Tensile and Buckling Analysis of the Polymer Composite Beam Reinforced by Natural Jute Fiber

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Abstract

This research focuses on the preparation of polymer matrix composite material by (hand lay – UP) method, where the material was prepared from unsaturated polyester resin (up) as a matrix reinforced by natural jute fiber with different volume fractions (3%, 4%, 5%, 6%).The experimental work and finite element techniques were used to analysis the tensile and the buckling analysis of the composite beam reinforced by natural jute fiber at different volume fraction.

The results of experimental work of the modulus of elasticity were in the range of the theoretical results. The critical load increased with increase the fiber volume fraction that (P_{cr}=610N) at (V_f = 3%) and (P_{cr}=830N) at (V_f =6 %) for the experimental results.While (P_{cr}=619N) at (V_f = 3%) and (P_{cr}=877N) at (V_f =6 %) for the finite element results.

Keywords: jute fiber, tensile, buckling, composite, beam

تحليل الشد و الانبعاج لعمود مركب بوليمري مقوى بألياف الجوت الطبيعية

الخلاصة

في هذا البحث تم تحضير مادة متراكبة ذات أساس بوليمري بطريقة الصب اليدوي من البولي استر غير المشبع كمادة أساس مقواة بألياف الجوت الطبيعية وبكسور حجميه مختلفة هي (3%, 4%, 5% و 6%). تم استخدام الجانب العملي و تقنية العناصر المحددة لتحليل الشد و الانبعاج لعمود مركب مقوى بألياف الجوت الطبيعية وعند كسور حجميه مختلفة. النتائج العملية لمعامل المرونة كانت ضمن مدى النتائج النظرية.لقد وجد أن الحمل الحرج يزداد بزيادة الكسر الحجمي بحيث (P_{cr}=610N) عند (V_f =3%) و(P_{cr}=830N)عند (V_f = 6 %) للنتائج العملية.بينما كانت (P_{cr} =619N) عند(V_f =3%) و (P_{cr}=877N) عند (V_f =6%),نتائج العناصر المحددة.

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Introduction

The industrial application of the composite beam widely used in the recent years to modified the structures and trusses.

A beam under axial compressive load can become unstable and collapse. This occurs when the beam is long and its internal resistance to bending moment is insufficient to keep staple. At the critical load the beam became unstable and buckled that a large deflection occurs due to small increase in force ,this force called critical load or (buckling load) [1].

The equations of the buckling of the beam have been derived many years ago and readily variable to design engineers [2]. Beam – columns made of polymer matrix fiber reinforced composite materials are increasingly used in automotive, aerospace, structural and mechanical engineering industries. And buckling loads are important parameter in the design and development of high – performance composite.

R Ganesan [3] determines the mean value of the buckling loads of the beam made from the polymer (epoxy) matrix and fiber (carbon) reinforced composite material.

Tai-Kuang Lee [4] proposes reliable and computationally efficient beam –column finite element model for the analysis of the composite under unaxial

bending and axial force .and make comparison between the modal and empirical data.

F.Alami [5] buckling loads for different kinds of structures under various loading and boundary conditions, are often expressed using approximate simply formula. Sometimes to get more accurate result based on, the finite element approach is commonly employed.

In this work the beam is made from polymer materials the matrix is polyester matrix reinforced by natural jute fiber at the different fiber volume fraction (3 %, 4 %, 5 %, 6 %).

In the composite material, the mechanics of materials approach embodies the usual concept of yeastily simplifying assumption regarding the hypothesized behavior of mechanical system. The elasticity approach actually is least three approaches: bounding principles, exact solutions, and approximate solutions. The objective of all of the micromechanics approaches is to determine the elastic moduli or stiffness or composite material in terms of the elastic moduli of the constituent materials [6].

The main objective of this work is to study the effect of the volume fraction of jute fiber on the tensile and the buckling characteristics of the polyester.

Theoretical analysis

The modulus of elasticity for the composite material beam determined in term of the properties of the fibers and the matrix and in term of the relative volumes of fiber and matrix [6].The upper modulus of elasticity equation is:

$$Ec\ (upper) = E_f \ V_f + E_m \ Vm \qquad ...(1)$$

Also the lower modulus of elasticity equation is:

$$Ec\ (lower) = E_f\, E_m / E_f\, Vm + E_m\, Vm) \qquad ...(2)$$

E_f =Young modulus for an isotropic fiber.

E_m =Young modulus for an isotropic matrix.
V_f = volume fraction for an isotropic fiber.
V_m = volume fraction for an isotropic matrix.
Where:

$$V_f = \frac{\text{Volume of fiber}}{\text{Total Volume of composit}} \quad \ldots(3)$$

$$V_m = \frac{\text{Volume of matrix}}{\text{Total Volume of composite}} \quad (4)$$

$$Vf + Vm = 1 \quad \ldots(5)$$

Column fails by buckling when the axial compressive load exceeds some critical load [7].
The compressive stress can be well below the material yield strength ate the time of buckling the factor that determines if a column is short or long is it is slenderness ratio (S), Where:

$$S = L / r \quad \ldots(6)$$

And $r = \sqrt{\frac{I}{A}}$.

That:
r: is radius of gyration.
L: is the length of the beam.
A: Area of cross section.
I: is moment of inertia.

A short column is usually defined as one whose slenderness ratio is less than about (10) [8].
The critical load of the long column can be calculated from the Euler equation as follows:

$$P_{cr} = C\frac{\pi^2 EI}{L^2} \quad \ldots(7)$$

Where:
C: is the end condition number, when both end are free to pivot use (C=1).

Experimental work

The samples which are made from the composite material consist of these materials:

1- Matrix material

The resin system in the present study is the unsaturated polyester submitted by (SIR) company. This is representing one type of thermosetting polymers.

Bulk resin sheets were prepared by mixing resin with 2% of hardening that formation from (Methy1 Ethy1 Keton peroxide) to increasing velocity of solidification. Must be use acceleration materials as catalyst which consist of Naphthalet Cobalt that is added with 0.5% to the resin.

2- Reinforced Materials

The Jute fibers represent the reinforced phase in the present studies. Jute fiber is long, soft, shiny, vegetable fiber that can be spun into coarse strong threads.

Jute fiber is one of the cheapest Natural fibers and is second only to Cotton in amount produced and variety of uses. Hand Lay- Molding Method is using to preparation of composite Materials in this research because it is simple of using and can be obtaining sample with different shape and size.

The mechanical properties of the polyester and jute fiber in Table (1).

Tensile test Figure (1) (The Microcomputer Control Electronic Universal Testing Machine, Time Group Inc., Model: WDW-50E) The Strain Rate equal to (0.5mm/min) used to calculate experimental modulus of elasticity from stress – strain curves applied for samples (formed according to ASTM-D638) made as same as buckling samples from composite material of polyester matrix and reinforced by natural jute fiber with different fiber volume fraction. and this experimental modulus of elasticity used as input data in ANSYS to calculate buckling load.

Buckling test Figure (2) (Universal Materials Tester, GUNT-Hamburg, Model: WP300) is the compression test piece was positioned in the Instron. The Instron produced a graph detailing versus displacement. The dial gauge is measured deflection. The force deflection plots for all samples with different fiber volume fraction. The sample dimension in (mm) was (length=160, width=22, thickness= 6). Where slenderness ratio (S=92) calculated from Eq. (1) so that the sample is long column.

Finite element analysis

The finite element analysis carried out as a part of this work was performed using Ansys package in the buckling analysis of composite plate to determine the critical load at which the structure become unstable. In 1970, the finite element method becomes more affect used in a wide range to solving the numerical engineering problem [11].

The ANSYS package is used here in the buckling analysis of the beam made from composite under axial loading to determine the critical loads at which the structure becomes unstable. The column is constructed of isotropic material with different fiber volume fraction.

Modeling

For the finite element method analysis of the buckling of the column problem, the ANSYS11package program is adopted. This program has very efficient capabilities to perform finite element analysis of most engineering problem.

The following steps represent the procedure of modeling the problem:-

(1) Build the model: in this step made definition to the element types, element real constants, material properties, and the model geometry.

(2) Applied loads and obtain the static solution in this step defined the analysis type and options, applied load (displacement and force), specify load step options, meshing of the problem and begin the finite element solution.

(3) Obtain the Eigen value buckling solution: this step requires files from the static analysis. Also, the database must contain the model geometry data to obtain the Eigen value buckling solution.

(4) Expand the solution: this step is used to review the buckling mode shapes.

(5) Review the results: it consists of buckling load factors, buckling mode shapes, and relative stress distributions.

The eigenvalue and eigenvector problem needs to be solved for mode-frequency and buckling analyses. It has the form of [12]:

$$[K]\cdot\{\psi_i\} = \lambda_i \cdot [M]\cdot\{\psi_i\}$$

Where:

[k] = Total structure stiffness matrix

$$= \sum_{m=1}^{N}[K]^e$$

$\{\psi_i\}$= ith eigenvector of displacements.

λ_i = ith eigenvalue.
[M] = total structure mass matrix

$$= \sum_{m=1}^{N} [M]^e$$

N = Number of elements.
$[K]^e$ = element stiffness matrix.
$[M]^e$ = element mass matrix.

For model analyses, the [K] matrix includes the stress stiffness matrix [S]. For eigenvalue buckling analyses, the [M] matrix is replaced with the stress stiffness matrix [S].

Element Selected:-

From the ANSYS 11 element library the beam 3 (2D-elastic beam) adopted to perform this type of analysis. This element is used to modal the column. This element is a uniaxial element with tension, compression, and bending capabilities. The element has three degree of freedom at each node translations in the nodal x and y directions and rotation about the nodal z-axis. The geometry, node locations and the coordinate system for this element are shown in figure (3). The mesh generation of the beam represents in figure (4).the composite beam is simply supported beam at points (1) and (2) and the load is applied axially on the two opposite edge.

Results and Discussion

The results obtained from the experimental work and theoretical equations and the finite element analysis of the tensile and buckling analysis of the composite beam are discussed here.

Figure(5) shows the stress – strain curves with different fiber volume fraction (3 % , 4 % , 5 % , 6 %) produced by tensile test and the modulus of elasticity was evaluated to use it for finite element analysis .The maximum stress is (127 Mpa) with strain(0.026) with fiber volume fraction (6 %). Because when the reinforcement of the jute fiber increase the stress increase.

Figure (6) shows the relationship between tensile strength and fiber volume fraction. The minimum tensile strength (112 Mpa) at (V_f =3%) and it is increase with increase the fiber volume fraction.

Figure (7) shows the experimental modulus of elasticity versus fiber volume fraction. The maximum experimental modulus of elasticity obtained from tensile stress test

(Ec =5.69 Gpa at V_f =6 %) increased with increase fiber volume fraction.

Figure (8) shows the lower and upper theoretical modulus of elasticity versus fiber volume fraction. The difference between the lower modulus of elasticity for the composite beam is very little; while the difference is appear clearly for upper modulus of elasticity the maximum value is (Ec(upper) =5.58 Gpa at V_f =6 %).

Figure (9) shows the critical load – deflection curves with different fiber volume fraction (3 %, 4 %, 5 %, 6 %) produced by buckling test. The plot shows how the beam became unstable and buckled with a load of approximately (860 N at V_f =6 %), the load will decrease with increase fiber volume fraction.

Figure (10) the critical load with different fiber volume fraction for Composite beams by Ansys. The finite element results show clearly the shape of the beam buckled at the critical load and the critical load will increase with increase fiber volume fraction.

Figure (11) the critical load with different fiber volume fraction for composite beams. The composite beam buckled at (P_{cr}=610N) for (V_f = 3%) and (P_{cr}=830N) for (V_f=6 %) for the experimental results. While (P_{cr}=619N) for (V_f = 3%) and (P_{cr}=877N) for (V_f=6 %) for the finite element by using experimental modulus of elasticity, and for the theoretical modulus of elasticity by using the Euler equation (6) the results was (P_{cr}=615N) for (V_f = 3%) and (P_{cr}=860N) for (V_f=6 %).

Conclusions

The study involved the tensile and the buckling analysis of the rectangular beam made from composite material of polyester matrix and reinforced by natural jute fiber at the different volume fraction, by using finite elements techniques compared with experimental method.

The main conclusion of tensile and buckling result is:

1- The maximum stress is (127 Mpa) with strain (0.026) with fiber volume fraction (6 %), the stress will increase with increase fiber volume fraction.

2- From experimental the maximum modulus of elasticity was (Ec =5.69 Gpa at V_f=6 %) .

3- The composite beam became unstable and buckled with a load of approximately (860 N at V_f=6 %), the critical load will decrease with decrease fiber volume fraction.

4- The maximum difference between the numerical results and experimental results for critical load was (5%) at (V_f=6 %).

5- The experimental, finite element and analytical results obtained for the buckling force are approximately agreement.

References

[1] N.G.Lyenger and S.Gupta, "Programming Methods in Structure Design", (1980).

[2] David Bushnell, "Buckling of Shells-pitfall for Designers", AIAA 80-0665R, Vol.19, No.9, (1918).

[3] R. Ganesan, "Buckling of Composite Beam-columns with stochastic properties" Concordia University Canada, (1998).

[4] Tai-Kuang Lee and Austin D. E. Pan, "Analysis of Composite Beam-Column under Lateral Cyclic Loading", Journal of Structural Engineering, Vol.127,No.2, February, (2001).

[5] F.Alami, “experimental and Numerical study of predication of linear Buckling load from frequency measurement", Journal Sains dan Technology, vol.7, No.1, pp. (1-11), 2004.

[6] Bank, L. C. “Composite For Construction “, J.Wiley & Sons. Hobken, 2006.

[7] Gabriella Tarjan And laszlo P. Kollar “Buckling of Composite Plates Subjected to Shear and Linearly Varying Loads “J.Materials and Structures Vol.4, No5.2007.

[8] Anres De juan And Julia Moran “Study of Buckling Stress in Steel Silos”n.16 Th Asce Engineering 16-17 July, 2003.

[9] William D. Callister J.,” Materials Science and

Engineering- An Introduction ", John wiley and Sons, Inc., (2003).

[10] W. Bolton," Engineering Materials Technology ", Butterworth Heinemann, (1998).

[11] T.R.Ch and Rupatla," Introduction to finite Elements in engineering", Second Edition, New Delhi, (1997).

[12] Prezemieniecki, J.S.," Theory of Matrix Structure Analysis ", McGraw-Hill Book Company, (1986).

[13] Kohnke P.,"ANSYS Theory Reference Release 5.4", ANSYS, Inc.,(1975).

Table (1) Composite material data [9, 10].

Material	Young modulus	density	Tensile Strength
Polyester Jute	2.4 Gpa 55 Gpa	1100 Kg/m^3 1300 Kg/m^3	89 Mpa -

Table (2) shows the values of tensile strength and experimental modulus of elasticity with varies fiber volume fraction.

fiber volume fraction	experimental modulus of elasticity	tensile strength
3 %	4.02 Gpa	112 Mpa
4 %	4.43 Gpa	115 Mpa
5 %	4.95 Gpa	122 Mpa
6 %	5.69 Gpa	127 Mpa

Table (3) shows the experimental bucking critical load and critical stress with varies fiber volume fraction.

fiber volume fraction	experimental bucking critical load	bucking critical stress
3 %	610 N	4.62 Mpa
4 %	675 N	5.11 Mpa
5 %	750 N	5.68 Mpa
6 %	830 N	6.29 Mpa

Figure (1) Tensile test apparatus

Figure (2) Buckling test apparatus

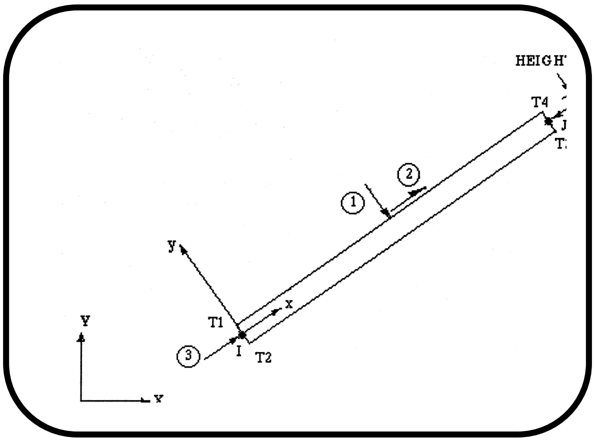


Figure (3): (2-D Elastic Beam) [13].

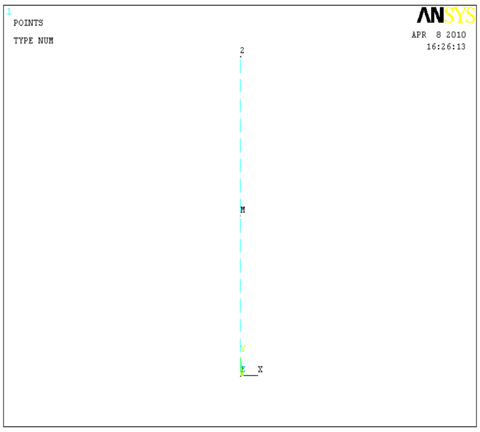


Figure (4): The mesh of the beam

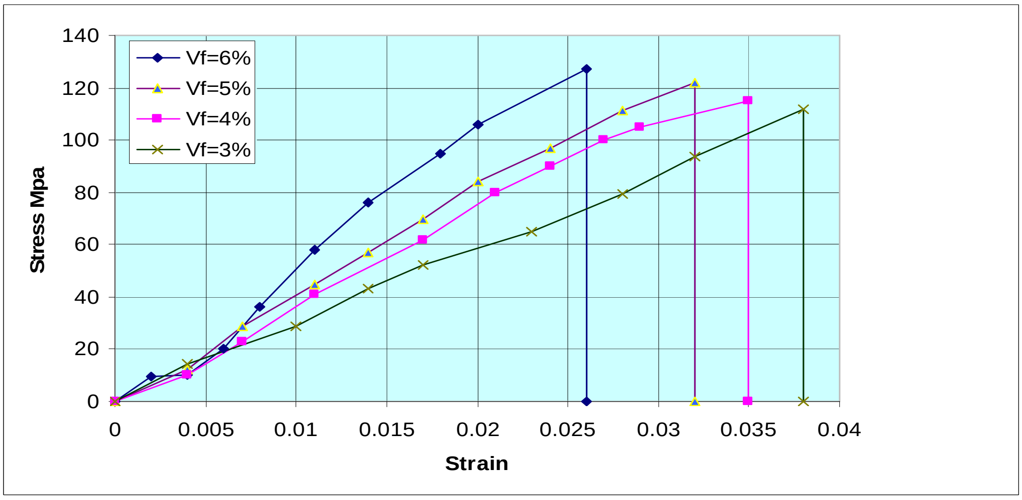


Figure (5) The stress – strain curves with different fiber volume fraction

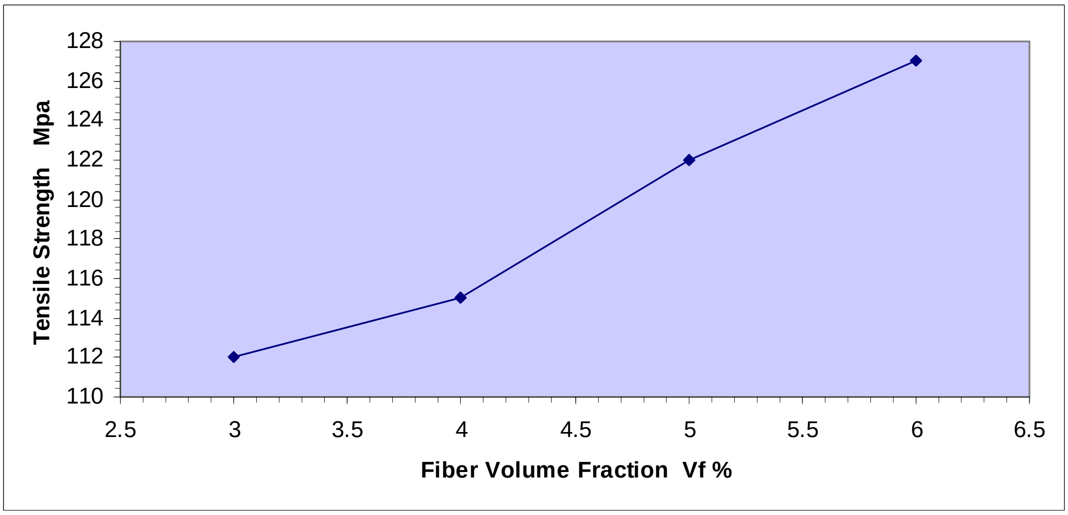


Figure (6) Relationship between tensile strength and fiber volume fraction

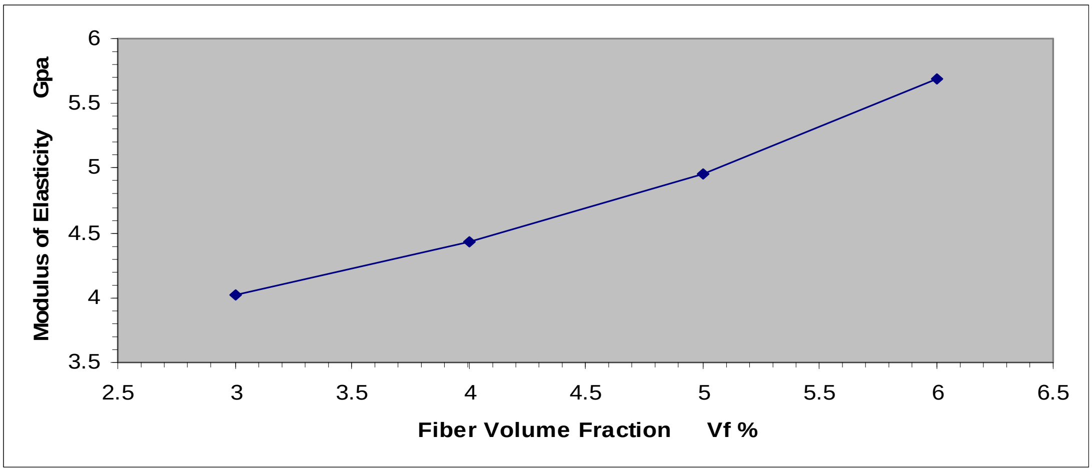


Figure (7) The experimental modulus of elasticity versus fiber volume fraction

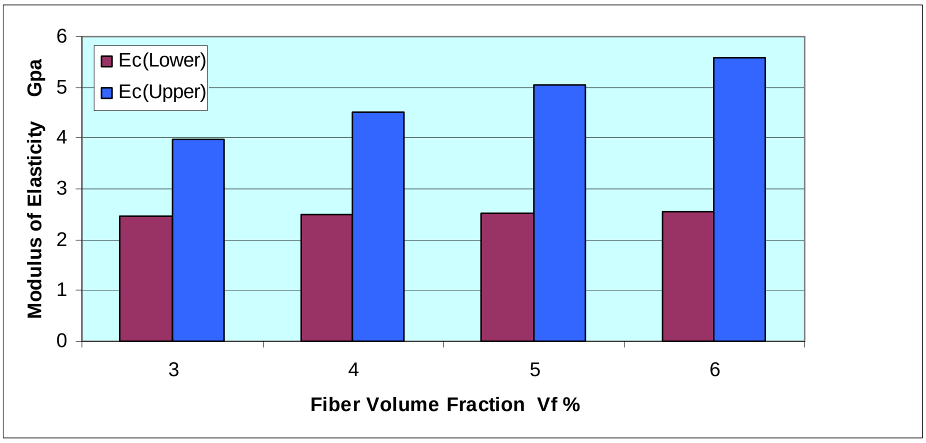


Figure (8) Shows the lower and upper theoretical modulus of elasticity versus fiber volume fraction

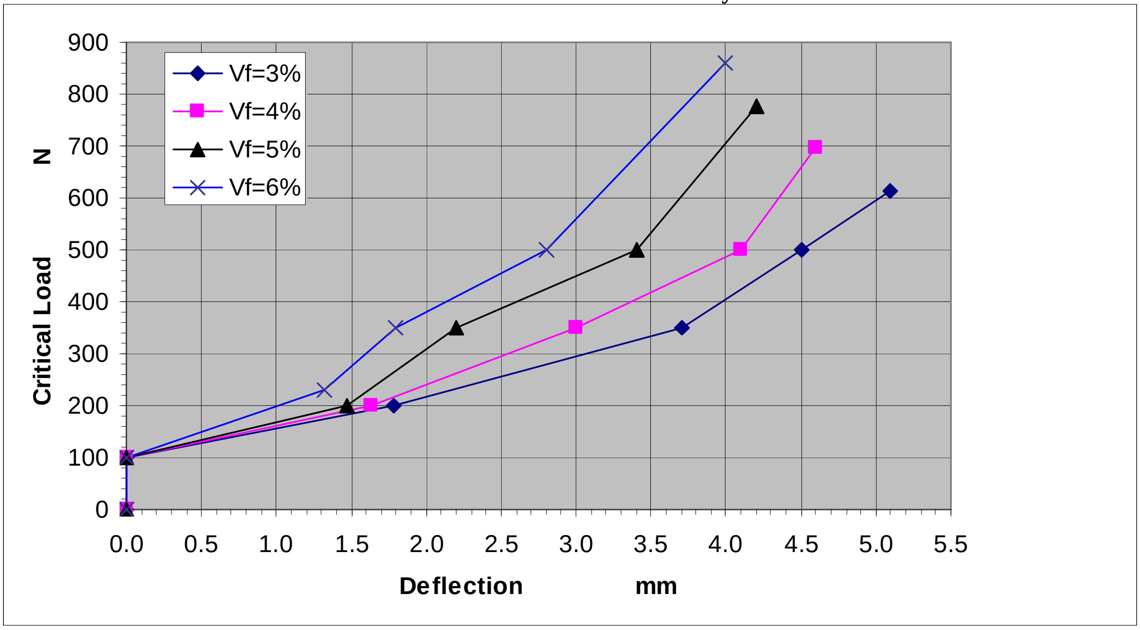
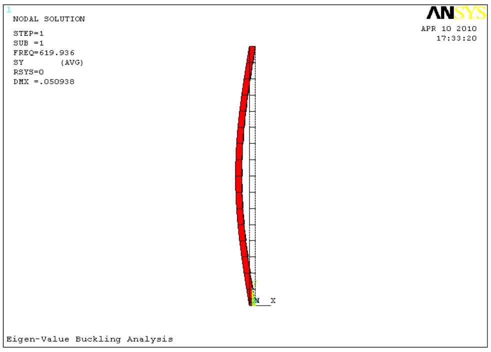
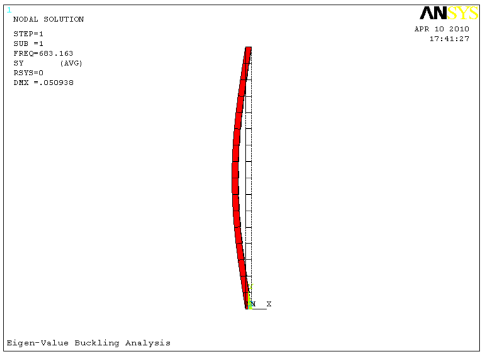


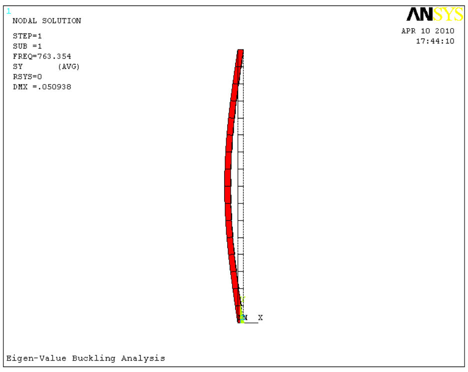
Figure (9) shows the critical load – deflection curves with different fiber volume fraction



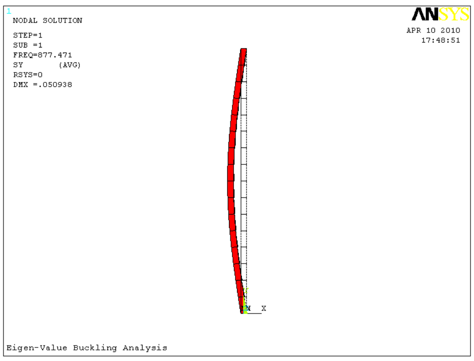
Vf = 3 %.



Vf = 4 %



Vf = 5 %.



Vf = 6 %.

Figure (10) The critical load with different fiber volume Fraction for Composite beams by Ansys

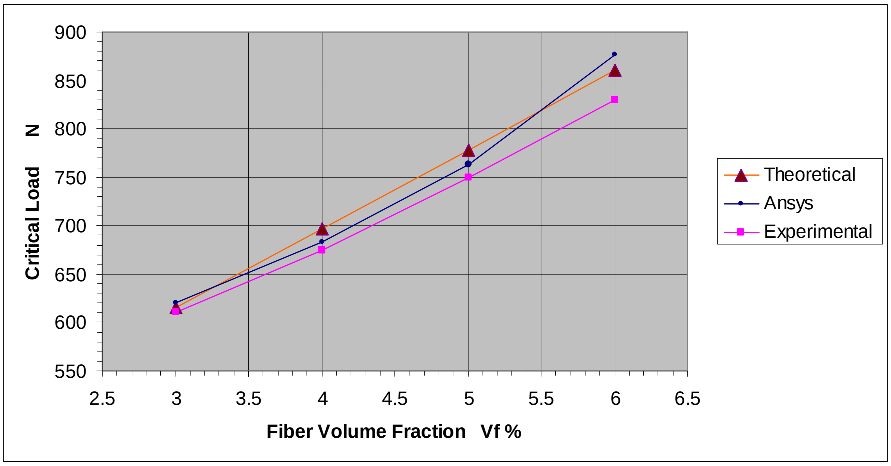


Figure (11): The critical load with different fiber volume fraction for