Numerical and Experimental Analysis of the Bending Deflection of the Composite Beam

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ABSTRACT

This work studies the numerical and experimental bending deflection of 3-point test of the composite beam made of epoxy reinforced by glass fibers and carbon fibers at different volume fractions .The results show that the deflection decrease in nonlinear relationship with increase volume fraction for both glass fibers and carbon fibers .The maximum difference between the experimental results and the finite element results difference was (11 %) at load (=20 N) and fibers volume fraction (V_f= 10 %) for glass fibers reinforcement. Also the results indicated that the maximum deflection was (1.65mm) when reinforced by glass fibers at (V_f =10 %) and at load (= 20 N) experimentally, while the maximum value of deflection was (0.55mm) when reinforced at the same load and fibers volume fraction.

Keywords: Composite Beam, Volume Fraction, Deflection, Glass Fibers, Carbon Fibers

التحليل العملي والعددي لتشوه انحناء عمود مركب

الخلاصة

تم في هذا البحث دراسة تشوه الانحناء العملي والتحليلي لفحص ثلاثي النقطة لعمود مركب مصنوع من راتنج الايبوكسي والمقوى بالياف الزجاج والياف الكاربون بكسور حجمية مختلفة.بينت النتائج بان التشوه يقل بعلاقات لاخطية مع زيادة الكسر الحجمي لالياف الزجاج والكربون.اقصى فرق بين النتائج العملية والتحليلية كان (11 %) عند حمل (20 N) وكسر حجمي للالياف (10 %) عند التقوية بالياف الزجاج.وكذلك بينت النتائج بان اقصى تشوه كان (1.65 mm) عند التقوية بالياف الزجاج عند كسر حجمي (V_f= 10 %) وحمل (20 N) عمليا. بينما اقصى قيمة للتشوه كانت (0.55 mm) عند التقوية بالياف الكاربون وعند نفس الحمل والكسر الحجمي للالياف.

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INTRODUCTION

Composite materials especially fiber-reinforced plastics have high specific strength and specific stiffness. Nowadays it's employed in many engineering structures, automotive, and aerospace industries such as helicopter and wing turbine rotor blades, boat hull, and buildings since the period of the inception. Fibers reinforced polymer (FRP) is a composite material generally consisting of carbon, aramid or glass fibers in a polymeric resin matrix. The mechanical properties of FRP are controlled by the type of fiber, quantity, fiber distribution, orientation, void content and durability characteristics are affected by type of resin. In addition to the nature of interfacial bonds at the interphase plays an important role [1 & 2].

Khashaba investigated the mechanical properties of woven glass fiber reinforced polyester (GFRP) Composites under monotonic and combined loading as typically experienced by many applications. Tests were performed under monotonic conditions in tension, three-point bending, four point bending, and combined tension/bending. The results show that, the composite have higher tensile strength than [0/±45/90] composite and vice versa for bending. The value of flexural strength determine from 4-point bending test is higher than that from 3-point bending test. Also the results show that the failure of the specimen was started at the tension side for the 3-point and 4-point bending test [3].

Sultan investigated the flexural characteristics of kenaf/phenol-formaldehyde (PF), fiberfrax/PF, and kenaf/fiberfrax hybrid PF composites as a function of fiber loading. The reinforcing effects of kenaf and fiberfrax fibers were evaluated at various fiber loadings, that is, 19, 28, 36, 43, 52, and 62 vol.%. The flexural strength vale of the fiberfrax/PF composites were found to be lower compared to the kenaf/PF composite [4].

Sudeep presented the results of the experimental and analytical investigation on the mechanical properties and their application as the internal reinforcement of the new type of FRP composite material called Basalt fiber reinforced plastic (BFRP) material, and proposed a relation for the effective moment of inertia for the BFRP beam for load-deflection analysis. The volume fraction was 44 %, 52%, and 41% with nominal size 3mm, 5mm, and 7mm [5].

Smulski studied the flexural properties of wood fiber matrix internally reinforced with continuous glass fiber composite and found that the static flexural modulus of elasticity increased volume fraction of the reinforcement [6].

Davies and Hamady studied the flexural properties of hybrid unidirectional fiber reinforced polymer (FRP) composite containing a mixture of carbon (C) and silicon carbide (SiC) Fibers were evaluated at span depth (S/d) ratios of 16, 32, and 64. The flexural strength generally increased with increasing S/d ratio with a maximum value of 2316 Mpa being at equal volume fractions of C and SiC Fiber [7].

Heiner etal. Compared the flexural rigidity of two synthetic fibular graft substitutes with natural human fibulas by one intended for physical laboratory study and one intended as a surgical implant and found both fibular graft substitutes had flexural rigidities comparable to natural fibulas [8].

The aim of this study is to investigate the effect of the different volume fraction of reinforcing of glass fibers and carbon fibers on the bending deflection of the composite beam and make comparison of the experimental results with finite element results.

THEORETICAL PART

Bending Analysis of the composite beam is used to determine the central deflection, bending modulus, flexural strength, and max. Shear stress and all of these depend on the geometry and properties of the composite beam.

The deflection of the simply supported beam is calculated by the following formula [9]:

$$\delta = \frac{P \cdot L^3}{48 \cdot E \cdot I} \qquad ...(1)$$

Where:

P- Applied load at the midpoint of the beam (N)

L- Length of the beam (m)

E- Young's Modulus in the longitudinal direction (N/m^2)

I- Moment of Inertia (m^{4})

The rule of mixtures was used to predict the elastic constant of the composite material which depends on the properties of reinforcement and matrix and volume fraction of its constituent. Therefore the density of the composite can be calculated by the following formula [10]:

$$\rho_c = \sum_{i=1}^{n} V_i \cdot \rho_i \qquad ...(2)$$

Where:

ρ_i- Density of each constituent (i).

V_i- Volume fraction of each constituent (i).

The modulus of elasticity in the fibers direction can be calculated by the following formula:

$$E_1 = \sum_{i=1}^{n} E_i \cdot V_i \qquad ...(3)$$

Where:

E_i- Modulus of elasticity of each constituent (i).

Also the modulus of elasticity in the matrix direction can be calculated by the following formula:

$$\frac{1}{E_2} = \sum_{i=1}^{n} \frac{V_i}{E_i} \qquad ...(4)$$

EXPERIMENTAL WORK

The matrix material used in this research was epoxy which represent one types of thermosetting polymers reinforced by woven glass fibers and woven carbon fibers with volume fraction (10 %, 20 % and 30 Vol.%) separately.

Table (1) represents some properties of the fibers and matrix used in this research [11].

Table (1) Some Properties Of Fibers And Matrix [11].

	Matrix	Reinforcement	
	Epoxy	Glass Fibers	Carbon Fibers
Density (g/cm^3)	1.25	2.58	1.78
Modulus of Elasticity (Gpa)	2.41	72.5	230
Tensile Strength (Mpa)	60	3450	4000
Percentage Elongation (%)	4.5	4.3	2
Thermal Conductivity (W.m/^{o}C)	0.19	1.3	11
Specific Heat (J/kg. ^{o}C)	1050	810	-

The load-central deflection data were recorded by using 3-point bending test (see figure 1) for the composite specimens with dimension (190mm *13mm *5mm) according to ASTM D790 [12].

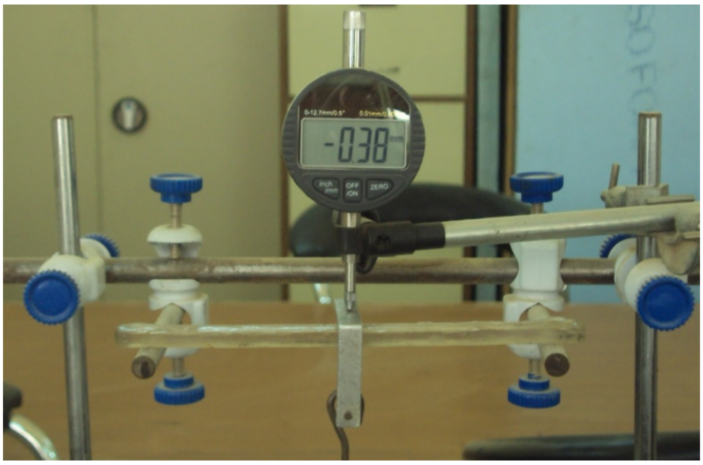

Figure (1)3-Point Bending Tests Device With Composite Specimen.

The number of the test specimens were (31), figure (2) represent the sample of the specimens used.

Figure (2) Sample Of The Composite Test Specimens.

The deflection of the composite beam was measured directly by using digital dial gauge fixed on the top surface of the composite beam.

MODELLING

The ANSYS package (Version 11) is used here for modelling and simulation of the composite beam as plane stress problem. The case study in this research is treated as a 2D problem with element type (solid 42). This element is defined by 4-nodes having two degree of freedom at each node translations in the nodal X and Y direction [13].

The solution of the algebraic equations of finite element problems is illustrated by the following form [14]:

$$[K]\cdot[X]=[F] \qquad ...(5)$$

Where:

[K] is the global stiffness matrix.
[X] is the global displacement vector.
[F] is the global applied load vector.

The local stiffness matrix $[k]_e$ can be determined by numerical integration in 2-dims in term of (ξ, η) from the following equation (eq. 6) [14].

$$[K]_e = t\cdot\int_{-1}^{1}\int_{-1}^{1}[B]^T\cdot[D]\cdot[B]\cdot|J|\cdot\partial\xi\cdot\partial\eta \qquad ...(6)$$

Where:

[B], [D] – is constant matrices.
|J| - is the determinant of the jacobian.

The local load vector for the element was:

$$[F]=[\ f_{x1}\ \ f_{y1}\ f_{x2}\ \ f_{y2}\ f_{x3}\ \ f_{y3}\ f_{x4}\ \ f_{y4}] \qquad ...(7)$$

The boundary conditions and meshing of the composite beam is represented in the figure (3) where the load is concentrated load at the centre of the beam.

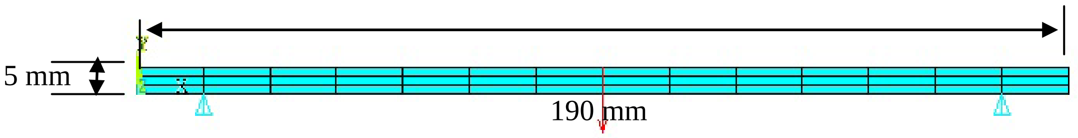

Figure (3) Boundary Conditions And Mesh Generation Of The Composite Beam (2d) With Width Of (13 Mm).

The elastic constants of the composite specimens represented in table (2), where calculated depend on equation (2, 3 and 4). Therefore the behaviour of material was (Anisotropic) orthotropic materials due to different properties in 3- perpendicular directions.

Table (2) Materials Properties Of Composite Material For Different Volume Fractions.

Property	Epoxy					
	Vol. % of Glass Fibers			Vol. % of Carbon Fibers		
	10 %	20 %	30 %	10 %	20 %	30 %
ρ (g/cm^3)	1.383	1.516	1.649	1.303	1.356	1.409
E_1 (GN/m^2)	9.419	16.43	23.44	25.17	47.93	70.69
E_2 (GN/m^2)	9.419	16.43	23.44	25.17	47.93	70.69
E_3 (GN/m^2)	2.41	2.41	2.41	2.41	2.41	2.41
G_{12} (GN/m^2)	1.01	1.13	1.28	1.01	1.135	1.29
G_{13} (GN/m^2)	0.91	0.91	0.91	0.91	0.91	0.91
G_{23} (GN/m^2)	0.91	0.91	0.91	0.91	0.91	0.91

RESULTS AND DISCUSSION

The results of experimental work and ANSYS package for the composite beam were discussed here. Figure (4) represents sample of the deflection contours of the simply supported composite beam specimen made from epoxy reinforced by glass fibers at (V_f= 10 %) and load (=20 N) at the centre of beam.

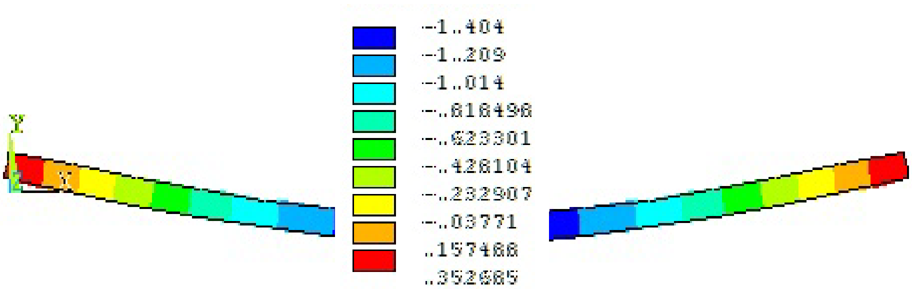

Figure (4) Sample Of Deflection Contours Of Composite Beam When Reinforced By Glass Fibers At (V_f= 10 %) And Load (=20 N).

Figures (5 and 6) show the relationship between load and deflection for both experimental and F.E.M. when reinforced by glass fibers and carbon fibers respectively.

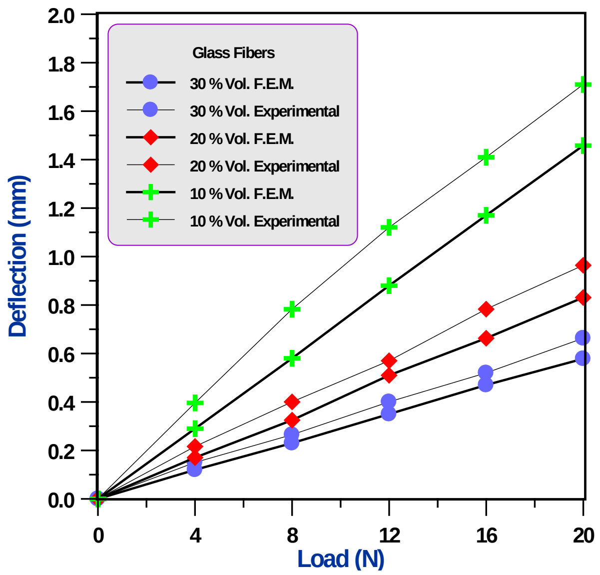

Figure (5) Load Deflection Of The Composite Beam Reinforced By Glass Fibers Experimental And F.E.Analysis.

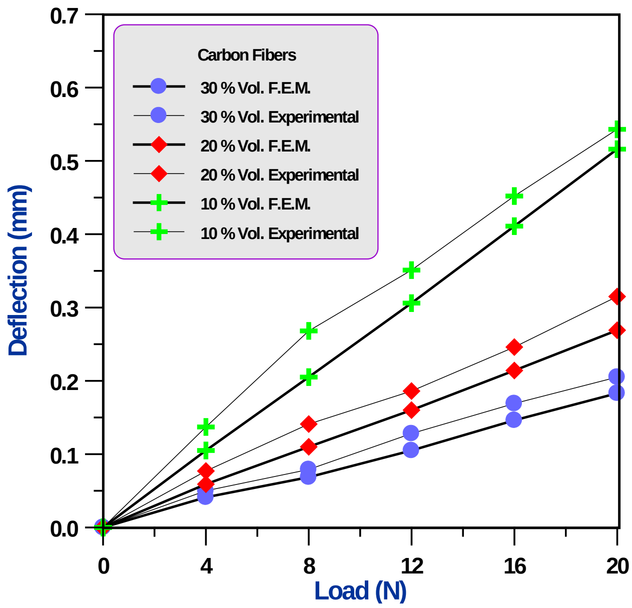

Figure (6): Load Deflection Of The Composite Beam Reinforced By Garbon Fibers Experimental And F.E.Analysis.

It is clear from these figures that the deflection is increased linearly with increasing the load for both experimental and F.E. Analysis.

It is clear from these figures that the results of experimental were higher than of the F.E. results and the maximum percentage difference between the results was (11 %) for glass the composite beam when reinforced by fibers, and was (4.5 %) when reinforced by carbon fibers at load (=20 N) and (V_f =10 %) because of the finite element case represent ideal case (solved numerically), while the experimental case depend on the working conditions of preparation of the composite specimens, like skill of preparation of the specimens, temperature and presence of micro voids during the preparation. Figures (7) show the relationship between the deflection and volume fraction at load (16 N) for both experimental and finite element results when reinforced by glass fibers and carbon fibers respectively.

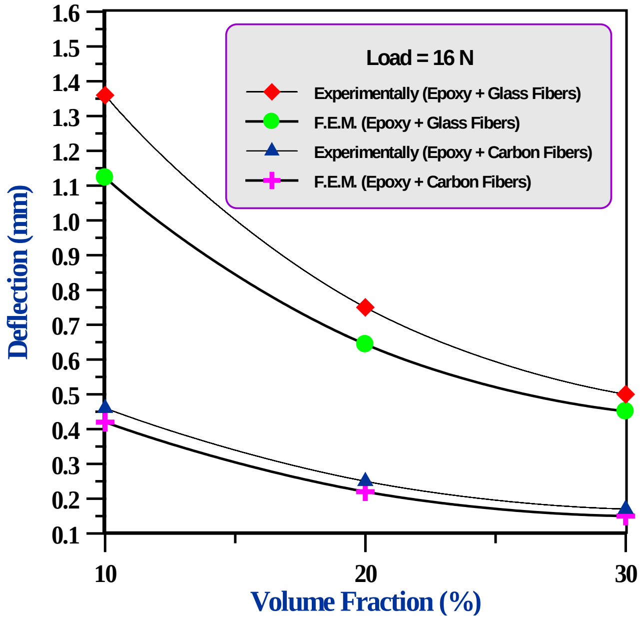

Figure (7) Relationship Between Deflection And Volume Fraction of Reinforcig Fibers for Experimental And Finite Element Analysis at (Load= 16n).

It is noted that the deflection decreased in nonlinear relationship with increasing the volume fraction of fibers for both experimental and finite element results.

The greater difference between the results of experimental and finite element method when reinforcing by glass fiber at (V_f= 10 %) and load (=16 N) was (0.237 mm), while the lowest difference was (0.02 mm) for carbon fibers at (30 %) that due to the conditions of the experimental work which are different from that of numerical case.

CONCLUSIONS

The conclusions of the numerical and experimental investigation of the bending characteristics of the composite beam are:

1-) Deflection decrease in nonlinear relationship with increasing the volume fraction of the reinforcement for finite element method and for experimental results.

2-) The value of deflection of the composite beam when reinforced by carbon fibers was higher than that when reinforced by glass fibers at all volume fractions and all values of loads.

3-)The maximum value of deflection was (1.65mm) when reinforced by glass fibers at (V_f=10 Vol %) and at load (20 N) experimentally, while the minimum value of deflection was (0.05 mm) at load (4 N) and (V_f=30 %) when reinforced by carbon fiber numerically.

4-) The results of the experimental work was higher than that of numerical work and give good agreement between them and the maximum different was (11 %) between both results at load (20 N) and (V_f=10 %).

5-) The deflection decrease from (0.38 mm) to (0.14 mm) with increasing the volume fraction from (10 %) to (30 %) for experimentally work when reinforced by glass fibers.

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