites (GR)

GR nanocomposites are undoubtedly a perfect substitute for other types of nanocomposite materials in engineering applications. Similar to CNTR nanocomposites, these materials can be strengthened to be employed in certain applications by adding graphene to the original matrix of the nanocomposite. There are numerous studies that discuss the analysis of continuous systems made of GR nanocomposites. For instance, Mirzaei and Kiani [85] used the FSDT of plates to account for the shear deformation up to first-order in the NURBS mathematical approximation to obtain an IGA regarding the thermo-mechanical buckling problem of FG-GR nanocomposite plates. Shen, Lin, and Xiang [86] conduct a nonlinear analysis to examine the thermal vibration behaviors of FG-GR nanocomposite beams while assuming that the structure is supported by an elastic substrate. Reddy's TSDT was used in this study to acquire the kinematic relations of the beam-type element, and a two-step perturbation technique was used to solve the achieved equations. Shen, Lin, and Xiang [87] have looked into the thermal stability and bending studies of GR nanocomposite beams within the context of the nonlinear expansion of higher-order shear approximation beam theories. The resultant nonlinear governing equations were solved using a two-step perturbation method, just like in the earlier article these authors proposed. On the basis of higher-order shell theories, Shen, Xiang, and Fan [88] investigated the nonlinear vibration responses of GR nanocomposite shells. The aforementioned paper also discussed the effects of exposing the shell to a temperature environment. Shen, Xiang, and Lin [89] have looked into the problem of thermally influenced buckling and postbuckling of FG-GR nanocomposite plates in relation to the temperature dependence of the material properties of graphene. The higher-order kinematic plate hypothesis was used to simulate the plate in this article, and it is assumed that the plate is resting on an elastic medium. The nonlinear deflection behaviors of FG-GR nanocomposite plates whenever the plate is placed on an elastic foundation were demonstrated by the same authors in a different study [90]. Shen, Xiang, Lin [91] and Shen, Xiang, Lin, Hui [92] investigated the effects of nonlinear strain-displacement relationship on the thermo-elastic natural frequency and buckling load behaviors of FG-GR nanocomposite plates while presuming that the structure under study is resting on an elastic substrate. Some researchers investigated the problem of GR nanocomposites' low-velocity impact reactions using higher-order shear deformation kinematic theories [93, 94]. To regulate the dynamic reactions of the continuous system when assaulted by an impactor, these publications assumed that the beam- and plate-type structures were made from multilayered GR nanocomposites and embedded on a viscoelastic substrate.

An FE research on the bending behaviors and natural frequency features of nanocomposite plates reinforced with both graphene and CNT was conducted by Garca-Macas, Rodriguez-Tembleque, and Sáez [95]. The micromechanical homogenization technique that is being used is strong enough to calculate the effects of CNT agglomeration on the mechanical responses of the plate. Additionally, the governing equations were developed using a plate-specific expansion of the FSDT. In the context of a NURBS-based IGA, Kiani [96] investigated the large amplitude natural frequency behaviors of FG-GR nanocomposite higher order plates in the presence of heat loading. On the basis of first- and third-order kinematic theories of beams and plates, respectively, the postbuckling characteristics of FG-GR nanocomposite beams and plates were examined [97, 98]. Lei, Su, Zeng, Zhang, and Yu [99] used the kp-Ritz numerical solution for the FSDT-based thermal stability analysis of multi-layered FG-GR nanocomposite plates. In a different

project, researchers developed independent publications that examined the effects of axial compression, heat loading, and external pressure on the critical postbuckling responses of cylindrical shells and panels made from FG-GR nanocomposite materials [100-102]. Additionally, Shen, Xiang, Fan, and Hui developed the nonlinear von-Karman relations to examine the bending and vibration behaviors of FG-GR nanocomposite panels in connection to the effects of the temperature environment on the mechanical response of the continuous system [103], [104]. The displacement field of the TSDT of Reddy served as the basis for deriving the motion equations. When the plate is assumed to be embedded on a viscoPasternak substrate, Fan, Xiang, and Shen [105] obtained a forced vibration analysis on the FG-GR nanocomposite shear deformable plates. The geometrical nonlinearity of the von-Karman type was thought to provide more trustworthy results in this research. In the most recent study in this area, Kiani [106] implemented a FE solution in conjunction with the FSDT to undertake a thermal buckling analysis of FG-GR nanocomposite conical shells.

Nanocomposites (GPLR)

In recent years, nanocomposites has been GPL. These nanostructures have the same TPa order Young's moduli as CNT or graphene itself. In addition to their enhanced mechanical characteristics, GPLR nanocomposites are said to also exhibit superior thermal and electrical properties [107]. In regards to the effects of the presence of porosities in the nanocomposite media, Kitipornchai, Chen, and Yang [108] presented the vibrational responses of FGGPLR nanocomposite beams on the basis of the FSDT of beams integrated with the Ritz technique. According to the kinematic relationships of the FSDT of rectangular plates, Song, Kitipornchai, and Yang [109] examined both the free and forced vibration responses of FG-GPLR nanocomposite plates. For the BCs with simple support, the governing equations were solved within the framework of the well-known Navier type solution. Song, Yang, Kitipornchai, and Zhu [110] investigated the nonlinear buckling and postbuckling properties of FG-GPLR multi-layered nanocomposite plates using the perturbation method. The impact of the first flaw was also taken into account in this work. A different study using the effective DQ numerical discretization method was done by Wu, Kitipornchai, and Yang [111] to analyze the thermally impacted stability of FG-GPLR nanocomposite plates. Using the strain-displacement relations of the FSDT, Wu, Yang, and Kitipornchai [112] examined the dynamic buckling reactions of FG-GPLR nanocomposite beams. Additionally, the effect of thermally loading the nanocomposite is taken into account. The governing equations were numerically solved using the well-known DQM. Feng, Kitipornchai, and Yang [113] carried out static deflection and stress evaluations of FG-GPLR nanocomposite beams based on the nonlinear von-Karman relations in conjunction with the FSDT. The FE-based Ritz approach was used to solve the resulting equations. On the basis of the FSDT, Yang, Wu, and Kitipornchai [114] examined the buckling and postbuckling reactions of FG-GPLR nanocomposite beams. Additionally, to improve the mechanical responses of C-C, C-S, and S-S beams, Feng, Kitipornchai, and Yang [115] acquired the nonlinear vibration analysis of GPLR nanocomposite beams within the Ritz method framework. The von-Karman relations and displacement field on higher-order beam hypothesis were integrated by Barati and Zenkour [116] to address the postbuckling issue of FG-GPLR nanocomposite structures. This study considered both the effect of geometrical imperfections and the effect of media porosities. First-order porous GPLR nanocomposite beams' postbuckling load and natural frequencies were discovered by Chen, Yang, and Kitipornchai [117] using the numerical Ritz technique. Researchers looked into how the presence of porosities in the nanocomposite material affected the 3D elasticity solution of thermally induced bending behaviors of GPLR nanocomposite rectangular and circular plates [118, 119]. Barati and Zenkour [120] addressed the problem of postbuckling analysis of FG-GPLR nanocomposite beams within the scope of an iteration-free analytical method with regard to the geometrical beam flaw.

Bahaadini and Saidi [121] addressed the vibrational responses of blades in supersonic airflow by applying the Timoshenko beam hypothesis in conjunction with the constitutive equations of GPLR nanocomposite materials. Furthermore, Barati and Zenkour [122] used the FSDT of shells to track the dynamic behaviors of FG-GPLR nanocomposite cylinders. In this study, the Halpin-Tsai micromechanical scheme with the saturated porous model was extended to include the effect of the porous nature of the nanocomposite material. The natural frequency characteristics of GPLR porous nanocomposite shells were examined by Dong, Li, Chen, and Yang [123] with regard to the impact of the structure's rotating motion along its axial axis. An examination by Dong, Zhu, Wang, Li, and Yang [124] in search of the natural frequency of GPLR shells incorporated the nonlinearity effect in addition to that of the axial loading in a publication dealing with the frequency behaviors of spinning nanocomposite shells. Ebrahimi, Habibi, and Safarpour [125] conducted a wave dispersion study of cylindrical shells reinforced with GPLs while taking into account the impacts of the thermal environment and porosities on the dispersion curves of nanocomposite shells. The natural

frequency of conventional nanocomposite plates enhanced with GPLs was determined using von-Karman relations [126]. For several kinds of BCs, the nonlinear set of governing equations was solved using DQM. In a different publication, Gholami and Ansari [127, 128] used shear deformable plate theories to conduct a nonlinear frequency analysis of GPLR nanocomposite rectangular plates. IMLS-Ritz technique, an effective numerical method, was used to examine the static and dynamic behaviors of quadrilateral non-rectangular FG-GPLR nanocomposite plates [129, 130]. The FSDT of plates served as the foundation for the governing equations. By expanding a new micromechanical technique, Hosseini and Zhang [131] examined the thermomechanical transient properties of GPLR nanocomposite cylinders. The finite difference method and the Newmark method were used to produce the time-dependent responses of the shell. In contrast, Li, Wu, Chen, Cheng, Liu, Gao, and Liu [132] conducted an IGA-based numerical analysis to determine the deflection, buckling load, and natural frequency characteristics of FG-GPLR nanocomposite plates with metallic matrix based upon both FSDT and TSDT. The damped dynamic behaviors of porous GPLR nanocomposite plates were investigated by Li, Wu, Chen, Liu, Yu, and Gao [133] while taking into account the geometrical nonlinearity mixing the displacement field of the Kirchhoff-Love plate hypothesis with the nonlinear von-Karman relations. In this investigation, it was possible to determine the natural frequency, dynamic deflection, and dynamic buckling load of the aforementioned structure. Liu, Kitipornchai, Chen, and Yang [134] investigated the buckling and vibration responses of FG-GPLR nanocomposite cylindrical shells using 3D elasticity while accounting for the impact of the presence of an initial pre-stress in the structure. Different distributions of GPLs were taken into consideration. Additionally, according to the FSDT, Reddy, Karunasena, and Lokuge [135] examined the vibrational properties of FG-GPLR nanocomposite plates placed on an elastic substrate. GPLR nanocomposite plates were subjected to elastic bending and buckling analysis by Song, Yang, and Kitipornchai [136] with regard to the effect of shear deformation up to first-order. They used the well-known Navier's approach to solve the aforementioned issues analytically. Wang, Chen, Hao, and Zhang [137] used a higher-order shear approximation hypothesis to address the bending and vibration issues associated with GPLR nanocomposite doubly-curved shallow shells. On the other hand, Wang, Feng, Zhao, Lu, and Yang [138] studied the problem of torsional buckling responses of FG-GPLR nanocomposite shells with cutout utilizing approximations of the FEM. Additionally, Wang, Feng, Zhao, and Yang [139] used FEM to resolve the buckling issue with FG-GPLR nanocomposite shells with cutouts. Using the effective discretization of the DQM, Wu, Yang, and Kitipornchai [140] examined the dynamic buckling behaviors of FG-GPLR nanocomposite plates. The FSDT served as the foundation for the motion equations. Yang, Mei, Chen, Yu, and Yang [141] created a 3D elasticity-based solution for the bending responses of FG-GPLR nanocomposite elliptical plates. On the basis of the Euler-Bernoulli beam hypothesis in the polar coordinate system, Yang, Yang, Liu, and Fu [142] conducted the nonlinear stability analysis of GPLR nanocomposite arches.

In an analytical solution method, Blooriyan, Ansari, Darvizeh, Gholami, and Rouhi [143] investigated the postbuckling behaviors of GPLR nanocomposite shells while taking into account the combined impacts of axial and lateral excitations. In a different study, Gholami and Ansari [144] studied the stability and frequency characteristics of GPLR nanocomposite plates using variational DQM (VDQM) and the nonlinear expansion of higher-order plate theory. Additionally, Haboussi, Sankar, and Ganapathi [145] conducted a FE-based analysis to determine the dynamic buckling load of spherical shells reinforced by GPLs using higher-order kinematic theories in the presence of a pressure on the structure. Qaderi, Ebrahimi, and Seyfi [146] conducted the damped frequency analysis of FG-GPLR nanocomposite beams supported on a three-parameter viscoPasternak medium using a higher-order beam model. using a modified version of the Hertz impact model. By combining the von-Karman relations with the FSDT, Song, Li, Kitipornchai, Bi, and Yang [147] examined the low-velocity impact responses of FG-GPLR nanocomposite plates. The nonlinear frequency behaviors of porous FGGPLR metal foam cylinders for simply supported shells, according to the classical theory of shells omitting the effects of shear deflection, have recently been studied by Wang, Ye, and Zu [148]. The stiffness and yield strength of nanocomposites can be amplified by GO nanosize reinforcement in a remarkable way, in addition to the previously mentioned nanoparticles that were utilized in their manufacture [149]. From this point on, a few of the researchers focused their work on examining the elastic properties of nanocomposites enhanced by GO. The creation of hydrogenated carboxylated nitrile-butadiene rubber nanocomposites amplified with GO shown that adding a small amount of GO to the initial matrix can significantly increase the resulting material's Young's moduli [150]. In recent years, there have been an increasing number of investigations into the improvements in GOR cement- or epoxy-based nanocomposites, and all of the proposed studies have emphasized the critical contribution of GO to the

enhancement of the primary matrix's material properties [151–153]. Even though GOR nanocomposites have improved mechanical properties, there aren't many studies in the literature on nanocomposites that discuss the static or dynamic reactions of structures made of GOR nanocomposite materials. In one of the most recent initiatives in this sector, Zhang, Li, Wu, Zhang, Wu, Jiang, and Chai [154] used the FSDT of beams to investigate the bending, buckling, and vibration behaviors of FG-GOR nanocomposite beams. Ebrahimi, Nouraei, and Dabbagh [155] have solved the thermally affected vibration problem of FG-GOR nanocomposite plates using a higher-order refined plate model. Utilizing the Navier-type analytical solution, the natural frequencies were obtained for the totally simple supported plates.

Nanocomposites (MSH)

In recent times, a brand-new class of nanocomposites has caught the interest of researchers as being superior than the aforementioned kinds of nanocomposite materials. This brand-new class of nanocomposites, known as MSH nanocomposites, uses macroscale fibers in conjunction with nanoscale reinforcements. Each of the following materials can be used to create nanocomposites, including nanofiller and macroscale fibers: CNT, graphene, GPL, and GO. The homogeneity of such materials is crucial, and Thostenson, Li, Wang, Ren, and Chou [156] achieved this process in the early 2000s as part of an experimental investigation. Mareishi, Rafiee, He, and Liew [157] used the nonlinear strain-displacement relations of the Timoshenko beam mode to investigate the bending, buckling, and vibration behaviors of MSH smart nanocomposites. Rafiee, Liu, He, and Kitipornchai's nonlinear vibration analysis of smart piezoelectric MSH nanocomposite plates was completed [158] using the FSDT combined with the von-Karman relations for rectangular plates. The well-known Galerkin's approach was used to solve the enhanced governing equations. He, Rafiee, Mareishi, and Liew also carried out the damped viscoelastic dynamic analysis of MSH nanocomposite beams [159].

The natural frequency of rotational MSH nanocomposite beams with arbitrary cross-section shapes was estimated by Rafiee, Nitzsche, and Labrosse [160]. Additionally, Ebrahimi and Habibi [161] used Reddy's TSDT combined with von-Karman relations to examine the thermo-mechanical low-velocity impact behaviors of MSH nanocomposite plates. Rafiee, Nitzsche, and Labrosse [162] investigated the nonlinear mechanical responses of MSH nanocomposite beams reinforced with GPLs as the nanosize reinforcing element on the basis of the classical beam theory. Researchers working with the constitutive equations of MSH nanocomposite materials conducted micromechanical investigations with respect to the naturally wavy nature of long and slender CNTs in the presence of the agglomeration of nanofillers [163-165]. Gholami and Ansari [166] presented a nonlinear bending study concerning the MSH nanocomposite structures using the TSDT in order to take into account the effects of various types of BC on the mechanical deflection of plates. Ebrahimi and Dabbagh [167] used the higherorder shear deformable beam hypothesis to ascertain the natural frequency of MSH nanocomposite beams whenever the structure is exposed to temperature conditions. In order to characterize MSH nanocomposite materials with various types of nanofillers, Rafiee, Nitzsche, Laliberte, Hind, Robitaille, and Labrosse [168] obtained the necessary data. Dabbagh, Rastgoo, and Ebrahimi [169] proposed a numerical FE study to determine the natural frequency of MSH nanocomposite shear deformable beams in consideration of the effects of nanofillers' aggregation in the nanocomposite media in one of the most recent studies addressing the mechanical responses of nanocomposite continuous systems. Later, Ebrahimi and Dabbagh [170] used a shear deformable beam hypothesis combined with the basic FE approximations to study the vibrational properties of MSH nanocomposite beams reinforced with GO and CF. In order to examine the stability responses of MSH nanocomposite structures based on smart shape memory alloy (SMA) with account of the effect of heat gradient as well as moisture concentration, Karimiasl, Ebrahimi, and Akgöz [171] adapted the TSDT for the doubly-curved shells. Additionally, a vibration study project to ascertain the free and forced vibrational properties of MSH smart nanocomposite doublycurved shells took the nonlinearity effects into account [172, 173].

CONCLUSION

The aforementioned discussions were put forth to demonstrate the amazing scientific efforts made by a diverse group of researchers who were looking for the mechanical behaviors of nanocomposite materials and structures while taking into account the effects of various working conditions and realistic phenomena. As a succinct conclusion, it is clear that the authors were able to address nearly all of the issues that could be identified with CNTR nano composites. Several attempts to analyze the mechanical responses of such nanocomposites explored the impacts of the

agglomeration and waviness of the nanofillers. Additionally, a lot of studies have been written about the mechanical properties of GR and GPLR nanocomposites. However, there is a lack of research on the behaviour of GOR and MSH nanocomposite materials and structures, leading to a number of unsolved issues in these areas. Researchers are advised to consider the realistic phenomena that occur during the fabrication of nanocomposites, such as the agglomeration of nanoparticles and the creation of the interphase zone between the nanoparticle and the initial matrix, when analyzing the mechanical responses of these types of nanocomposites.

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