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NUMERICAL AND EXPERIMENTAL STUDY OF BENDING AND TENSILE BEHAVIOR FOR THE ALUMINUM –SILICON COMPOSITE BEAM REINFORCED BY ALUMINA

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ABSTRACT

This research includes experimental and numerical analysis using finite element method by ANSYS11 package to study effect of reinforcement of Aluminum –Silicon with ceramic particles (Alumina) for different beam width (12, 14 and 16mm) on the hardiness and bending properties.

The composite material is produced using the vortex technique by cutting the base alloy to small pieces and put inside steel crucible. Put the steel crucible inside gas furnace in temperature (700^{o}C). The electrical mixer used to vortex the mixture and adding the aluminum oxide particles (Alumina) (5% and 10%) and after that pouring the melting in metallic mold.

The results of the study showed that Vickers micro hardness increased from (HV=105) for pure Aluminum –Silicon alloy to (HV=127) with (10%) Alumina, also the tensile strength increased from (95 Mpa) to (135 Mpa). The maximum flexural strength was (451 MPa) and the maximum shear stress was (33 MPa) at (width=16 mm) with volume fraction (10 %) of Alumina. the maximum strain decrease with increase volume fraction of Alumina. The experimental and finite element results obtained are approximately agreement.

Keywords: Aluminum –Silicon, Composite beam, Alumina, Bending modulus, Flexural strength,
maximum Strain and maximum Shear stress.

دراسة عددية وعملية لسلوك الانحناء والاجهاد لاعمدة متراكبة من المنيوم – سليكون مقواة بدقائق الومنيا

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الخلاصة

تضمنت الدراسة الجانب العملي و تقنية العناصر المحددة باستخدام برنامج انسيز 11 لمعرفة تاثير تقوية سبيكة المنيوم سليكون بدقائق مادة سيراميكية(الومينا) على قيم الصلادة وخواص الانحناء لعرض اعمدة (12 ,14و16mm).

تم انتاج الاعمدة المتراكبة باستخدام تقنية الدوامة بقطع السبيكة الاساس الى قطع صغيرة حيث يتم وزنها وتوضع في البودقة الفولاذية وتدخل الى فرن غازي تصل درجة حرارته (700 ^{o}C) لتامين ذوبان المادة المتراكبة بالكامل ونستخدم خلاط كهربائي فولاذي مع اضافة دقائق اوكسيد الالمنيوم بنسب وزنية (5 % و10 %) وبعد ذلك يتم صب الخليط المعدني في قالب معدني.

النتائج بينت زيادة قيم الصلادة المجهرية من (HV=105) قبل التقوية الى(HV=127) بعد التقوية بنسبة 10% الومينا كذلك مقاومة الانحناء ازدادة من (95 Mpa) الى (135 Mpa) واكبر اجهاد قص كان (33 MPa) عند عرض عمود (16 mm) مع كسر حجمي (10%) لدقائق الالومينا. ينخفض الانفعال بزيادة الكسر الحجمي لدقائق الالومينا. كذلك كانت نتائج العناصر المحددة مقاربة للنتائج العملية.

الكلمات المفتاحية: المنيوم - سليكون ,عمود متراكب, الومينا, معامل مرونة الانحناء, مقاومة الانحناء ,اكبر انفعال ,اكبر اجهاد قص.

INTRODUCTION

Aluminum alloy are gaining huge industrial significance because of their outstanding combination of mechanical, physical and tribological properties over the base alloys. These properties include high specific strength, high wear and seizure resistance, high stiffness, better high temperature strength, controlled thermal expansion coefficient and improved damping capacity.

Mechanical properties of composite Aluminum –Silicon material reinforced with ceramic particles depend on the matrix type, mutual wettability, amount of the reinforcing phase, and size of the reinforcing particles. Hardness of these materials depends on the contents of ceramic fibers in the matrix and grows with its increase.

Yusof et al. [1] Ambient temperature mechanical properties of Al-7Si/SiCp composite prepared by stir casting process were studied. Microstructure, flexural, hardness and tensile tests of Al-7Si alloy reinforced with 10 and 20 wt. % SiCp were investigated. Samples were characterized by scanning electron microscopy (SEM) while three point bend tests were performed to study the flexural strength of the composites. Hardness and bending tests indicated that reinforcing the Al-Si matrix with SiCp improved the hardness and flexural strength.

L.A. Dobrza ski [2] Investigation results are presented in the paper of composite materials with the EN AC - AlSi12(Cu) magnesium alloys matrix reinforced with the Al_2O_3 particles of 0.5 and 2μm size and with the 50% volume fraction of ceramic particles, made by squeeze casting. Results of the metallographic examinations and the qualitative X-ray phase analysis of the obtained composites were presented.

Hardness of these materials depends on the contents of ceramic fibers in the matrix and grows with its increase.

T. Watario, et al. [3] Al_2O_3/metal composites were fabricated by heating three kinds of commercial multi refractories in contact with Al, and their mechanical properties were investigated. Aluminum reacted with the multi and SiO_2-glass constituting the multi refractory and changed them into α- Al_2O_3 and Si. The bending strength of the composites fabricated from the multi refractories was increased.

K. Ueno et al. [4] Al_2O_3 matrix composites with unidirectional oriented high-purity Al_2O_3 fiber with and without carbon coating were fabricated by the filament-winding method, followed by hot-pressing at 1573–1773 K. The composite with non-coated Al_2O_3 fiber exhibited a bending strength (594 MPa) comparable to that of monolithic Al_2O_3 (589 MPa).While the composite with a carbon-coated fiber had lower strength (477 MPa).

Liang, et al. [5] discusser appreciates the authors' comprehensive work to evaluate the ultimate strength of composite beams in combined bending and shear based on a finite-element analysis. Design models for vertical shear proposed for design of the simply supported composite beams in combined bending and shear provided an economical solution when the concrete slab connected to the top steel flange contributes to the shear strength of the beam as far as the shear connection is efficient.

In this study the experimental work and finite element techniques were used to analysis the tensile and the bending characteristics of the aluminum silicon alloy (Al -12%Si) reinforced by (5% and 10%) of Alumina for different beams width.

THEORETICAL ANALYSIS

a- Composite material preparation:-

The mounts of reinforced particle were calculated according to the following Equation [6].

$$\phi = \frac{1}{1 + \frac{1-\psi}{\psi} \times \frac{\rho_f}{\rho_m}} \tag{1}$$

b- Bending properties:-

The studying mechanical properties for engineering material is very important because of after definition mechanical properties for each material can be selection proportion of material for suite application [7].

Bending strength can be defined ability of sample to bending under external load applied on it without happen any fracture in the sample [8].It calculated by Three point test is most common widely used and more simple and easy.

The bending modulus of elasticity calculates by the following formula [9, 10]:

$$E_b = \frac{P.L^3}{48.I.\delta} \tag{2}$$

In the bending test, the upper band of the sample was exposing to compression stress while the lower band of the sample was exposing to the tensile stress [11].

c- Flexural strength and shear stress test:-

From the bending test the flexural strength can be calculated which can be defined as the resistance of material to the outer bending stress when expose to the different centre load to obtain the fracture (Figure (1)), the flexural strength is calculate by the following formula [10-13]:

$$F_s = \frac{3.F.L}{2.b.d^2} \tag{3}$$

Also the maximum shear stress can be calculated by the following formula [14]

$$\tau_{\max} = \frac{3.F}{4.b.d} \tag{4}$$

The maximum strain in the mid-span is calculated by the following formula [14]:

$$r = \frac{6 \cdot \delta \cdot b}{L^2} \tag{5}$$

EXPERIMENTAL WORK

In this study, the aluminum silicon alloy (Al -12%Si) used with eutectoid and the chemical analyses for these specimens as shown in table (1).

Table (1) Chemical structure of Aluminum-silicon alloy

Si	Cu	Fe	Mn	Mg	Zn	Al
12.1	0.83	0.65	0.2	0.27	0.45	Balance

The composite material using the vortex technique is produced by cutting the base alloy to small pieces. Weight of these pieces should be known. The next step is to put these pieces inside steel crucible. To insure melting the alloy completely, steel crucible expose to (700°C) through a specific gas furnace. After that using the electrical mixer which made from steel and that mixer contain far inside the rotate the melting in 300 rpm speed. When vortex from adding the aluminum oxide Al_2O_3 particles (5% and 10%) and the grain size (50-75 μm) which is heated before to (250°C) to remove the moisture by continuous moving for (3 min) after that pouring the melting in metallic mold (d=17mm and L=20mm).

The hardness values of the Aluminum-silicon composite material was measured with Vickers micro hardness tester which uses diamond pyramid indenter.

The tensile test was performed by the (Microcomputer Control Electronic Universal Testing Machine, Time Group Inc.,Model:WDW-50E).The Strain Rate equal to (1mm/min) was used to calculate experimental modulus of elasticity from stress – strain curves applied for samples (formed according to ASTM- A370 –03a) and this experimental modulus of elasticity used as an input data in ANSYS 11.

The bending samples for different beams width (12, 14 and 16 mm) and span length (100 mm) bend with apparatus (Universal Materials Tester, GUNT-Hamburg, Model: WP300). The Instron is produced a graph detailing force versus displacement. The dial gauge is measured deflection as shown in Figure (1).

FINITE ELEMENT ANALYSIS

The finite element analysis carried out as a part of this work was performed using ANSYS11 package. The program ANSYS is used for analysis the stress, shear stress, strain and deflection of the composite Aluminum –Silicon material reinforced with Alumina particles.

The finite element method was became a powerful tool for the numerical solution of a widely range of engineering problem.

The term of finite element was first used by Clough in 1960 where in this year the engineers used the method for approximate solution of problems in stress analysis.

In 1970, the finite element method become more affect used in a widely rang to solve the numerical problems [15].

The ANSYS11 package is used in the bending analysis of the composite beam with simply supported under concentrated load, to determine the maximum central deflection and maximum tension and compression stresses. The beam is constructed of isotropic material with different beam width.

Modeling:-

The composite beam is simply supported and the load is concentrated on the middle span.

The displacement approach to the solution of finite element problem is ulestrated by unaxial loading spring [15].

$$[K]^e \cdot [\delta]^e = [F]^e \qquad (6)$$

Element Selection:-

Figure (2) shows the solid element model (solid 8 Node 45) was adopted from the ANSYS 11 element library to perform this type of analysis. The 8-node, 3-D solid element, SOLID45, with three degrees of freedom per node (UX, UY and UZ) is designed to model thick layered shells or layered solids, the element with bending,

RESULTS AND DISCUSSION

The results obtained from the experimental work, finite element analysis and theoretical equations of the bending analysis of composite Aluminum –Silicon beam with (5% and 10%) of Alumina, are discussed here.

Table (2) shows the values of tensile strength and experimental modulus of elasticity, Experimental bending modulus of elasticity and Vickers micro hardness increases when increase the particle volume fraction.

Fig.(4) the stress – strain curves of composite beam with (5% and 10%) of Alumina resulted from tensile test and the experimental modulus of elasticity was evaluated to use in finite element analysis. The maximum tensile strength was (135 Mpa) with strain (0.003) at (10%) of Alumina while the tensile strength for pure Aluminum –Silicon was (95 Mpa) with strain (0.00315),because the modulus of elasticity of pure Aluminum –Silicon is less than of Alumina particles.

Fig. (5) shows the experimental load – deflection curves of composite beam with (5%) of Alumina with different beams width (12, 14 and 16) produced by bending test. The deflection increase with increase load and maximum deflection was (0.37mm) at load (2 KN) at (b=12 mm). The deflection will decrease with increase beams width at constant load and this depend on the relation between deflection and width of the beam as in equation (2) and equation (5).

Fig. (6) shows the experimental load – deflection curves of composite beam with (10 %) of Alumina with different beams width (12, 14 and 16), the maximum deflection was (0.32 mm) at load(2 KN) at (b=12mm).

Fig. (7) shows the experimental and finite element results of Flexural strength and width of composite beam with (5% and 10%) of Alumina.
There were slightly differences and agreement between the experimental and finite element results, the flexural strength increase with increase of Alumina volume fraction of composite beam and the maximum flexural strength was (451 MPa at b=16 mm) with volume fraction (10 %) of Alumina.

Fig.(8) shows the experimental and finite element results of maximum shear stress and width of composite beam with (5% and 10%) of Alumina, the shear stress increase with increase beams width slightly difference between experimental results and FEM. The maximum shear stress was (33 MPa at b=16 mm) with volume fraction (10 %) of Alumina.

Fig.(9) shows maximum strain and width of composite beam with (5% and 10%) of Alumina for experimental and finite element results. The maximum strain decrease with increase volume fraction of Alumina. The maximum experimental strain was (0.00496) with volume fraction (5 %) of Alumina, because the increase of bending modulus of elasticity leads to deflection decrease (Eq. 2) and when deflection decrease the maximum strain decrease (Eq. 5).

Fig.(10) shows the maximum shear stress with (10%) of Alumina with different width of beam by Ansys 11. It shows the 3D composite beam shear stress distribution and the maximum shear stress (32.8 Mpa at b=16 mm) because the increase of Applied load at the mid-point of the sample at fracture with increase beam width.

Fig.(11) shows the comparison between Flexural strength with (5% and 10%) volume fraction of Alumina composite beam at width (b=14 mm) by Ansys11.It is clearly that the maximum Flexural strength distribution of 3D beam was (439 Mpa) with (10%) volume fraction of Alumina because the modulus of elasticity of Aluminum –Silicon matrix is less than the modulus elasticity of Alumina particles and the distribution of Alumina particles in beam increase with (10%) volume fraction leads to reinforcement increase.

CONCLUSION

The experimental work and finite element techniques were used to analysis the tensile and the bending characteristics of the aluminum silicon alloy (Al -12%Si) reinforced by (5% and 10%) Alumina for different beams width.

The main conclusion of result is:

1- The tensile strength, experimental bending modulus, the microhardness, Flexural strength and shear stress of composite beam results increased while the maximum strain and the maximum deflection of composite beam decrease with increase the volume fraction of Alumina.

2- The maximum difference between the numerical and experimental results for Flexural strength was (0.9%), the shear stress was (3.7%) at width (14 mm) and the maximum strain was (2%) at width (12 mm) with Alumina (5%) these results was calculated from figures.

3- The experimental, finite element and results obtained for the bending analysis are approximately agreement.

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Nomenclature

ϕ: Volume fraction of fiber.

ψ: Weight fraction of fiber.

ρ_f: Fiber density (g/cm^3).

ρ_m: Matrix density (g/cm^3).

P=Applied load at the midpoint of the sample (N).

E_b = Bending modulus of elasticity (Mpa).

L=Length of the sample (m)

δ = Deflection of simply supported (m)

I = Moment of inertia = bd^3/12 (m^4)

b = width of sample (m).

d = Thickness of sample (m).

F = Applied load at the mid-point of the sample at fracture. (N)

r = Maximum strain (m/m).

F_s =flexural strength.

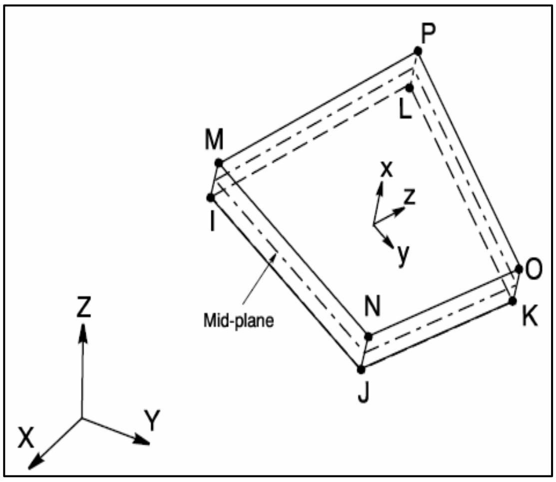
τ_{max} = maximum shear stress

$[K]^e$ = element stiffness matrix.

$[\delta]^e$ = the displacement vector.

$[F]^e$ = the element applied load vector

Figure (1) Bending test apparatus



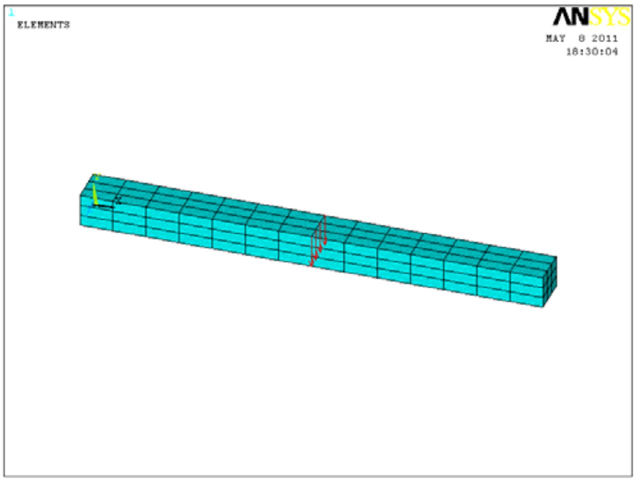


Figure (2) The solid element 8-node

Figure (3) The mesh of the 3D beam

Table (2) shows the values of tensile strength and experimental modulus of elasticity and Vickers
micro hardness.

	tensile strength	experimental modulus of elasticity	experimental bending modulus	Vickers microhardness
As received condition	95 Mpa	72.5 Gpa	71.3 Gpa	105
Reinforced with 5% Alumina	114 Mpa	84 Gpa	82 Gpa	113
Reinforced with 10% Alumina	135 Mpa	98 Gpa	95 Gpa	127

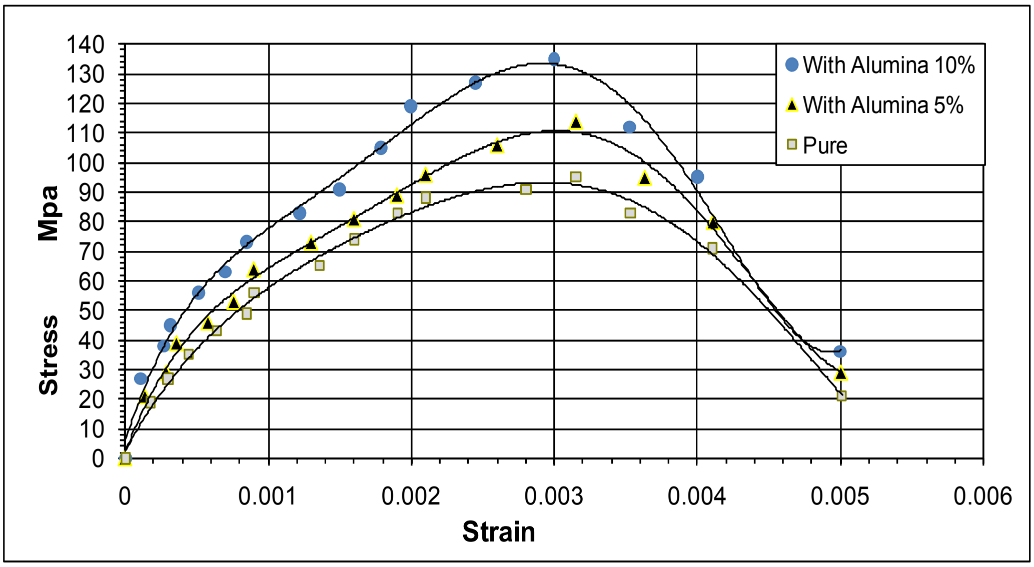


Figure (4) The stress – strain curves of composite beam with (5% and 10%) of Alumina.

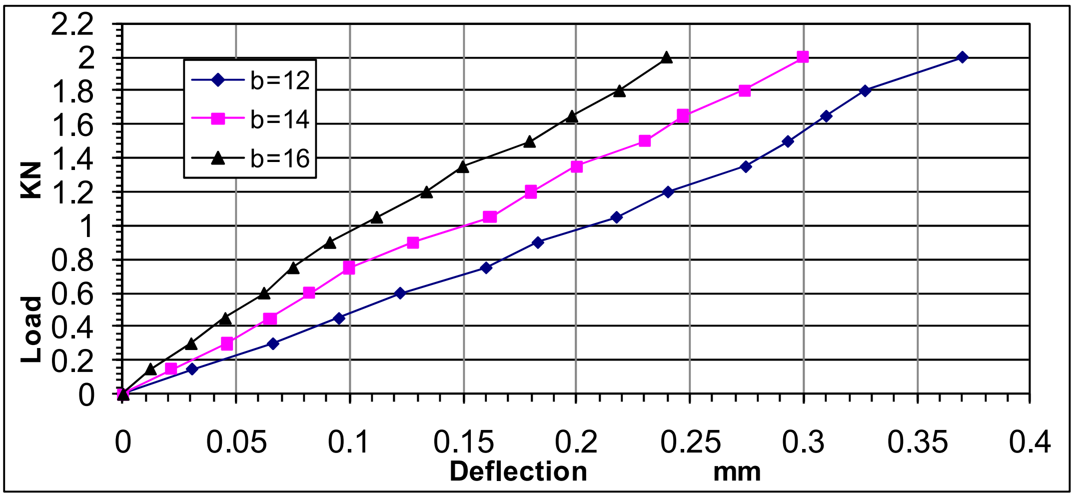


Figure (5) Shows the The experimental load – deflection curves of composite beam with (5%) of Alumina.

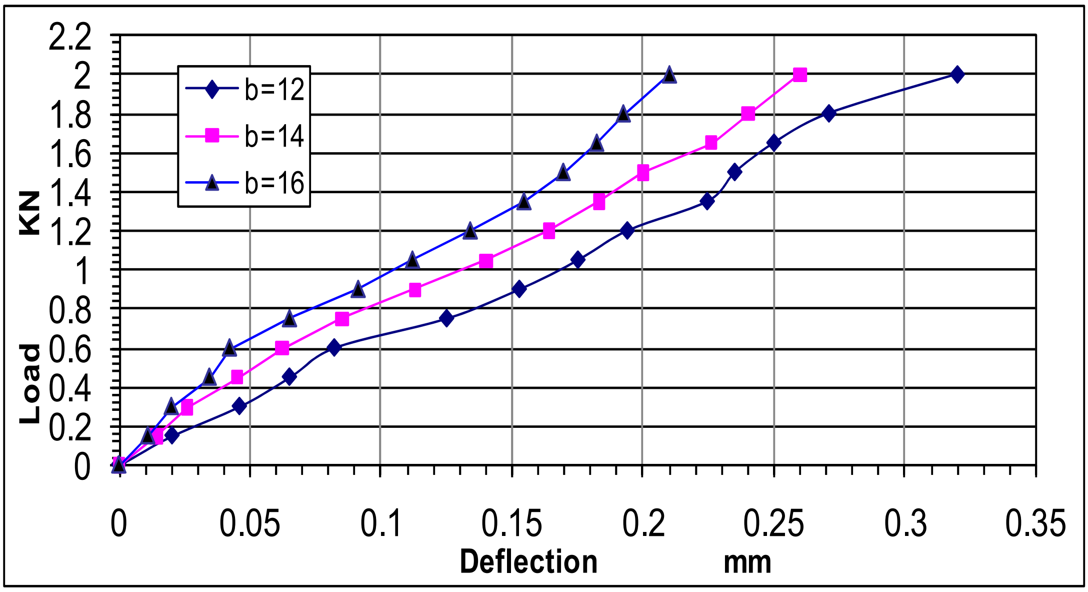


Figure (6) Shows the The experimental load – deflection curves of composite beam with (10 %) of Alumina.

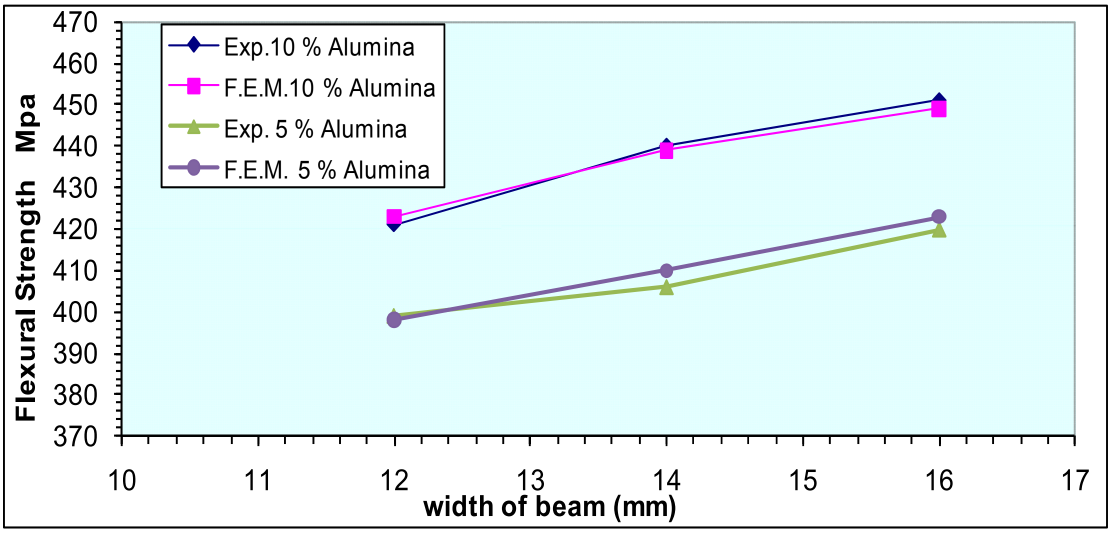


Figure (7) Relationship between Flexural strength and width of composite beam with (5% and 10%) of Alumina.

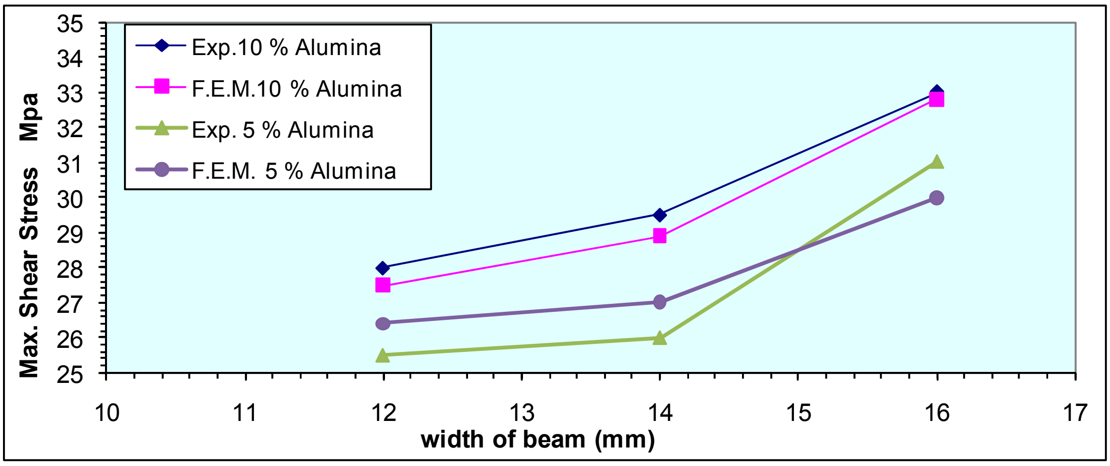


Figure (8) Relationship between maximum shear stress and width of composite beam with (5% and 10%) of Alumina.

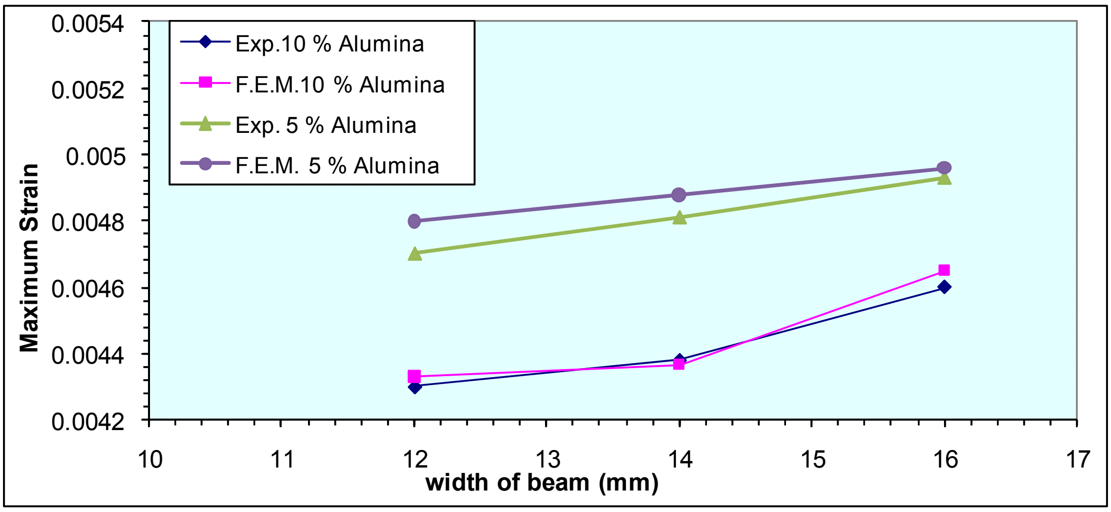
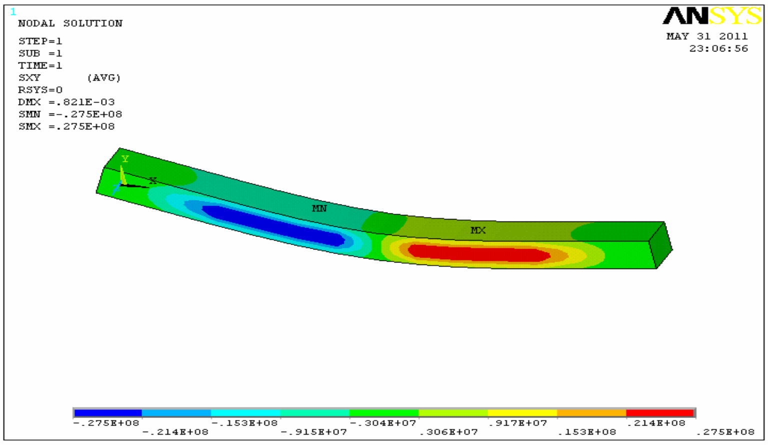
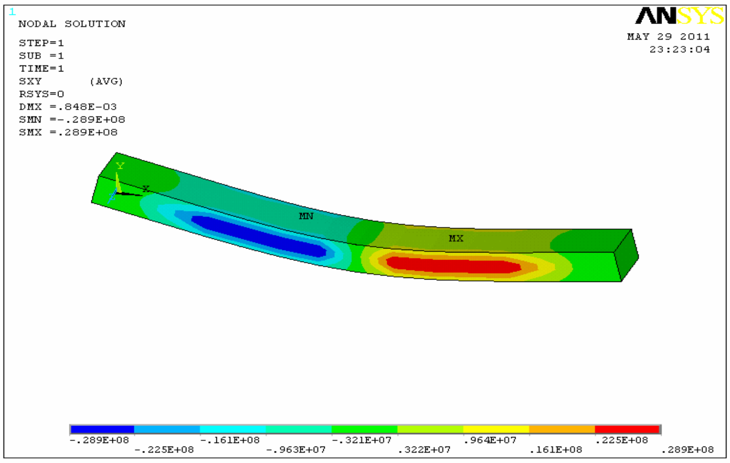


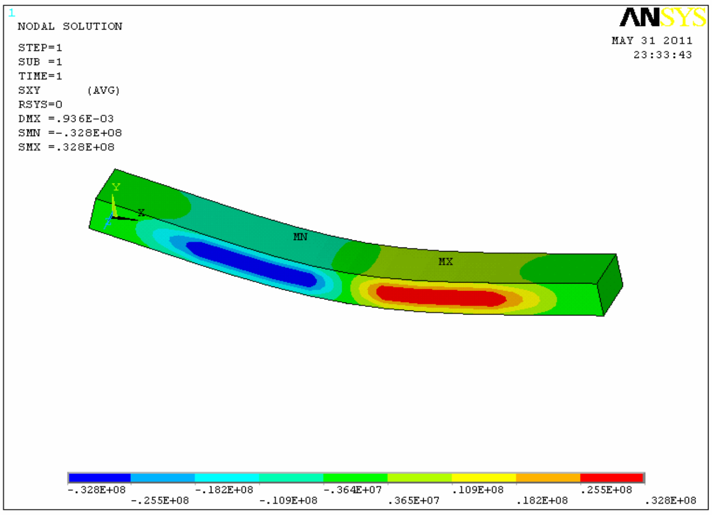
Figure (9) Relationship between maximum strain and width of composite beam with (5% and 10%) of Alumina.



b=12

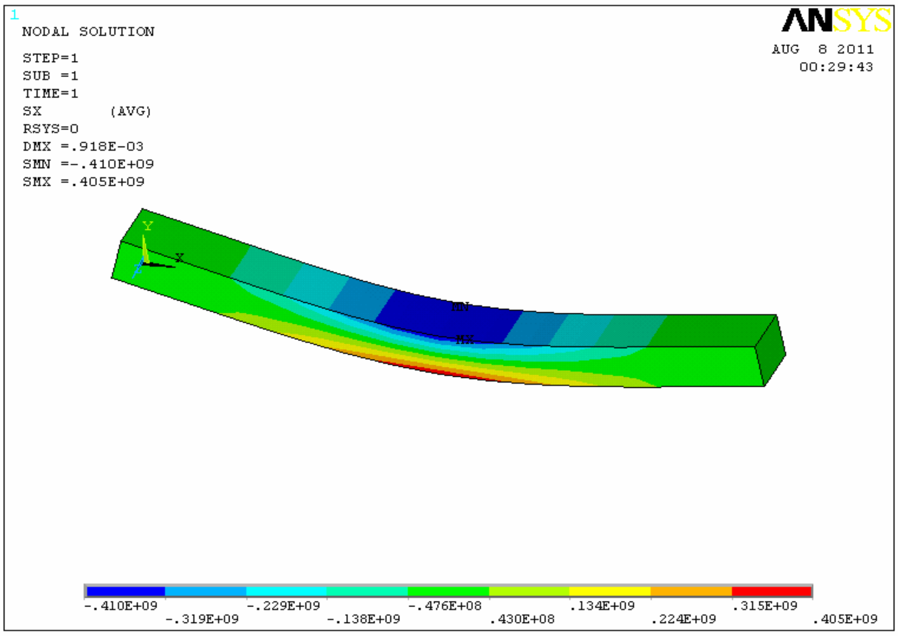


b=14

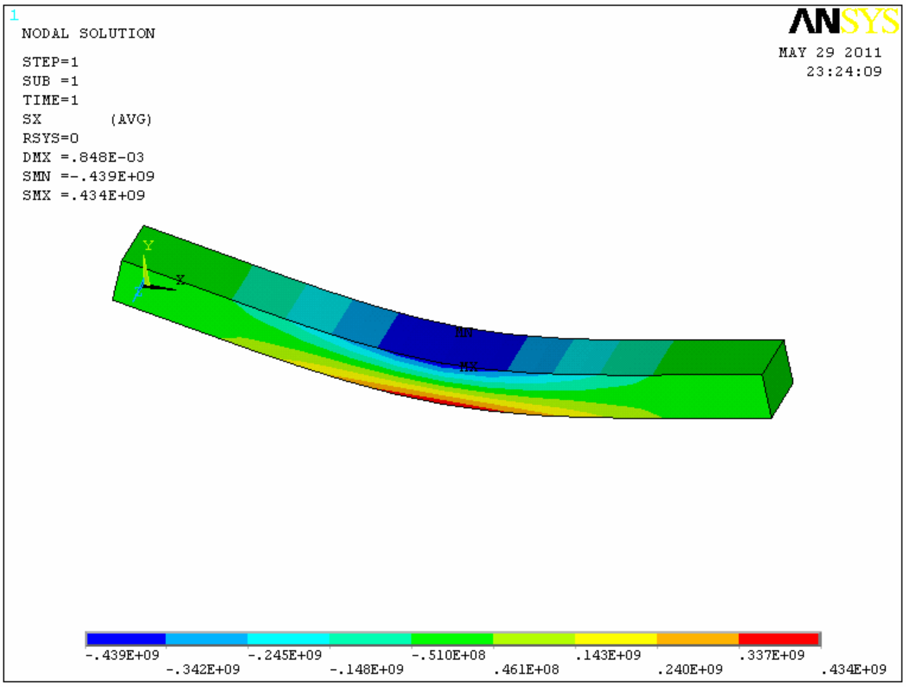


b=16

Figure (10) The shear stress with (10%) of Alumina with different width of beams by Ansys.



5 % Alumina



10 % Alumina

Figure (11) The comparison between Flexural strength with (5% and 10%) of Alumina at (b=14) by Ansys.