EFFECT OF THERMAL SHOCK ON FLEXURAL ANALYSIS OF COMPOSITE LAMINATED SIMPLY SUPPORTED RECTANGULAR BEAMS

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ABSTRACT

The effect of thermal shock on bending test of composite laminated simply supported rectangular beam is investigated experimentally and numerically.In experimental part, three types of fiber reinforcement [Matt fiber glass (600 kg/m^3) and Random fiber glass(450 kg/m^3, and 300 kg/m^3)] are used with polyester resin. The flexural bending test with and without thermal shock load on top or bottom surfaces of the specimen are investigated. The heating and cooling temperature applied are (70C^o and -30C^o) respectively. In numerical part, the ANSYS software is used to compare the results with the experimental work. Effect of volume fraction is also investigated. The results showed that, the increasing volume fraction causes decreasing the maximum deflection. Random fiber glass (300 kg/m^3)composite materials gives minimum deflectionwhen compared with other two types of fiber for same volume fraction. The heating on top surface and cooling on bottom surface of the beam causes decreasing in maximum deflection.The cooling on top surface and heating on bottom surface of the beam causes increasing in maximum deflection. Good comparisons are found between experimental data and numerical work.

الخلاصة

في هذا العمل تم التحقيق التجريبي والعددي في تاثير الصدمة الحرارية على اختبار الانحناء للعتبة ذات المسند البسيطة المصنوعة من المواد المركبة. في الجانب العملي، تم استخدام ثلاثة انواع من الفايبرهي (حصيرة الفايبر كلاس (600 kg/m3)، الفايبر العشوائي (450 kg/m^3,300 kg/m^3)) مضاف له الراتنج (البوليستر). تم دراسة اختبار الانحناء بوجود وعدم وجود حمل صدمة حرارية على السطح العلوي والسفلي للعينات. كانت درجات حرارة التسخين والتبريد (70C^o, −30C^o) على التوالي. في الجانب العددي، تم استخدام برنامج ال ANSYSللمقارنة مع نتائج الجانب العملي. كذالك تمت دراست تاثير الكسر الحجمي. بينت النتائج ان زيادة الكسر الحجمي يسبب تقليل قيمت اقصى انحناء وان العتبة المصنوعة من الفايبر(300 kg/m^3)بثبوت الكسر الحجمي تعطي اقل قيمة للانحناء مقارنة بباقي انواع الفايبر. تسخين السطح العلوي وتبريد السطح السفلي للعتبة يسبب تقليل قيمت اقصى انحناء. بينما تبريد السطح العلوي وتسخين السطح السفلي للعتبة يسبب زيادة قيمت اقصى انحناء. تم الحصول على تقارب جيد بين النتائج العملية والنظرية.

Key words:composite, laminated, thermal, shock, bending, beam

1. INTRODUCTION

Many materials which are ductile at high temperature are brittle at low temperature. If a solid material is heated instantaneously it will not be able to expand immediately to its new equilibrium size because of inertia. Initially the material is under compression before it starts to expand ,this resulting thermal stresses in material, for this reason it is very important for the engineer to be aware of the effect of thermal shock specially on composite because its complicated structure.

Hendricks and et. al.1983developed analysis and experimental data for thermomechanical effect of multilayered materials on the heat sink substrate of cylindrical geometry subjected to thermal cycling. The geometry is heated in cross-flow by a high velocity-flame and cooled in cross flow by ambient-temperature air from a critical flow orifice. **Maensiriand Roberts2002** studied the thermal shock behavior of sintered alumina and alumina /SiC nanocomposites 1, 2.5 and 5 vol. % SiC. The thermal shock testing was carried out by means of quenching into water from high temperatures (temperature in the range 0–750C^{o}). The damage introduced by thermal shock was characterized by degradation of strength in four-point bending and by changes in Young's modulus.

Harade and et. al. 1993 investigated of Y_2O_3 content on the thermal shock resistance of ZrO_2-Y_2O_3 ceramics including 12 vol % of ZrO_2-Y_2O_3 fiber by varying the content of Y_2O_3 from 1.5 to 0.8 mo; %. After specimens were sintered at 1300C, 1400C to 1500C for 2h, bending strength was measured. Thermal shock resistance was characterized by strength degradation before/after thermal shock experiment, and it was increased as the Y2O3 content was decreased.

Young-Hag Kohand et. al. 2004 investigatedthermal shock resistance of fibrous monolithic Si3N4/BN ceramic by measuring the strength retention after varying the temperature difference (ΔT) up to 1400C and was compared with that of monolithic Si3N4. Monolithic Si3N4 showed catastrophic drop in flexural strength above ΔT of 1000C.

Zenkour and et. al. 2009 presentedthe quasistatic bending response for a simply supported functionally graded rectangular plate subjected to a through-the-thickness temperature field under the effect of various theories of generalized thermoelasticity. Material properties of the plate are assumed to be graded in the thickness direction according to a simple exponential law distribution in terms of the volume fractions of the constituents.

In this paper, the effect of thermal shock on bending test of composite laminated simply supported rectangular beam is investigated. The cooling and heating load on top and bottom surfaces of the bending test specimen will be solved experimentally and numerically.

2. EXPERIMENTAL WORK

The field of work is divided into three stages;the first one is the preparing of mold and molding the samples of composite material. The second stage exposing exposition the specimens to thermal shock. Finally,the specimens are testing under bending load.

2.1. Molding Operation

The first step of making any specimen is to preparing a suitable mold with the requirement dimensions of this specimen. The mold can be making of glass, wood or aluminum, etc. In this work the mold was chosen to be made of wood, because it is easier than other materials for machining process, and hand processing if required to improve the dimensions, and also the wood is less brittle than glass which may fail and collapse when the specimen taken out from it.

The mold dimensions are (25cmlength*20cmwidth*6mm thickness). The mold is making by use a square frame of wood with dimensions of (25cm*20cm) with height equal to required thickness of specimen (6mm) as shown in **Fig.1**

2.2. Specimens Preparation

The materials used in the manufacturing process of the samples were including matrix and reinforcement fiber.The ratio of fiber volume to the total volume of specimen is called *volume fraction,* in this study the volume fraction is between (10 to 50 %).

2.2.1. Matrix Material

Polyester resins are the most widely used. In the cured state polyester resin are hard, light colored transparent materials, which may be rigid or flexible. It can be used at temperature up to about 175°F(79C°) or higher, depending upon the particular resin or service requirement**Schwartz 1984**.In this study, the polyester resin (with 3% hardener) used has a density of (1120 kg/m^3). It is viscous liquid at room temperature and can be turned into a hard state after adding the hardener. The properties of polyester resin are shown in **Table 1**

2.2.2. Reinforcement Materials

Three types of woven glass fiber are used (E-glass type) as reinforced materials, see **Fig.2**:

a) Matt fiber glass density of (600 kg/m^3).

b) Random fiber glass density of (450 kg/m^3).
c) Random fiber glass density of(300 kg/m^3).

The properties of glass fiber are shown in **Table 2**

Also, the theoretical properties of specimens are calculated from the equations **Daniel2003**:-

$$E = E_f V_f + E_m (1 - V_f) \quad (1)$$

$$\nu = \nu_f V_f + \nu_m (1 - V_f) \quad (2)$$

$$\alpha = \alpha_f V_f + \alpha_m (1 - V_f) \quad (3)$$

Where:

E, E_f, E_m: modulus of elasticity of composite specimen, fiber, and polyester respectively.
v, v_f, v_m: Poisson's's ratio of composite specimen, fiber, and polyester respectively.
$\alpha, \alpha_f, \alpha_m$: Thermal expansion of composite specimen, fiber, and polyester respectively.
V_f: Volume fraction

The theoretical values of modules of elasticity, Poisson's ratio, and thermal expansion with volume fraction calculated from equations (1, 2, and 3) are listed in **Table 3**

2.3. Specimen Molding

The specimens used in this study were prepared by hand-lay up molding for each type of glass fibers shapes (mat and random fibers). The molding process including multiple steps, Firstly is preparing the mold by covering it with layers of a wax insulation material and nylon sheets respectively in order to protect it from adhesion with the composite material and to simplify removing the sample from the mold after solidification. Then weight the polyester and hardener and mixing them together. At the beginning of molding process, a little amount of polyester was pouring in the mold and apportion it equally on the whole base by using a brush, then add a layer of fiber which is cutting before to (25*20)cm.

Next step is putting polyester on the fiber layer, and continuing by adding layers of fiber and polyester respectively until the sample thickness reaches to the height of the mold boundaries. Covering it with the mold cover, this is also insulated with wax and nylon. Finally pressurized the sample by putting a heavy weight on the mold's cover in order to assurance that the specimen thickness will not exceed mold height. Working stages and the product sample are shown in **Fig. 3**.

2.4. Bending Test Specimen Geometry

After completing the forming process with different types of fiber and different volume frictions the resulting composite sheet is cutting to the specific dimensions (h=6mm, b=15mm, L=116mm {10 mm from both sides for supporting specimen}) according to the ISO standards for flexural test **Handbook 1975** as shown in the **Fig. 4**.

In this study, L_c = 16 h for all flexural specimens.**Fig.5** shows the photograph of the specimens. The flexural testing apparatus used in this work is shown in **Fig. 6**.

2.5. Thermal Shock

Each specimen was treated by subjecting it to heating and cooling load, by using a hair dryer for heating, and spray gas for cooling. The temperature degrees were 70°C for heating and -30°C for cooling. The thermal treatment was applied on top or bottom surface of the bending test specimen.

3. NUMERICAL SOLUTION

The effect of thermal shock on bending test of composite materials is solved numerically using finite element method.One of the best applications of the finite element methods is the ANSYS program, which is used for solving design problems.

The usefulness of this program is to obtain the displacement of the beam sample under different loads. The tensile test process is accomplished basically to calculate, practically, the mechanical properties of the composite material sheets in order to recruit them in the numerical solution, which is prepared according to the ASTM standard **D3039 1982**.

3.1 Element, Meshing, and Boundary Conditions

The element used in this study is (SOLID185) used for 3-D modeling of solid structures. It is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions.

After created the beam which is have dimension (h=6mm, b=15mm, L=96mm), the beam is meshing by (5*10*20) elementsin (h, b, and L) direction respectively, the resulted beam having(4158 D.O.F).

The boundary conditions for this study are simply supported from both sides. **Fig.7**show boundary condition, load, and meshing in this study.

4. RESULTS AND DISCUSSION

4.1 Tensile Test Results

Fig.8 show the comparison of theoretical modules of elasticity (from equation 1) and experimental result of tensile test for three types of composite materials (mat, randam1 {450kg/m^3}, and randam2 {300kg/m^3}) with changing volume fraction.It can be seen that increasing volume fraction causes increasing in modules of elasticity of composite due to increasing volume fraction means increasing in fiber which is more stiffened than polyester matrix. Also, good agreement was found between theoretical and experimental result with (14.5%, 14.8%, and 11.8%) maximum error for (mat, randam1, and randam2 composite materials) respectively.

Fig.9 shows the comparison of theoretical Poisson's Ratio (from equation 2) and experimental result of tensile test for three types of composite materials (mat, randam1, and randam2) with changing volume fraction. It can be seen that increasing volume fraction causes decreasing in Poisson's Ratio of composite due to increases volume fraction means decreasing in fiber which is have Poisson's ratio less than polyester. Also, good agreement was found between theoretical and experimental result with (11.2%, 9.8%, and 14.6%) maximum error for (mat, randam1, and randam2 composite materials) respectively.

4.2Bending Results

Fig.10 gives the shape of deflection found from ANSYS package using mat fiber composite materials with (10%) volume fraction

Fig.s (11, 12, and 13) show the comparison between experimental and numerical result of maximum deflection of (mat, randam1, and randam2)composite materials respectively with different volume fractions From Fig.s, increasing volume fraction causes decreasing in deflection because increasing volume fraction means increasing of fiber which is increases the stiffness of sample. Also, good agreement was found between experimental and numerical with (15.6%, 14.2%, and 13.6%) maximum error for (mat, randam1, and randam2 composite materials) respectively. The randam2 composite materials have minimum deflection comparison with another type of composite materials.

4.3 Thermal Shock Results

Fig. 14 shows the effect of heat treatment (cooling {-30 C^o} and heating {70C^o}) on top surface of the mat fiber composite beam with different volume fraction. From Fig., the heating on top surface of the beam causes decreasing in deflection of the beam because the heating causes extended of particles on the top surface which is lead to increasing deflection on apposite side of applied load. In another word, the cooling treatment on the top surface of the beam causes increasing in maximum deflection of the beam due to decreasing the distance between particles on top surface which is lead to increasing the deflection in same side of applied load. Also, good agreement was found between numerical and experiential investigation.

Fig. 15 shows the effect of heat treatment (cooling {-30 C^o} and heating {70C^o}) on bottom surface of the mat fiber composite beam with different volume fraction. From Fig., the cooling on bottom surface of the beam causes decreasing in deflection of the beam because the cooling causes decreasing the distance between particles on the bottom surface which is lead to increasing deflection on apposite side of applied load. In another word, the heating treatment on the bottom surface of the beam causes increasing in maximum deflection due to extended of particles on bottom surface which is lead to increasing the deflection in same side of applied load.

Fig.s (16, 17, 18, and 19) give the effect of heat treatment on top and bottom surface of randam1 and randam2 composite materials respectively. Same resultsare found as in Fig.s (14 and 15) with good agreement between experimental and numerical results.

5. CONCLUSIONS

Many conclusions can be drawn from the present work which can be summarized, as follows:

1) Increase in volume fraction causes increasing modules of elasticity and decreases passion ratio of composite materials.

2) The increasing volume fraction causes decreasing in maximum deflection of (mat, randam1 {450kg/m3}, and randam2 {300kg/m3}) composite materials.

3) The randam2 composite beam gives minimum deflection compared with mat and randam1 composite materials.

4) The heating of top surface of the beam causes decreasing in maximum deflection. While when the bottom surfaceof the beam is heating, the maximum deflection is increases.

5) The cooling of top surface of the beam causes increasing in maximum deflection. While when the bottom surface of the beam is cooling, the maximum deflection is decreases.

Table [1] Properties of polyester resin [Danial 2003]

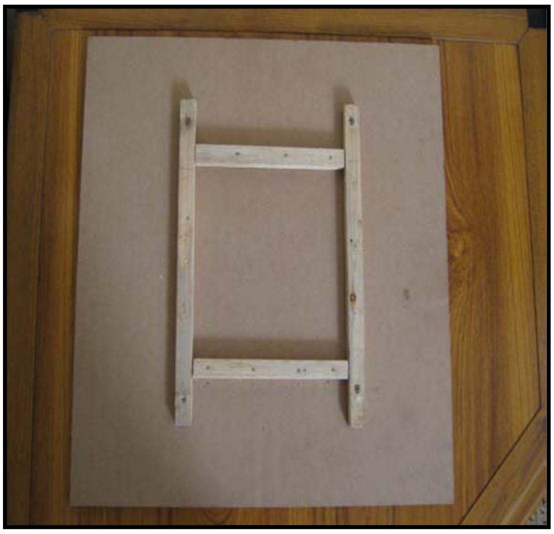
Modules of Elasticity (Gpa)	Passion's ratio	Coefficient of Thermal Expansion $(C^o)^{-1}$
4	0.4	8E-5

Table [2] Properties of glass fiber[Danial 2003]

Modules of Elasticity (Gpa)	Possion's ratio	Coefficient of Thermal Expansion $(C^o)^{-1}$
74	0.25	0.5E-5

Table [3] Properties of composite specimens

Property	Volume fraction %				
	10	20	30	40	50
Modules of Elasticity (Gpa)	10.8	17.6	24.4	31.2	38
Poisson's ratio	0.385	0.37	0.355	0.34	0.325
Thermal Expansion $(C^o)^{-1}$	7.25E-5	6.5E-5	5.75E-5	5E-5	4.25E-5



Base

Cover

Fig. (1) The Mold Parts

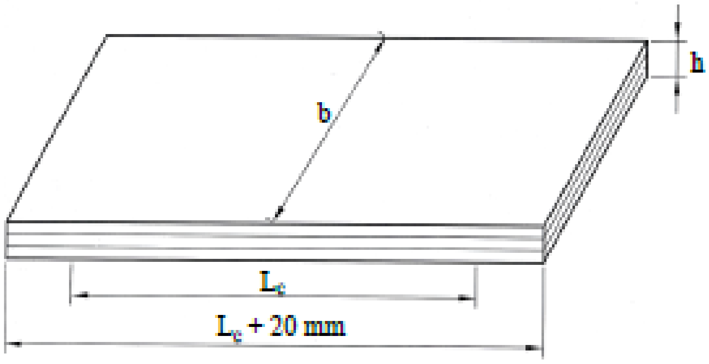
(a) (b) (c)

Fig. (2) types of fibers

a- Mat fiber glass of 600 kg/m^3, b- Random fiber glass of 450. kg/m^3

c- Random fiber glass of 300 kg/m^3

Fig. (3): Working stages and the product sample



where

$L_c = (15 - 17)\,h.$

$b = 15\ mm \pm 0.5\ mm$ for $h < 10\ mm$

In this study, $L_c = 16\,h$

Fig. (4) Bending specimens dimension

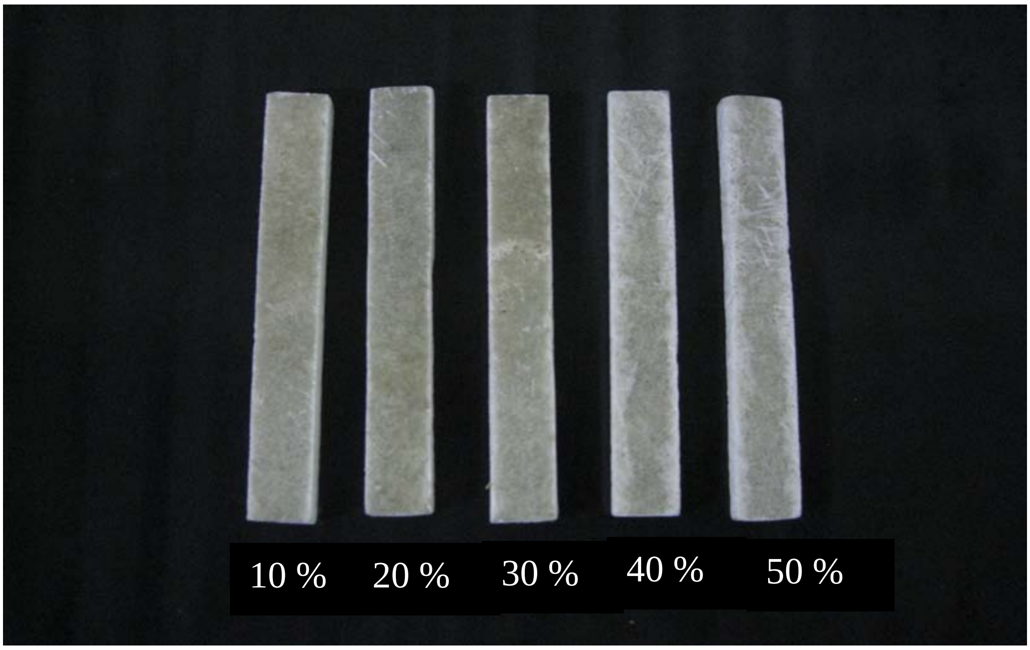


Fig. (5): The specimen's photograph with different volume fractions

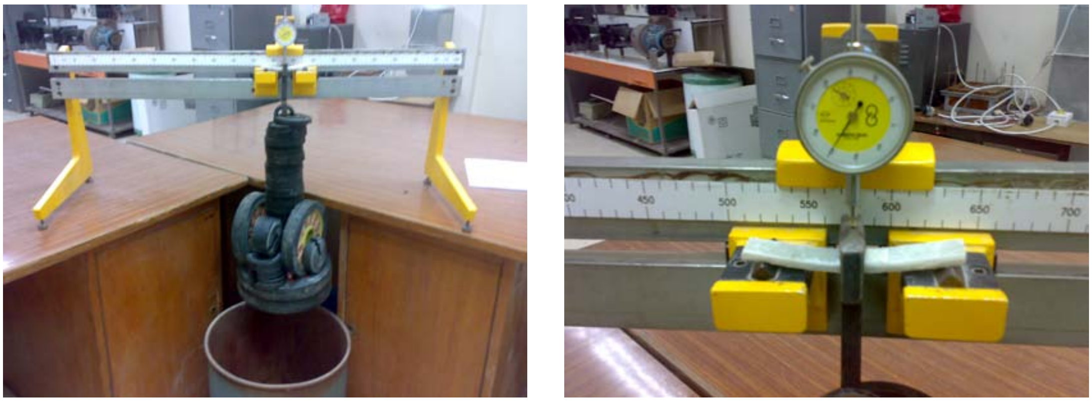


Fig. (6): Flexural test apparatus

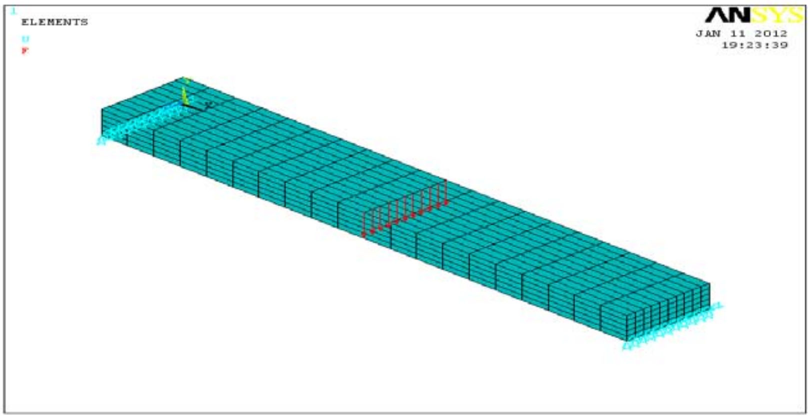


Fig. (7) Meshing, Load, and Boundary Condition

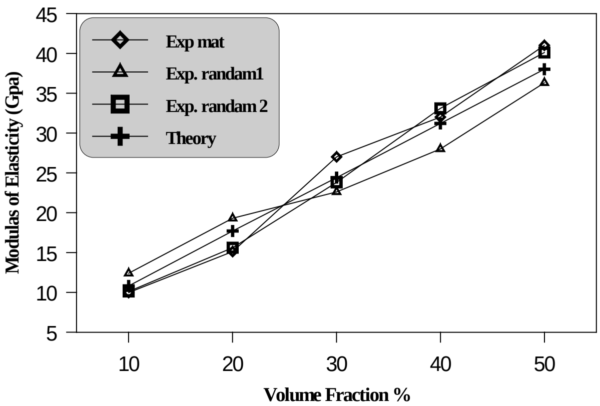


Fig. (8) Comparison between theoretical and experimental result of modules of elasticity for (mat, randam1, and randam2 composite materials)

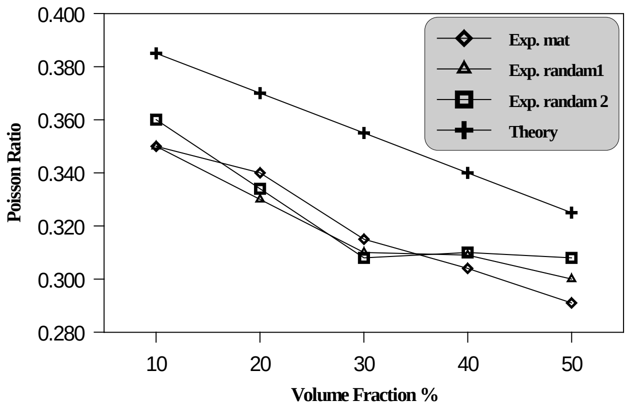


Fig. (9) Comparison between theoretical and experimental result of Poisson ratio for (mat, randam1, and randam2 composite materials)

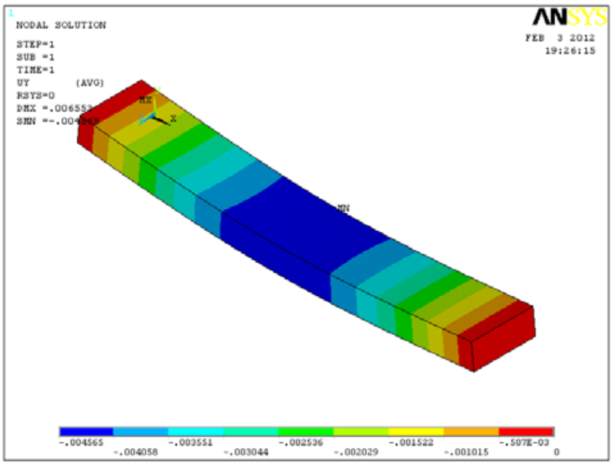


Fig. (10) Deflection beam, using ANSYS Package for mat fiber composite materials (10% volume fraction)

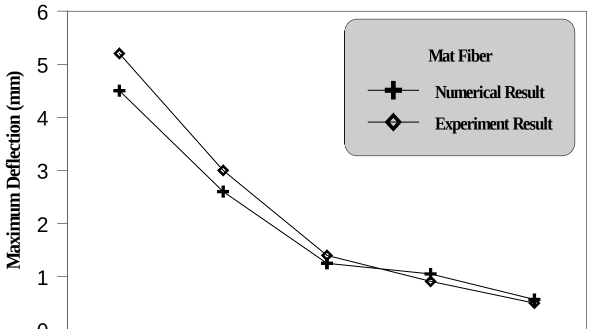


Fig. (11) Comparison between numerical and experimental results of maximum deflection for mat fiber composite materials

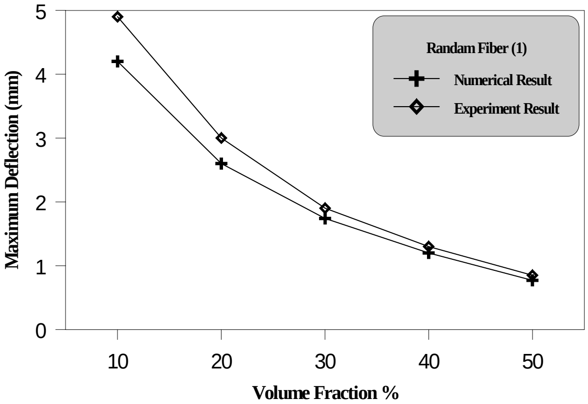


Fig. (12) Comparison between numerical and experimental results of maximum deflection for randam1fiber composite materials

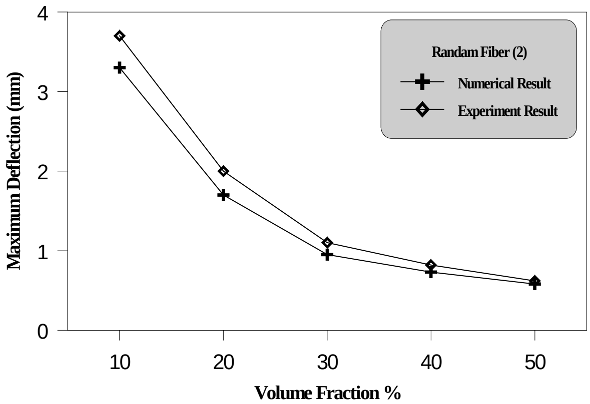


Fig. (13) Comparison between numerical and experimental results of maximum deflection for randam2 fiber composite materials

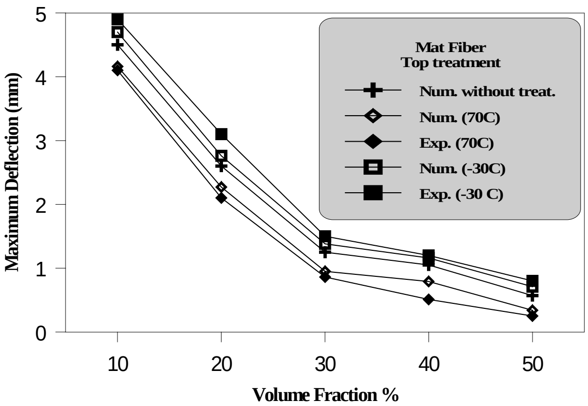


Fig. (14) Maximum deflection for mat fiber composite materials with *top* heat treatment

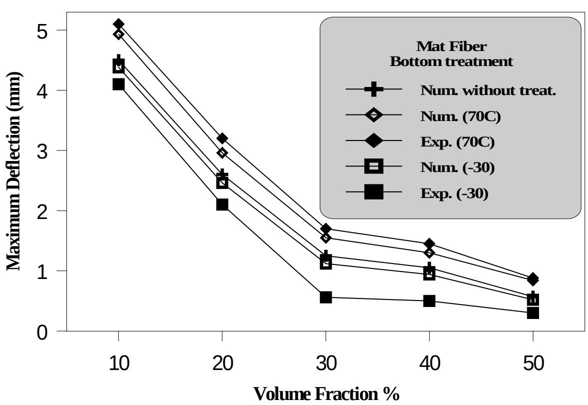


Fig. (15) Maximum deflection for mat fiber composite materials with *bottom* heat treatment

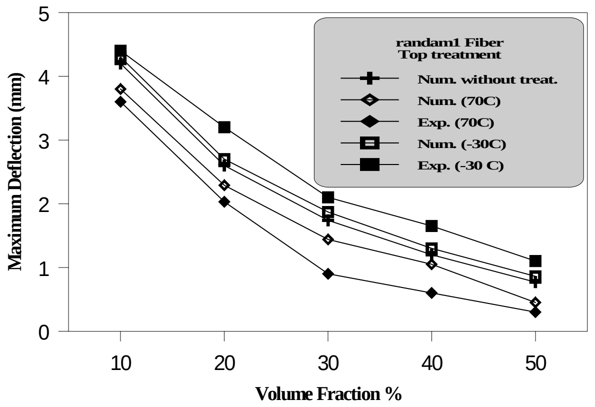


Fig. (16) Maximum deflection for randam1 fiber composite materials with *top* heat treatment

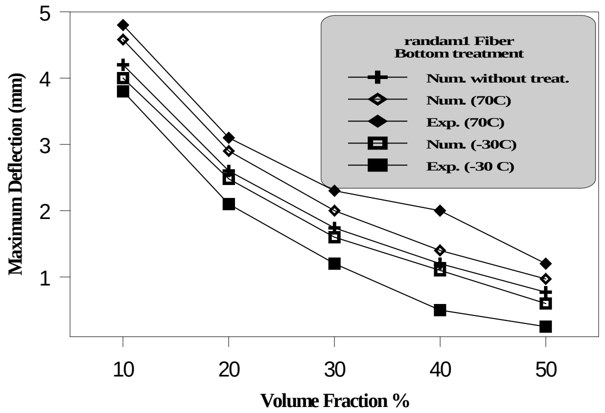


Fig. (17) Maximum deflection for randam1 fiber composite materials with *bottom* heat treatment

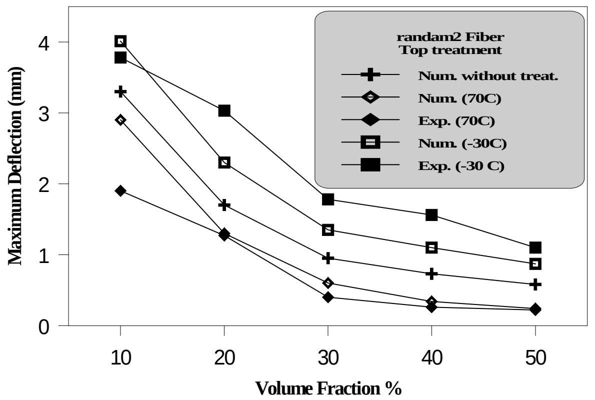


Fig. (18) Maximum deflection for randam2 fiber composite materials with *top* heat treatment

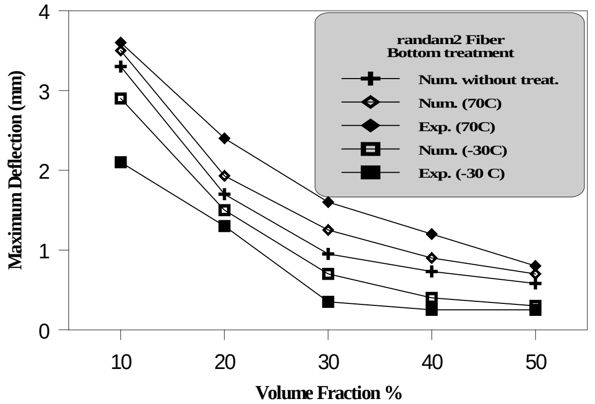


Fig. (19) Maximum deflection for randam2 fiber composite materials with *bottom* heat treatment

6. References

A. M. Zenkour, D. S. Mashat, and K. A. Elsibai;" Bending Analysis of Functionally Graded Plates in the Context of Different Theories of Thermoelasticity" Hindawi Publishing Corporation Mathematical Problems in Engineering Volume 2009, Article ID 962351, 15 pages doi:10.1155/2009/962351.

Daniel Gay, Suong V. Hea., and Steplen W. Tsai" Composite Materials, Design and Applications"; CRC press LLC. 2003

Handbook;"Plastics (Terminology, Sampling and Properties), 21 (1984), Vol.1, ISO 178-(1975), (E).

R.C. Hendricks, G. McDonald, R. L. Mullen, and M. J. Braun:" Thermomechanical Loading of Multilayered Cylindrical Geometries in Thermal Cycling From 300 to 1300 K" NASA technical Memorandum 83312, March 20-24, 1983.

R. harada, T. Kurushima, H. Ishida, and K. Ishizake;" Thermal Shock resistance of Fiber Dispersed ZrO2 ceramics" Journal of the Ceramic Society of Japan, Int. Edition, Vol. 102, 1993,pp. 55-59.

Schwartz, M.M." Composite Materials, Handbook"; McGraw-Hill, Inc.1984

S. Maensiri, S.G. Roberts; "Thermal Shock of Ground and Polished Alumina and Al2O3/SiC Nanocomposites" Journal of the European Ceramic Society Vol. 22 (2002) 2945–2956.

"Standard Test Method for Tensile Properties of Fiber-Resin Composite"; Designation: D3039-76 (Reapproved 1982).

Y. Koh, H. Kim, H. Kim ,and J. Halloran;" Thermal shock resistance of fibrous monolithic Si3N4/BN ceramics" Journal of the European Ceramic Society 24 (2