Numerical investigation of flexural strength for functionally graded composite and laminated composite materials

To cite this article: Ahmed Fadhil Hamzah *et al* 2021 *J. Phys.: Conf. Ser.* **1973** 012167

Numerical investigation of flexural strength for functionally graded composite and laminated composite materials

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AbstractMaterial properties that can be done to show a smooth and constant change starting with one surface then onto the next, along these lines taking out interface issues and alleviating concentrations of thermal stress. In the present work, a polymeric composite with functionally graded mode and their deflection behavior were studied using analysis through Finite element analysis via ANSYS 16.1 and visual basics 6.0 language depending on Mori Tanka formula and classical laminated theory in order to decide the stiffer material under flexural load. The proposed tests were essentially using the square plates under static uniform stress. The two kinds of composites were involved in a paired of materials with constant volume fraction. The outcomes revealed that stiffness of FGM less than laminate composite.
Key words: FGM, Laminate, ANSYS, Visual basic, Flexural.

1. INTRODUCTION

A significant change in the properties of the material can take place when composite it with more than one ingredient phases with the variety in structure and arrangement gradually over volume and the resultant composition is known as a functionally graded material (FGMs) [1]. The FGMs are typically connected with particulate matter. They have gotten an extraordinary significance, due to the eligible properties of every constituent phrase and they can be used for applications and certain function [2,3].
The FGMs have various favorable circumstances that can be appealing in required applications, involving a reduction of in-plane and transverse along-the-thickness stresses, enhancement of the residual stresses, upgraded the higher strength at break, thermal properties, and diminished stress intensity factors (SIF) [1,4]. Procedures of the global argument on functionally graded composite also shelter light on the at the end of research in these kinds of materials, application, thermal characteristic, mechanics, and their production applications [5].
In the FGMs the properties change gradually relying upon the chemical composition, microstructure, design, and phase distribution which can be changed in specific direction [1]. Two main categories of FGMs were continuous and discontinuous. Miyamoto et al,[6] clarified the whole concept of "material ingredient". Due to using FGMs in different sector like medical

industries, electronics, pressure vessels, and aerospace, different methods are used for FGMs manufacturing [7]. Recently, the FGMs multilayer has considered due to their enormous gradation of mechanical properties, physical, and chemical direction of material depends on desired design. Regardless of the significance of polymer-setup FGMs, has got little attention [8].

Composite Laminated Polymers are a sort of Fiber Reinforced Plastics which is produced by arranging layers of fiber with very high strength to strength the polymer in various orientation to supply, wanted planning properties and can encounter comparative delamination between laminar stresses, the polymer base and phase of reinforcing to show a troublesome circumstance, for instance, a moist environment [9].

In order to evaluate the mechanical properties of functionally graded composite materials by utilizing various modes, a few research papers theoretical and experimental were done. Klingshirn and Friedrich [10] experimentally made composite materials made of short carbon fibers and thermosetting matrix by using centrifugation technique in order to find better distribution of fiber and modify set of equation to be useful for the spheres motion. It has found a good agreement between the theoretical and experiment result. Tilbrook et.al [11] studied experimentally and by using simulation graded alumina/epoxy composite specimens and check the spread of cracks under monotonic and cyclic four-point bend loading displaying a variety in composition from 5% to 65% epoxy were utilized. Crack inception and propagation were checked and development rates and crack trajectories were estimated. An agreement between theoretical and computational prediction for the initial crack deflection was observed.

Kamarian et.al [12] proposed an exact arrangement strategy dependent on the three-dimensional theory hypothesis for the free vibration examination of Functionally Graded Sandwich (FGS) plates were no presumptions on stresses and removals have been utilized Interesting outcome shows that by using a reasonable four-parameter model for materials volume portion, frequency parameter can be gotten more than the frequency parameter of the identical FGS plate with sheets made of 100% ceramic and at the same time lighter.

Dastjerdi et.al [13] study the impacts of carbon nanotube (CNT) orientation and aggregation on the static behavior of functionally graded nanocomposite cylinders reinforced by CNTs based on a mesh-free method The acquired mechanical properties are checked by test and theoretical results that are reported in works of literature. Rizov [14] is examined the delamination break of a two-dimensional practically evaluated multilayered four-point bending beam that exhibits non-linearity behavior of the material, it is found that the material non-linearity leads to an augmentation of the strain energy release rate. The mechanical properties had been studied by Muslim et.al [15] using wollastonite particles reinorced epoxy as functionally graded compositeIt is discovered that fracture toughness of graded reinforced composite is higher than that of the unreinforced epoxy and non-graded reinforced composite Fadhil et.al [16] lead numerically and experimentally discuss, of flexural and impact behaviour of functionally graded rubber filled with wollastonite as core in sandwich composite. The outcomes show great agreement between finite element analyses and trial.

On the other side, when the number of layer and nonlocal parameter in macro-structure are increased lead to the natural frequency decreased for the nanoplate. Also, it is found that there is an effect of size, geometry and weight fraction of GNPs on fundamental structure’s frequency which is important for researcher and designer for optimization purpose. Mohammad Arefi et al [17], have used FG composite nanoplates reinforced with GNPs to study free vibration response. It have found by theoretical examination display that the greatest natural frequencies associated with FG-X through the investigated appropriations due to high bending stiffness of the composite material with reinforcement design. Narasimha Rao Mekala1 et al [18] they simulated and modeled of functionally graded polymer composites strengthened with graphene nanofillers under the huge applied electric actuation of bonded piezoelectric layers have been performed. The impacts of different dispersion examples of GPLs through the thickness and scale impacts like geometry and size on the static reaction of GPL/polymer composites over the piezoelectric loads have been explored. the higher or lower stiffness of the structure can be accomplished by changing the GPL distribution design. So in the static shape control and actuator issues, a viably design smart GPL/polymer composite structural system with a reasonable variety of GPL appropriation designs. it has been seen that littler the length scale parameter impacts the length scale is higher in electric loading cases.Chuang Feng et al [19] examined the nonlinear free vibration of a multi-layer polymer nanocomposite beam strengthened with a non-uniformly distributed along with the thickness direction graphene platelets (GPLs) . using the Halpin-Tsai mode of micromechanics influence of Young’s modulus GPL/polymer composites have been evaluated to calculate for the influence of dimensions and GPL geometry. Nonlinear and linear free vibration practices of nanocomposite beams enriched with nonuniform disseminated GPLs are exhaustively examined inside the system of the von Karman nonlinear strain displacement and Timoshenko beam theory relationship. The outcomes display that using a quite small quantity of GPLs into polymer matrix as reinforcements fundamentally increment the natural frequencies of the beam. Utilizing larger sized GPLs with fewer single graphene layers and placing more GPLs near the top and bottom surfaces of the beam are the best approaches to strengthen the beam stiffness and increment the linear and nonlinear natural frequencies. The objective of the present work is to focus on the determination of the flexural strength of functionally graded composite material and compare it with a laminated composite with two types (cross and angle) ply by using finite elements technique through (ANSYS) up to the best resistance to bending loads.

2. SIMULATION PROCEDURE

2.1 LAMINATED COMPOSITE MATERIALS:

To test the deflection of laminated composite plates theoretically by utilizing ANSYS, the Poisson's ratio, shear modulus and modulus of composite plate elasticity (appeared in Figure 1) were detect by utilizing mixture rule to compute the elastic constants of laminated plate.

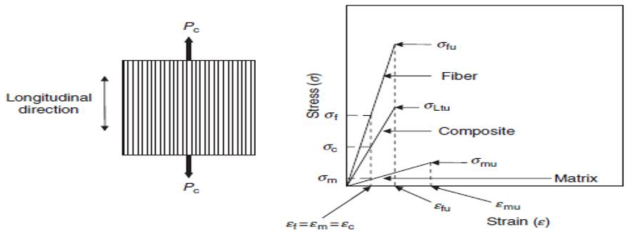

Figure 1 Composite ply.

The laminates composites consist of Epoxy as matrix and Carbon fiber as reinforcement, which have mechanical properties appeared in Table 1.

Table 1 elastic constants of composite constituents**.**

$material$	$E\ (GPa)$	ν	$G\ (GPa)$
$Epoxy$	3.5	0.33	1.33
$Carbon\ fiber$	220	0.22	91.67

There are two sorts of composites laminated plates contemplated was a cross ply arrangement where the employs layers stacked at 90° comparative with one another. Different composites laminated plate was the angle ply with layer stacked a 45° comparative with one another, each composite have (20) layers and each ply have fiber volume fraction (60%) and thickness (0.2 mm).

The mechanical elastic (shear modulus, Poisson's proportion, and elastic modulus) of the material utilized in this research notice in table 2 are hypothetically decided relying upon the theoretical condition (mixture rule) as following: [20]

$$E_1 = E_f V_f + E_m V_m \quad (1)$$

$$E_2 = \frac{E_f E_m}{E_f + V_f (E_f - E_m)} \quad (2)$$

$$G_{12} = \frac{G_f G_m}{G_f - V_f (G_f - V_m)} \quad (3)$$

$$\nu_{12} = \nu_f V_f + \nu_m V_m \quad (4)$$

$$\nu_{23} = \frac{E_2}{2G_{23}} - 1 \quad (5)$$

Where E elastic modulus, υ Poisson's ratio, G shear modulus and V volume fraction. These conditions gave qualities to $E1, E2, \nu 12, \nu 23, and\ G12$. Nevertheless, to direct the FEM examination the estimations of $E3, \nu 13, G23, and\ G13$ were additionally wanted. The qualities were determined by expecting isotropic transverse (as appeared in Figure 2) that for a unidirectional lamina the modulus in the ways opposite to the fiber orientation are generally equivalent and a lot littler than the modulus in the fiber orientation.

Table 2 elastic properties of lamina

Property	Values	Units
E_1	113.4	GPa
E_2	8.546	GPa
ν_{12}	0.26	
ν_{23}	0.345	
G_{12}	3.104	GPa

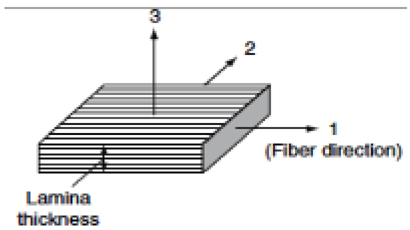

Figure 2 Transverse isotropy lamina.

In the present study, the plates were displayed utilizing element SHELL181 in software (ANSYS). This kind of element has 4 nodes. In this manner, when the properties of material of a lamina was recorded, the plate was built in ANSYS software by arranging the right number of laminas, each speaking to utilize, in the right angle direction. The layers were set in a $[0\ 90\ 0\ 90\ 0\ 90\ 0\ 90\ 0\ 90]$s direction for each cross ply, and in a $[0\ 45\ 0\ -\ 45\ 0\ 45\ 0\ -\ 45\ 0\ 45]$s direction for each angle ply as appeared in Figures 3.

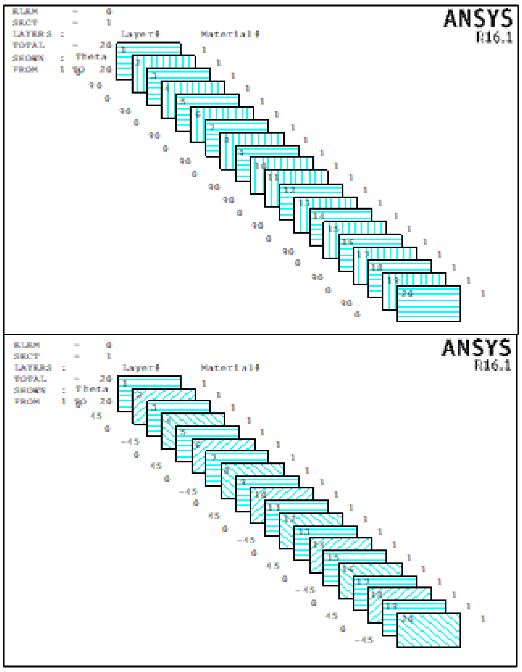

Figure 3 Cross ply and angle ply laminated composites**.**

Every one of the square plates with constant lengths of side (200 mm) and a height of (4 mm). The composite plate was then meshed by tool meshing. The force and conditions were applied to the composite sheet as simply supported plate as appeared in figure 4 with a constant and typical weight applied of load to plate. To accomplish the boundary conditions, all plate sides were obliged at the z axis. At that point, sides 1 and 3 were kept from pivoting about the y axis and sides 2 and 4 were kept from turning around the x axis. To completely oblige the mode$l$, side 1 was kept from translating along the $y\,axis$, and $side$ 4 was kept from moving in the $x\,axis$. Finally, the weight of 30 kPa was applied equally at the top.

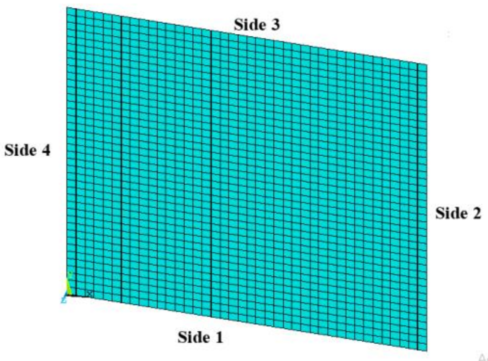

Figure 4 Cross ply and angle ply laminated composites.

2.2 FUNCTIONALLY GRADED COMPOSITE:

The elastic modulus of the functionally graded composite reinforced by graphite is lower comparative with the laminated composite. This decrease in elastic modulus happens in light of the fact that the particle of graphite in the FGM composite is kept in grains.

The properties of the FGM composite were assessed by means of the Mori-Tanaka strategy. This technique determine the material characteristics by utilizing the through thickness volume fraction of every part making up the FGM composite material. It separates the composite plate into a picked number of isotropic lamina and determine each ply properties dependent on the ingredient's volume fraction for that lamina. In the $Mori - Tanaka$ conditions beneath, the subscript "p" represents plate, "L" for lamina, "1" for material 1 which is the graphite, and "2" for material 2, which is the matrix as epoxy. The two material characteristics required for each lamina are Poisson's ratio, the modulus of elasticity and shear modulus. The equations speaking to these properties are [21]:

$$E_p = 3.K_p.\left(1 - 2.\upsilon_p\right) \quad (6)$$

$$\upsilon_p = \frac{1}{2.\left(1+\frac{G_p}{\lambda_p}\right)} \quad (7)$$

Gp is the shear modulus of the FGM composite plate which can indicated by:

$$G_p = G_1 + \frac{(G_2-G_1).V_2}{\left(1+\frac{(1-V_2).(G_2-G_1)}{G_1+f_1}\right)} \quad (8)$$

Where f_1 is represented by:

$$f_1 = \frac{G_1(9.K_1+8.G_1)}{6.(K_1+2.G_1)} \quad (9)$$

λ_p is Lamè first parameter, represented by:

$$\lambda_p = K_p - \frac{2}{3}.G_p \quad (10)$$

Kp is the bulk modulus of the FGM plate which can be calculated by:

$$K_p = K_1 + \frac{(K_2-K_1).V_2}{\left(1+\frac{(1-V_2).(K_2-K_1)}{K_1+\left(\frac{3}{4}\right).G_1}\right)} \quad (11)$$

V_2 which is volume fraction of material 2 along the material thickness and $K1$ and $K2$ are the mass modulus of materials 1 and 2, respectively. It can be computed as follow:

$$K_n = \frac{E_n}{3.(1-2.\nu_n)} \quad (12)$$

$G1$ representing the shear modulus of which can be determined by:

$$G_n = \frac{E_n}{2.(1-\nu_n)} \quad (13)$$

$Where\ n\ =\ 1, 2.$

The FGM composite plate divided into 20 similarly layers with evaluated volume fraction. For these estimations it was accepted that the Poisson's ratio and modulus of elasticity fluctuate straightly inside the ply. This supposition that is legitimate in light of the fact that the layer is extremely meager regarding the plate thickness. At that point, the qualities for E and ν were determined for each layer by explaining the particular conditions for the z esteem speaking to the center plane of each lamina.

The calculations of this type of composite is very complicated so for modeling this type we develop a program visual basic 6.0 for finding material properties.

The FGM composite plates were demonstrated in ANSYS like the laminated composite plates. The element picked was SOLID 185. Likewise, a similar boundary condition applied to compel $the\ 4 - sides$ and applying load on the laminated plates, were utilized to applying a boundary conditions on the FGM composite plates.

3. RESULTS AND DISCUSSION

3.1 DEFLECTION

Three kinds of composite materials were considered, an angle ply laminated, a cross ply laminated and functionally graded composite. Notwithstanding giving an examination information point about deflection. To start with, the cross ply composite was demonstrated in ANSYS utilizing the technique described above of with 20 layers as appeared in the figure 3 and angle ply and lastly functionally graded plate. Figures 5, 6 and 7 shows deflection counter for cross ply, angle ply and functionally graded composite respectively.

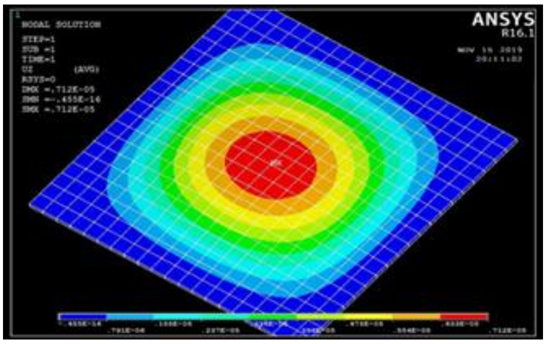

Figure 5 Counter plot for deflection of cross ply laminated**.**

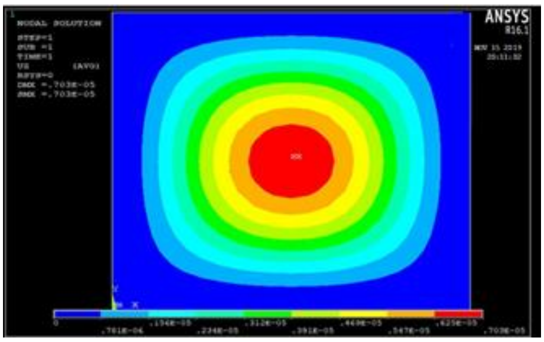

Figure 6 Counter plot for deflection of angle ply laminated.

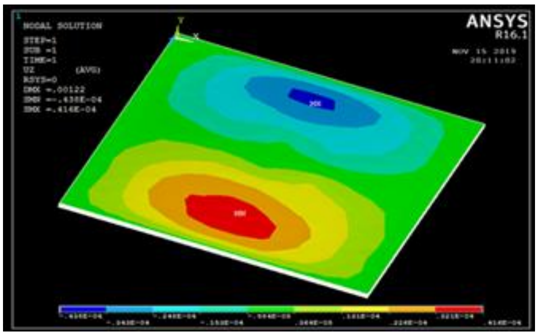

Figure 7 Counter plot for deflection functionally grade composite

The above figures show the general appropriation of the deflection all through the material, just as to detect the area and estimation of the greatest deflection, where the most noteworthy estimations of deflection. As shown in figures the deflections value (0.00712 m and 0.00703 m) for cross ply and angle ply composite laminated respectively, so that is seen that angle ply deflected which is not exactly the cross ply plate.

Twenty Graded composite plates with various graphite appropriations along plate thickness were detect to decide if plate deflections can be equivalent to composite plates. The primary plate was higher graphite volume fraction (60 %), while the remainder of the plates utilized a steady move of the graphite inboard toward the last plate, so that is seen that estimation of deflection (0.0416 m) and It is higher than the deflection estimations of laminated composite plates, this implies it has less stiffness and this decrease in stiffness happens in light of the fact that the graphite content in the functionally graded composite is kept in grains, consequently losing a portion of the high strength capacity got from the fibrous condition.

Journal of Physics: Conference Series **1973** (2021) 012167 doi:10.1088/1742-6596/1973/1/012167

3.2 EQUIVALENT VON-MISES STRESS

The Von Mises yield stress, otherwise called the most extreme distortion energy criterion proposes that yielding of a flexible material starts when the second deviator stress invariant arrives at a basic worth. It is a piece of plasticity hypothesis that applies best to bendable materials, for example, a few metals. Before yield, material reaction can be thought to be of a nonlinear elastic, viscoelastic, or elastic linear behavior [22].

Figures 8, 9 and 10 shows Von Mises stress counter for cross ply, angle ply and functionally graded composite respectively.

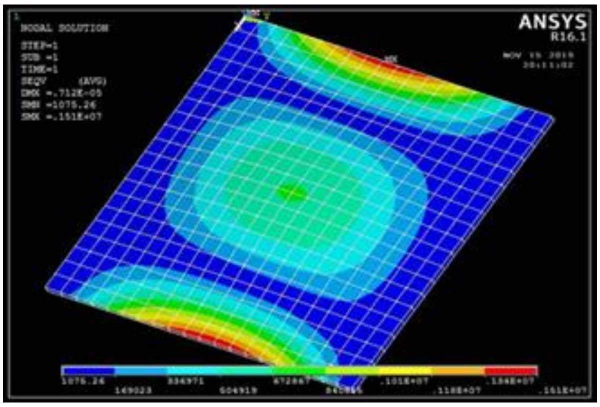

Figure 8 Counter plot for Von Mises stress in cross ply laminated

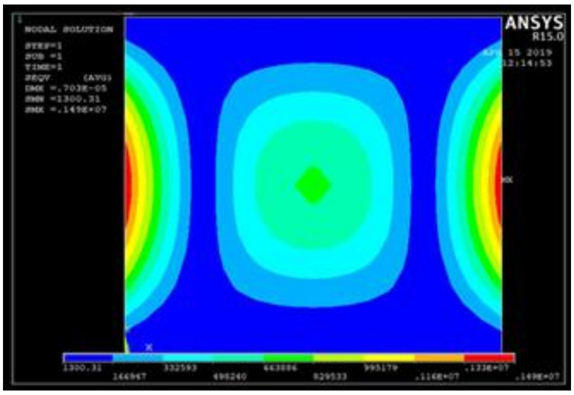

Figure 9 Counter plot for Von Mises stress in angle ply laminated.

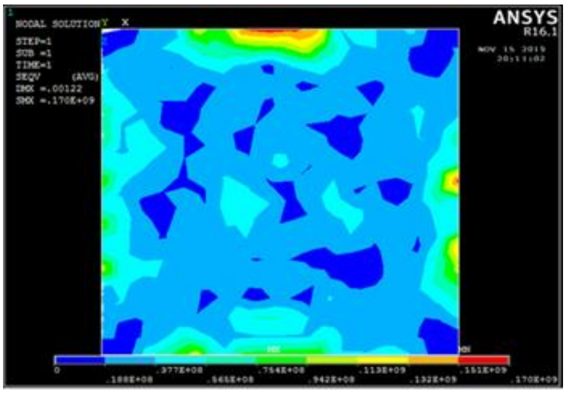

Figure 10 Counter plot for Von Mises stress in functionally grade composite.

The minimum estimation of identical Von Mises stresses, implies the greatest basic strength is gotten, and if audit the past figures, find that the most extreme equivalent stress comprises in the functionally graded composite plate (17 MPa), while the minimum value found in angle ply laminated composite (1.4 MPa), while the value of Von Mises stress in cross ply laminated composite is (1.5 MPa).

Figure 10 shows that the distribution of stresses in the functionally graded composite plate is more uniform and differs from the behavior of the laminated composite and this is what distinguishes functionally graded materials that lead to delete the sharp interface that existed in the ordinary laminated composite which is the serious issue in this sort of composite and to supplant it with the bit by bit evolving interface, which was converted into the changing chemical structure of this composite at this interface area. The developing enthusiasm for this kind of material has brought about various kinds of FGMs being created.

4. CONCLUSIONS:

This study investigated a total deflection for functional graded and laminated polymer matrix composite sample due to applied of concentrated force on the samples. All the investigated plates have the same dimensions and it made of the balanced volume fraction of reinforcement phase in epoxy matrix, and the most important conclusions are the following:

The laminated composite deflected one-fifth of what happens in the functionally graded case, the main causes is that the modulus of elasticity for the graphite filler used in functionally composite sample is one-sixth for laminated composite and one-tenth of carbon fiber used in laminated, which leads to loss of used graphite powder a lot of the stiffness it comes from used fiber and thus more deflection.

Despite the fact that FGP composite experienced more deflection than composite laminated, it offers the advantage of modification the transfer of thickness components to reduce deflection.

ACKNOWLEDGEMENTS

The authors would like to thank laboratory members of polymer in the faculty of material engineering university of Babylon

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