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Effect of (Al_2O_3) on Flexural Analysis of Polymer Matrix Composite Reinforced by Unidirectional Glass Fiber

Dr. Jawad Kadhim Uleiwi
Material Engineering Department
University of Technology, Baghdad, Iraq

Abstract

The flexural analysis of the composite specimens made from polymer matrix composite that reinforced with different volume fraction of glass fiber and alumina powder (Al_2O_3) were studied here experimentally and numerically by using finite element method.

The composite specimens was employed in this research made three ratios of volume fraction of glass fiber and five ratios of volume fraction of alumina powder (Al_2O_3).

The results illustrated that the deflection increases in linear relationship with increase of the load, while decrease in nonlinear relationship with increase the volume fraction of (glass) and (Al_2O_3) for both experimental and numerical studies.

The maximum value of deflection for the specimen equals to 1.85 mm at V_f of (glass) = 10% only and without V_f of (Al_2O_3). While the minimum value of deflection equals to 0.392 mm at V_f of (glass) = 30% and V_f of (Al_2O_3) = 5% for the same value of load = 10 N and for experimental results.

الخلاصــــــة

إن تحليل الانحناء للعينات المركبة المصنوعة من أساس بوليمري والمقوى بكسور حجمية مختلفة من ألياف الزجاج ومسحوق الألومينا (Al_2O_3) قد تمت دراسته عمليا" وتحليليا" باستخدام طريقة العناصر المحددة.

لقد أعدت العينات المركبة المستخدمة في هذا البحث من ثلاثة كسور حجمية مختلفة من ألياف الزجاج وخمسة كسور حجمية من مسحوق الألومينا (Al_2O_3).

بينت النتائج بان التشوه يزداد بعلاقة خطية مع زيادة الحمل المسلط، بينما يقل بعلاقة غير خطية مع زيادة الكسر الحجمي لكل من ألياف الزجاج و مسحوق الألومينا (Al_2O_3) لكلا الدراستين العملية والتحليلية.

*وأن أقصى قيمة تشوه للعينة تساوي (**1.85 mm**) عند كسر حجمي للزجاج (**V_f = 10 %**) وبدون كسر حجمي لمسحوق الالمونيا. بينما أقل قيمة تشوه للعينة يساوي (**0.392 mm**) عند كسر حجمي للزجاج (**30 %**) وكسر حجمي لمسحوق الألومينا (5 %) ولنفس قيمة الحمل المسلط (**10 N**) وللنتائج العملية.*

1. Introduction

The volume fraction of glass fiber and volume fraction of alumina powder (Al_2O_3) have greater effect on the flexural analysis of the composite beam specimens.

The ability of the specimen to resist bending depends on the quantities and qualities of the constituents that used in the preparation of it.

In this research the specimens was made from three different volume fraction of unidirectional glass fiber which are (10, 20 and 30%) and some additive of alumina powder (Al_2O_3) of volume fraction (1, 2, 3, 4, and 5%), which represent the main factors that have an effect on the flexural characteristics of the composite beam.

The purpose of this work is to study the effect of (Al_2O_3) on the flexural analysis of the composite material for different fiber volume fraction and make comparison between the experimental results and finite element results.

Most of the work concentrated on determining the deflection of the composite beam against the applied load with different boundary conditions. The subject was taken both numerically by ANSYS 5.4 and experimentally.

Smulski, S. J. studied the flexural behavior of glass fiber reinforced wood fiber composite and found that the static flexural modulus of elasticity increased with increasing effective reinforcement volume fraction [1].

G. Tolf and P. Clarin used the three-point bending test machine for composite materials to study the deflection and computing the Young's modulus [2].

Narottam P. Bansal measured room temperature mechanical properties in three-point flexure and studied the influence of fiber volume fraction on mechanical behavior of CVD SiC fiber/$SrAl_2S_iO_8$ Glass-Ceramic matrix [3].

G. J. Turvey determined the initial flexural failure loads, and associated central deflections for simply supported composite plates subjected to a uniform lateral pressure [4].

B. P. Hughes and N. I. Fattuhi determined the various efficiency factors for steel and polypropylene fibers in cement-based composites with particular reference to flexural specimens [5].

A. Heiner, et. al. studied the flexural rigidity of two synthetic fibular graft substitutes and compare the data with flexural rigidity of natural human fibulas and found both fibular graft substitutes had flexural rigidities comparable to natural fibulas [6].

K. Kabo Yashi and R. Cho obtained fiber-reinforced concrete of superior toughness by dispersing short, discontinuous steel and polyethylene fibers, in randomly oriented states, in the concrete and found the maximum hybrid effect was obtained by (1%) volume of steel fibers and (3 %) volume of polyethylene fibers [7].

2. Theoretical Analysis

The flexural analysis of the composite beam made from unidirectional composite material (polymer composite material) reinforced with glass fibers and alumina powder (Al_2O_3) have been interested here because it has a wide range of application in the structure of the components.

Flexural analysis is used to determine the deflection, bending modulus and flexural rigidity of the beam which depends on their constituents (matrix and fiber) and geometry.

From theory, the deflection of simply supported beam is calculated by the following formula [8]:

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

where:

P: Applied load at the mid point of the beam (N)

L: Length of the beam (m)

E: Modulus of elasticity in the longitudinal direction (N/m^2)

I: Moment of Inertia = ($b.d^3/12$) (m^4)

Therefore the rule of mixtures was used to predict the elastic constant of the composite material.

The elastic constants of a fiber-reinforced composite must be determined in terms of the properties of the fiber and the matrix and in terms of the relative volumes of them: [9]. Thus,

Density of composite (ρ_c)

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

where:

ρ_i: Density of each constituent (i) (kg/m^3)

V_i: Volume fraction of each constituent (i) (%)

n: Number of the constituents.

Modulus of elasticity in the longitudinal direction (E_1)

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

where:

E_i: Modulus of elasticity of each constituent (i) (N/m^2)

And modulus of elasticity in the lateral direction ($E_2 = E_3$)

$$\frac{1}{E_2} = \frac{1}{E_3} = \sum_{i=1}^{n} \frac{V_i}{E_i} \quad \text{.....} \quad (4)$$

Flexural analyses of the composite beam behave in a different manner from that of one-element material. This difference may be viewed by deflection value and it may be higher or lower than that of the one element material according to the rule of mixture.

Figure (1) represents the tested specimen which is fixed horizontally by simple supported at both ends. And make experimental work by acting a rate of weight at the middle of the specimen in order to obtain the load and deflection from both dial gauge and applied load.

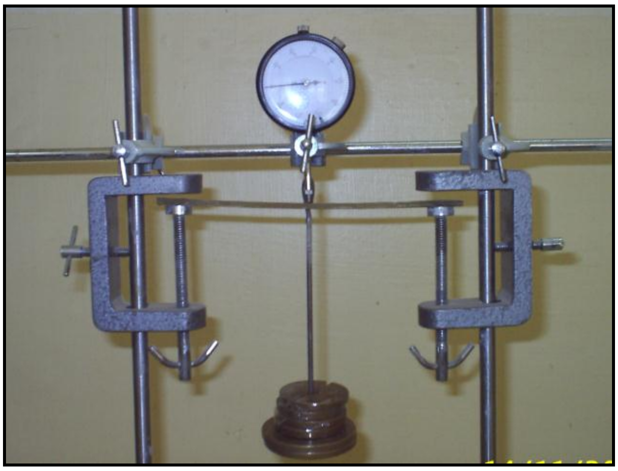


Figure (1) Flexural apparatus with specimen test

3. Modeling, Element Selected and Mesh Generation

The specimens are treated as a three-dimensional problem with different glass fiber volume fraction and different volume fraction of alumina (Al_2O_3). The ANSYS 5.4 package is used here for this type of flexural test.

The displacement approach to the solution of finite element problems is illustrated by an axial loading spring [10].

$$[K]^e \cdot \{\delta\}^e = [f]^e \quad \text{.....} \quad (5)$$

where:

$[K]^e$: is the element stiffness matrix.

$[\delta]^e$: is the displacement vector.

$[f]^e$: is the element applied load vector.

$$[K]^{e}_{24*24} = \iiint_{e} [B]^{T}_{24*6} \cdot [D]_{6*6} \cdot [B]_{6*24} \cdot dx \cdot dy \cdot dz \quad \text{.............................. (6)}$$

where:

[D]: is the elasticity matrix.

[B]: Strain – displacement relationship matrix.

For this type of analysis, the three-dimensional element (solid 45) is used here to modeling of solid structure. This element is defined by eight nodes, orthotropic material properties and having three degrees of freedom at each node; translations in the nodal X, Y, and Z directions. The geometry, node locations, and coordinate system for this element are shown in **Fig.(2)** [11].

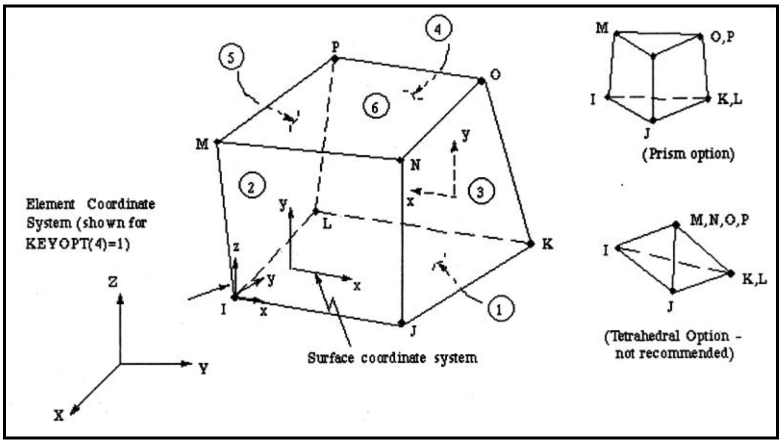


Figure (2) 3-Dimensional Element (Solid-45) [11]

While for meshing the structure of the composite beam, it is necessary to discretize it into a sufficient number of elements. The mesh generation of this composite beam is shown in **Fig.(3)**.

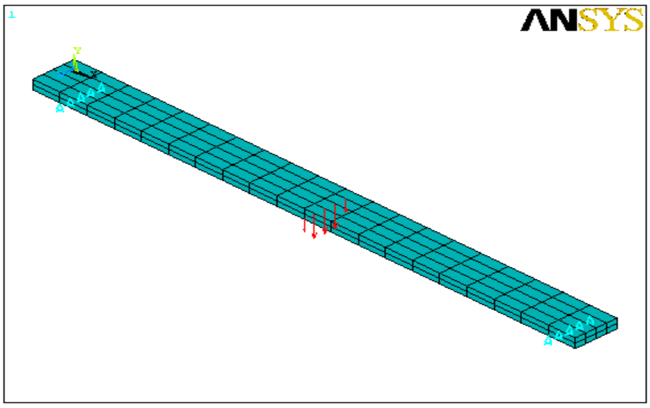


Figure (3) Mesh Generation of Composite Beam

4. Results and Discussion

The results obtained from experimental and finite element analysis for the flexural of the beam specimens made from unidirectional Glass fiber-Epoxy matrix reinforced with different volume fraction of Alumina (Al_2O_3) are based on the following case study:

Geometry

The geometry of the composite beam has the following dimension [12].

Length (L) = 170 mm

Width (b) = 13 mm

Depth (d) = 3.5 mm

Therefore the elastic constants of the specimens at different volume fractions illustrated in **Table (1)** [13].

Also the results of the deflection of the beam illustrated in **Table (2)** which are measured experimentally and calculated numerically by ANSYS 5.4 program.

Figure (4) shows the lateral deflection contours of the specimens of the composite beam under a given case studies of glass fiber volume fraction and volume fraction of alumina.

Figures (5a, b and c) show the relationship between deflection and volume fraction of (Al_2O_3) for three different glass fiber volume fractions (10, 20 and 30%) for experimental and finite element method.

It is seen from these figures that the deflection decreases in nonlinear relationship with increase of volume fraction of (Al_2O_3) for experimental and finite element method. These figures show that there are difference in the deflection for finite element analysis and experimental analysis due to the conditions of preparation of the specimens. Where the experimental results was higher than that of the finite element analysis by maximum value (7%) at V_f of glass fiber = 10% and at load = 10 N.

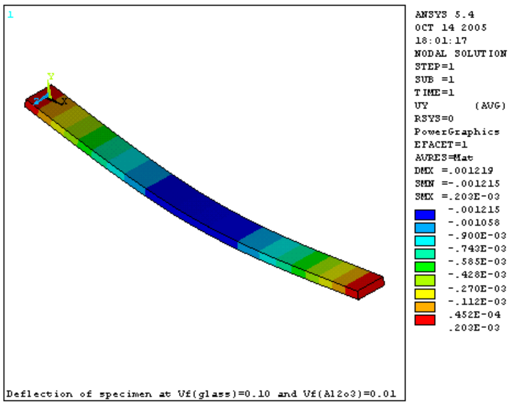
Also it is clear from these figures that all the values of deflection of the composite at glass fiber volume fraction = 10% was higher than that at fiber volume fraction = 30% due to increase of reinforcing material.

Table (1) Material properties of composite material for different volume fractions

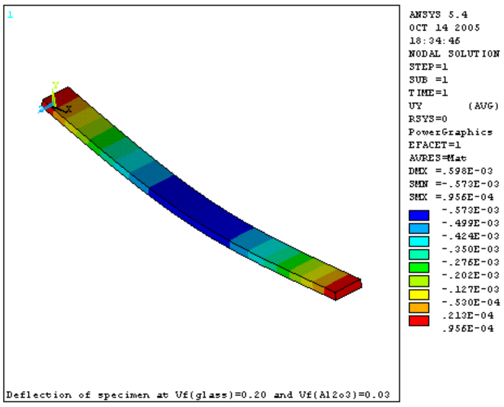
V_f of Glass	V_f of (Al_2O_3)	ρ (g/cm^3)	E_1 (GN/m^2)	E_2 (GN/m^2)	E_3 (GN/m^2)	G_{12} (GN/m^2)	G_{13} (GN/m^2)	G_{23} (GN/m^2)	υ_{12}	υ_{21}	υ_{13}	υ_{31}	υ_{23}	υ_{32}
V_f of Glass = 10 %	0 %	1.38	9.42	2.67	2.67	1.16	1.16	0.15	0.15	0.15	0.15	0.15	0.15	0.15
	1 %	1.41	13.2	2.67	2.67	1.18	1.18	0.15	0.15	0.15	0.15	0.15	0.15	0.15
	2 %	1.44	17.0	2.73	2.73	1.19	1.19	0.15	0.15	0.15	0.15	0.15	0.15	0.15
	3 %	1.47	20.8	2.76	2.76	1.20	1.20	0.15	0.16	0.15	0.16	0.15	0.15	0.15
	4 %	1.49	24.5	2.79	2.79	1.22	1.22	0.15	0.16	0.15	0.16	0.15	0.15	0.15
	5 %	1.52	28.3	2.82	2.82	1.23	1.23	0.15	0.16	0.15	0.16	0.15	0.15	0.15
V_f of Glass = 20 %	0 %	1.52	16.4	2.99	2.99	1.30	1.30	1.05	0.16	0.16	0.16	0.16	0.15	0.15
	1 %	1.54	20.2	3.03	3.03	1.32	1.32	1.05	0.16	0.16	0.16	0.16	0.15	0.15
	2 %	1.57	24.0	3.06	3.06	1.34	1.34	1.05	0.16	0.16	0.16	0.16	0.15	0.15
	3 %	1.60	27.8	3.10	3.10	1.35	1.35	1.05	0.16	0.16	0.16	0.16	0.15	0.15
	4 %	1.62	31.5	3.14	3.14	1.37	1.37	1.05	0.16	0.16	0.16	0.16	0.15	0.15
	5 %	1.65	35.3	3.18	3.18	1.39	1.39	1.05	0.16	0.16	0.16	0.16	0.15	0.15
V_f of Glass = 30 %	0 %	1.65	23.4	3.39	3.39	1.48	1.48	1.05	0.17	0.16	0.17	0.16	0.15	0.15
	1 %	1.68	27.2	3.44	3.44	1.50	1.50	1.05	0.17	0.16	0.17	0.16	0.15	0.15
	2 %	1.72	31.0	3.49	3.49	1.52	1.52	1.05	0.17	0.16	0.17	0.16	0.15	0.15
	3 %	1.73	34.8	3.54	3.54	1.56	1.56	1.05	0.17	0.16	0.17	0.16	0.15	0.15
	4 %	1.76	38.6	3.60	3.60	1.57	1.57	1.05	0.17	0.16	0.17	0.16	0.15	0.15
	5 %	1.79	42.3	3.65	3.65	1.59	1.59	1.05	0.17	0.17	0.17	0.17	0.15	0.15

Table (2) Results of deflection for the composite material at load = 10N

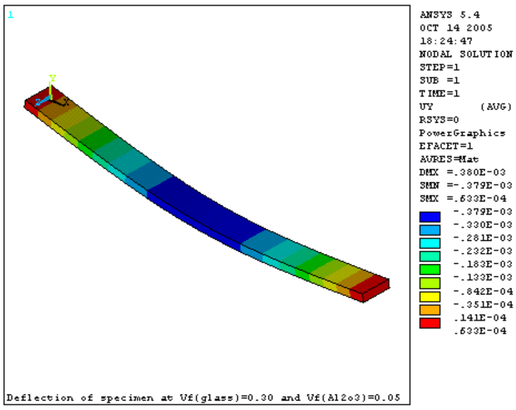
V_f of (Al_2o_3) %	Deflection (mm)					
	Vf (Glass) = 10%		Vf (Glass) = 20%		Vf (Glass) = 30%	
	F.E.M.	Experimental	F.E.M.	Experimental	F.E.M.	Experimental
0	1.7	1.85	0.97	1.1	0.684	0.74
1	1.22	1.321	0.794	0.854	0.59	0.63
2	0.94	1.0	0.67	0.713	0.52	0.55
3	0.77	0.73	0.57	0.60	0.46	0.48
4	0.65	0.68	0.51	0.53	0.42	0.44
5	0.57	0.59	0.454	0.47	0.38	0.392



(a)

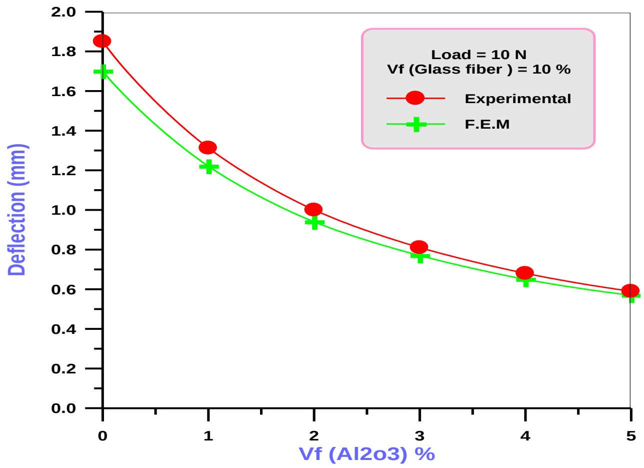


(b)

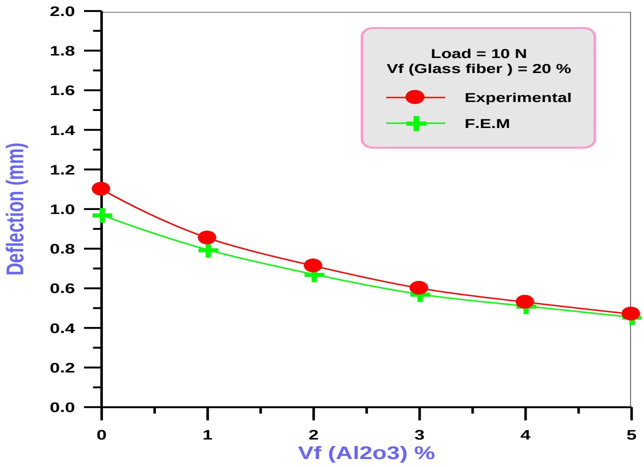


(c)

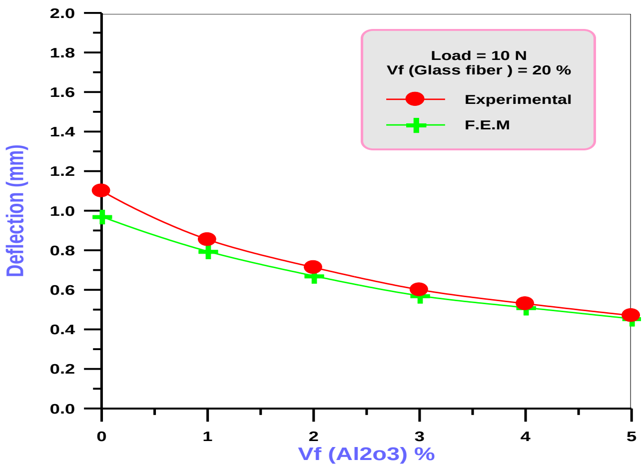
Figure (4) Lateral deflections contours for the composite beam at:
(a) V_f of (Glass) = 10% and V_f of (Al_2O_3) = 1%
(b) V_f of (Glass) = 20% and V_f of (Al_2O_3) = 3%
(c) V_f of (Glass) = 30% and V_f of (Al_2O_3) = 5%



(a)



(b)



(c)

Figure (5) Relationship between deflection and volume fraction of alumina (Al_2O_3) for experimental and finite element method for:
(a) V_f of Glass Fiber = 10% and Load = 10 N
(b) V_f of Glass Fiber = 20% and Load = 10 N
(c) V_f of Glass Fiber = 30% and Load = 10 N

Figures (6a, b and c) show the relationship between the deflection of the beam specimens and load for different value of glass fiber volume fraction and volume fraction of (Al_2O_3) for both experimentally and finite element analysis.

It is clear from these figures that the deflection is increased approximately in linear relationship with load. And the result of experimental work was higher than that of finite element analysis.

It is found that for the same load (=15 N) the maximum value of deflection equals to (1.89 mm) for experimental and by the value equals to (1.75 mm) for finite element analysis at V_f (Glass) = 10% and V_f (Al_2O_3) = 1%, while the minimum value of deflection equals to (0.64 mm) for experimental and by the value equals to(0.59 mm) for finite element analysis at V_f (Glass) = 30% and V_f (Al_2O_3) = 5% respectively.

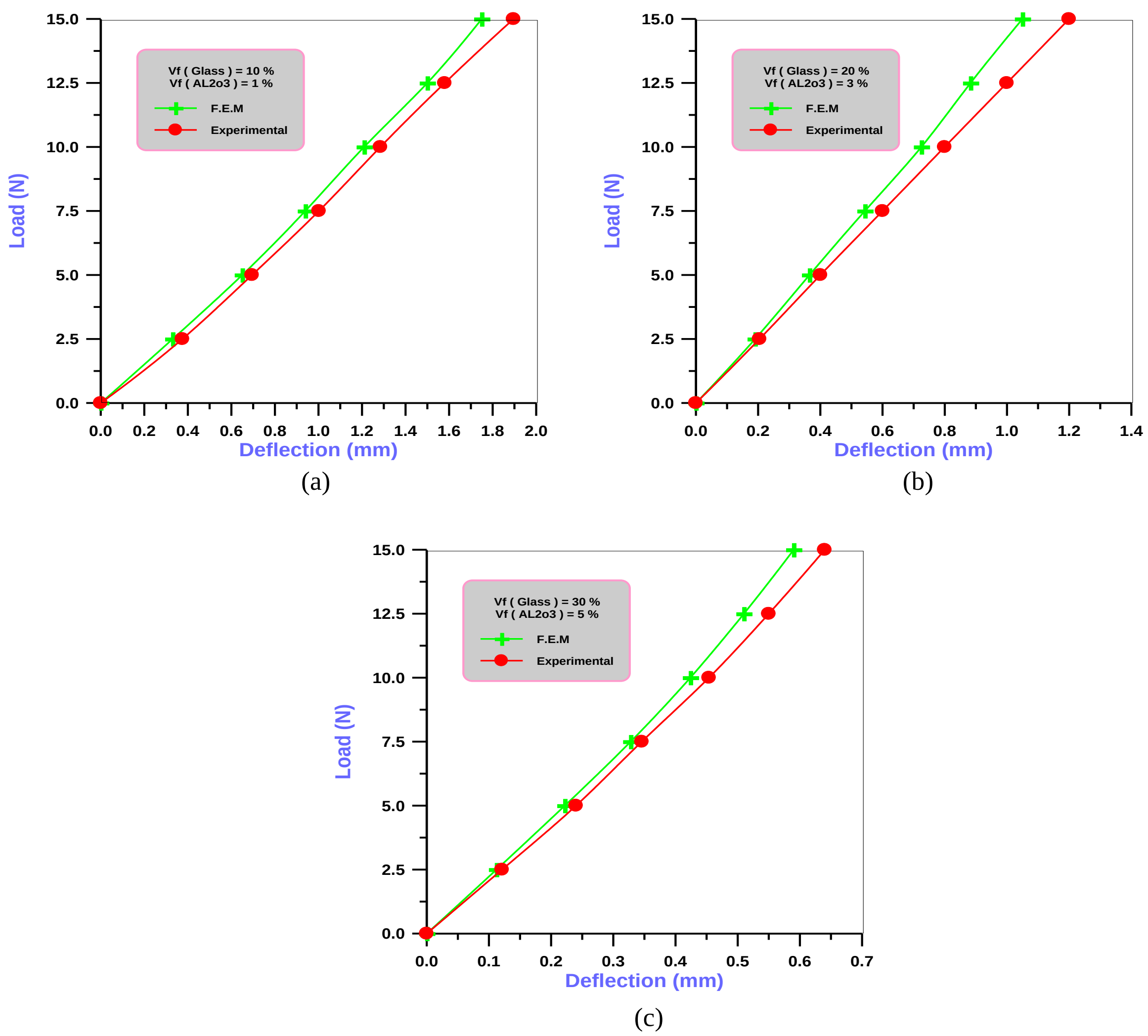


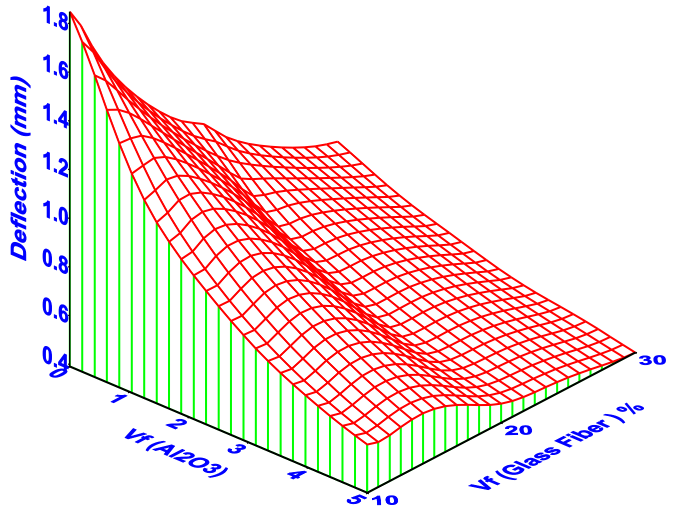
Figure (6) Relationship between load and deflection for experimental and finite element method for:
(a) V_f of (Glass) = 10% and V_f of (Al_2O_3) = 1%
(b) V_f of (Glass) = 20% and V_f of (Al_2O_3) = 3%
(c) V_f of (Glass) = 30% and V_f of (Al_2O_3) = 5%

Figure (7a and b) show the 3-Dimensional relationship between deflection, volume fraction of (Al_2O_3) and glass fiber volume fraction for both experimental and finite element method.

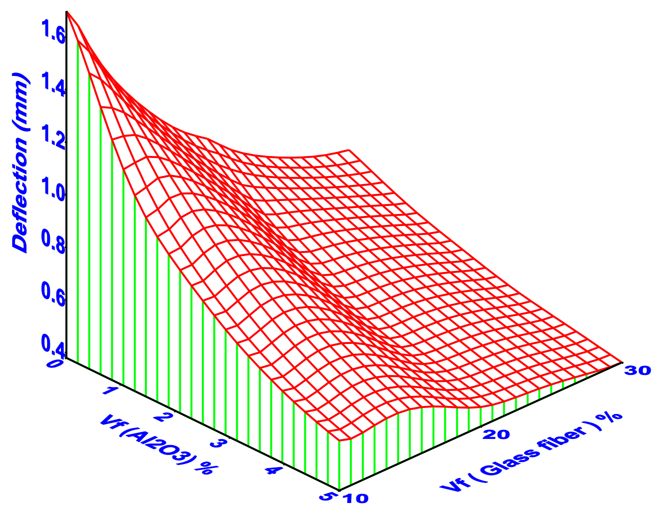
It is clear from this figure that the deflection depends on the volume fraction of both of (Al_2O_3) and glass fiber.

The maximum value of deflection which is equal to (1.89 mm) and minimum value of deflection which is equal to (0.375 mm) at V_f (Glass) = 10% and V_f (Al_2O_3) = Zero% and = 5% respectively.

And the maximum difference between experimental and finite element results which is equal to (0.146 mm) at load =15 N and V_f (Glass) = 10% and V_f of (Al_2O_3) = 1%.



(a) Experimental



(b) Finite Element Method

Figure (7) Relationship between deflection and volume fraction of alumina (Al_2O_3) at different fiber volume fraction of glass

Figure (8) shows the relationship between deflection and fiber volume fraction of glass at load = 10 N and volume fraction of (Al_2O_3) = 3% for finite element method and experimental.

It is clear from this figure that the value of deflection is decreased in nonlinear relationship with increasing fiber volume fraction due to increasing of reinforcing of material for both experimental and finite element method.

It can be seen that the maximum difference between experimental and finite element results happen at V_f = 10% which is equal to (0.06 mm) while the minimum difference between experimental and finite element results happen at v_f (Glass) = 30% which is equal to (0.02 mm).

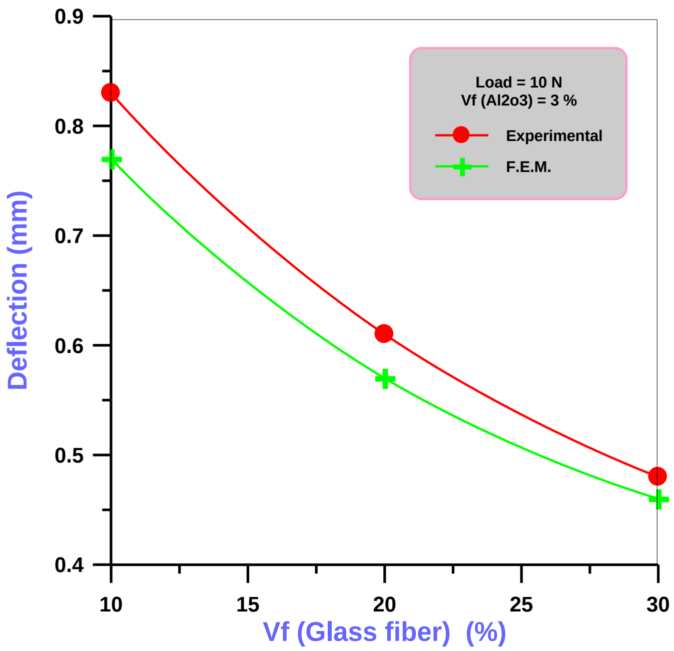


Figure (8) Relationship between deflection and fiber volume fraction of glass for experimental and finite element method at load = 10N and volume fraction of alumina (Al_2O_3) = 3%

5. Conclusions

The study of flexural characteristics of beam specimens which made from unidirectional composite material with various ratios of volume fraction of (Al_2O_3) and glass fiber involved experimental and finite element analysis.

The main conclusions of the present work are:

1. The maximum percentage of deflection for experimental was higher than that of finite element analysis by the value (7%) for fiber volume fraction of glass (V_f =10%) and volume fraction of alumina (V_f = 0%), while the minimum percentage of deflection equal to (3%) for fiber volume fraction of glass (V_f = 30%) and volume fraction of alumina (V_f =5%) at load = 10 N.

2. For the same value of load which is equal to 10 N and for the same value of glass fiber volume fraction = 10% the deflection decreases from (1.85 mm) at V_f of (Al_2O_3) = 0% to (0.59 mm) at V_f of (Al_2O_3) = 5% for experimental results.

3. For the same value of V_f of (Al_2O_3) = 1% and load = 10 N the deflection decrease from (1.312 mm) at glass fiber volume fraction = 10% to the (0.63 mm) at glass fiber volume fraction = 30% for experimental results.

4. The deflection decreases from (0.73 to 0.48 mm) with increase of V_f of glass fiber from (10 to 30%) for experimental work respectively.

5. The value of deflection equals to (1.85 mm) at load =15 N while the deflection equals to (0.65 mm) at load = 5 N for the same value of V_f of glass fiber = 10% and V_f of Al_2O_3 =1 % for experimental results.

6. The deflection increases in linear relationship with increase of load for both experimental and finite element method while decrease in nonlinear relationship with increase volume fraction of both (glass) and (Al_2O_3).

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