Bending Characteristics of Carburized Low Carbon Steel Experimental and Numerically Study

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Abstract

This research includes experimental and numerical studies by using finite element method to study the effect of carburized low carbon steel for different beams width on the hardness and bending properties.

The back of carburization consists from hardwood charcoal mixed with barium carbonate as the Activator. The specimens were carburized using (30%) of Activator at temperature equal to (900ºC) for five hours.

The modulus of elasticity obtained from experimental work used in FEM (ANSYS) to calculate flexural strength, maximum strain and maximum shear stress and these results increase with carburized low carbon steel. The results of the study showed that the Vickers micro hardness increased, the maximum flexural strength (1750 MPa) and maximum shear stress was (121.5 MPa) at width (16 mm) for the experimental results carburized low carbon steel. The experimental, finite element and analytical results obtained for the bending analysis are approximately agreement.

Keywords: Low carbon steel, carburization, flexural strength, maximum strain, maximum shear stress.

الخلاصة

تضمنت الدراسة الجانب العملي و تقنية العناصر المحددة لمعرفة تاثير كربنة الفولاذ المنخفض الكربون على قيم الصلادة وخواص الانحناء لعرض اعمدة مختلف.

أن وسط الكربنة مكون من مسحوق الفحم النباتي مع كاربونات الباريوم كمادة منشطة.وأن العينات يتم كربنتها بأستخدام نسبة (30%) من مادة التنشيط وعند درجة حرارة (900ºC) ولمدة خمسة ساعات. النتائج العملية لمعامل المرونة استخدمت في تقنية العناصر المحددة (برنامج انسيز) لحساب مقاومة الانحناء واكبر انفعال واكبر اجهاد قص بينت النتائج زيادة هذه القيم بعد كربنة الفولاذ منخفض الكربون.كذلك بينت النتائج أن الصلادة المجهرية للسطح المكربن تزداد، متانة الانحناء (1750 MPa) واكبر اجهاد قص (121.5 MPa) عند عرض عمود (16 mm) بعد الكربنة للنتائج العملية .و كذلك كانت نتائج العناصر المحددة مقاربة للنتائج العملية.

الكلمات المفتاحية :- الفولاذ منخفض الكربون الكربنة ، مقاومة الانحناء ،اكبر انفعال ، اكبر اجهاد قص .

1 Introduction

The carbon content in the steel determines whether it can be directly hardened. If the carbon content is low (less than 0.25% for example) then an alternate means exists to increase the carbon content of the surface. The part then can be heat-treated by either quenching in liquid or cooling in still air depending on the properties desired.

The carburizing is a process of adding carbon to the surface. This is done by exposing the part to a carbon rich atmosphere at an elevated temperature and allows diffusion to transfer the carbon atoms into steel. This diffusion will work only if the steel has low carbon content, because diffusion works on the differential of concentration principle.

Atanda *et.al.,* 2009 reports an investigation of the effect of carburizing variables – temperature, time and percentage of Activator –on the case properties of C2R steel. A carburizer consisting of hardwood charcoal and coke respectively in the ratio of 2:1 was used for the research with sodium carbonate as the Activator. The results of the study showed that the average hardness of the C2R steel cases increased with temperature for any given carburizing time and temperature.

(Gupta, 1974) studied the investigation of the mechanical and wear behaviors of mild steels carburized at different temperature range of 850, 900 and 950 ºC and it is found that the simple heat treatment greatly improves the hardness, tensile strength and wear resistance of the mild steels.

(Lames, 2006) studied some mechanical and physical properties for unsaturated polyester composites reinforced by nylon and glass fibers result of the work shows that the values of (tensile stress at fracture, tensile modulus of elasticity, fracture toughness, and impact strength) increased with the increase of nylon fibers volume fraction but the values of (compression stress, and hardness) decrease with the increase of nylon fibers volume fraction.

Liang *et.al.,* 2005 discussed 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 should provide 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.

Sung *et.al.,* 2002 investigated the post-buckling capabilities of stiffened and unstiffened steel compression plates were investigated through geometric and material nonlinear finite element analysis. Also, an experimental investigation was carried out in order to evaluate the actual bending strength of open-top steel box girders subjected to negative moment.

(Shahin and Mohamed,2008**)** studied the Multilayer feed-forward neural networks that are trained with the back-propagation algorithm are constructed using four design parameters (i.e. tube thickness, tube diameter, yield strength of steel and modulus of elasticity of steel) as network inputs and the ultimate pure bending as the only output.

The main aim of this work is to study the effect of carburized low carbon steel for different beams width on the experimental work and finite element analysis of the hardiness and bending properties.

2 :Theoretical Analyses

2.1 Solid carburization

The solid or pack carburization involves heating the steels parts embedded in powdery mixture of 70% coal and 30 % $BaCO_3$ at a temperature in range 880-900 degree Celsius. The residual air in the box combines with carbon to produce Co gas. Carbon monoxide gas is unstable at the process temperature and thus decomposes upon contacting the iron surface by reaction.

$$2CO = C + CO_2 \quad \ldots\ldots 1$$

The atomic carbon enters the steel through the following reaction.

$$Fe + 2CO = Fe(C) + CO_2 \quad \ldots\ldots 2$$

The addition of $BaCO_3$ enhances the carburizing effect. $BaCO_3$ decomposes and evolves CO_2 which react with coal to form carbon monoxide.

$$C + CO_2 = 2CO \quad \ldots\ldots 3$$

Solid carburization is a time consuming procedure. Typical carburizing time to obtain a case depth of 0.8-2 mm is around 4-8 hours.

2.2 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 (Askel *et.al.,* 2003).

Bending strength can be defined ability of sample to bending under external load applied on it without happen any fracture in the sample (Lawrence *et.al.,* 1974). 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 Hibbeler, 2005 ; Delmont, 1981 :

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

Where:
E_b: Bending modulus of elasticity (MPa).
P: Applied load at the midpoint of the sample (N).
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).

In the bending test the upper band of the sample expose to compression stress while the lower band of the sample expose to the tensile stress (Bolton, 2000).

2.3 Flexural strength and shear stress test

From the bending test can be calculated flexural strength which can be defined 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 (Delmont, 1981; William and Callister 2003).

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

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

Also can be calculated the shear stress by the following formula (ASTM D2990-2010).

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

The maximum strain in the mid-span is calculated by the following formula (ASTM D2990-2010).

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

Where:
r: Maximum strain (m/m).
δ: Maximum deflection at mid-span (m).

3- Experimental Processes

The carburizing process used for the low carbon steel samples have mechanical properties (Tensile strength (690 MPa) and yield strength (520 MPa)) according to (ASTM A 615/A 615M Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement) the carbon content is (0.14 %) from (Sky Ray Instrument cs-168 type infrared carbon &Sulfur analysis instrument) where the Chemical structure of low carbon steel by (wt %) is given in Table (1).

Table (1): The Chemical structure of low carbon steel.

C	Mn	Si	Ni	Cu	Cr	S	P	Fe
0.14	0.43	0.06	0.03	0.01	0.01	0.04	0.1	Balance

A carburizer consisting from hardwood charcoal mixed with barium carbonate as the Activator. The carburizing box was filled with 10 mm thick carburizer compound prior to fixing the steel samples in place. The specimens were carburized using 30 percentages of Activator at temperature equal to (900 ºC) for time (five hours). The treated samples were heat treated to refine the core and case by dual heat treatment. First refine the core by heating to 860 ºC and then the samples are water quenched so that a fine ferrite/pearlite/martensite structure is obtained. Second refine the case by heating to 750 ºC and then quenched to gives refine-grained martensite in the case, finally, the samples are tempered at 220 ºC to relieve any quenching strain present in the case.

The case depth was measured using the calibrated ocular of an inverted metallurgical microscope fixed at 100 x magnification, the case depth obtained of (0.9 mm).

The hardness values of the steel cases were measured with Vickers micro hardness tester that uses diamond pyramid indenter.

The tensile test Fig.(1) (Microcomputer Control Electronic Universal Testing Machine, Time Group Inc.,Model:WDW-50E).The strain rate equal to (5mm/min) 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 input data in ANSYS.

The bending samples for different beams width (12, 14 and 16 mm) and span length (100 mm) bend with same apparatus for tensile test as in figure (2).

4 Finite element analyses

The finite element analysis carried out as a part of this work was performed using ANSYS11 package .The program ANSYS is used here for analysis the stress, shear stress, strain, deflection, etc. of the carburized beam which basic on the numerical analysis of the equations that formed from the principle of finite element Method.

In 1941, Hrenik off presented a solution of elasticity problem using the frame.

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 solving the numerical engineering problems (Tirupath and Chandrupatha, 1997).

Therefore, the finite element method has become a powerful tool for the numerical Solution of a widely range of engineering problem.

The ANSYS11 package is used here in the bending analysis of the carburized 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 beams width.

4.1 Modeling

For the finite element method analysis of the bending of the composite beam problem, the ANSYS11 package program is adopted. This program has very efficient capabilities to perform finite element analysis of most engineering problem. The displacement approach to the solution of finite element problem is ulestrated by unaxial loading spring (Tirupath and Chandrupatha, 1997).

$$[K]^e . [\delta]^e = [F]^e$$

$[K]^e$ = element stiffness matrix.
$[\delta]^e$ = is the displacement vector.
$[F]^e$ = is the element applied load vector.

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 (displacement and force), specify load step options, meshing of the problem and begin the finite element solution.
(3) Review the results: it consists of bending deflection and stress ,strain and shear stress distributions.

4.2 Element Selected

Figure (3) shows the solid element model solid (8 Node 45) was adopted from the ANSYS 11 element library to perform this type of analysis. This element is used to modal the beam. The 8-node, 3-D solid element, SOLID45, with three degrees of freedom per node (UX, UY, UZ). It is designed to model thick layered shells or layered solids, the element with bending, tension, and compression capabilities. The mesh generation of the beam represents in figure (4).the composite beam is simply supported beam and the load is applied concentrated on the middle span.

5 Results and Discussion

The results obtained from the experimental work, finite element analysis and theoretical equations of the bending analysis of the carburized condition for 5 hrs at (900 ºC) of low carbon steel beams, are discussed here.

Table (1) shows the values of tensile strength and experimental modulus of elasticity, experimental bending modulus of elasticity and Vickers micro hardness increases when the low carbon steel carburized for 5 hrs at 900 ºC and this return to increase the hardness of the case after carburization.

Figure (5) demonstrates the relation between Vickers micro hardness and the case depth of the carburized surface. It is clearly that the micro hardness decreases from maximum value (525) at the outer surface of case depth to the core direction.

Figure (6) the stress – strain curves for thermo-chemical heat treatment (carburizing) of low carbon steel produced by tensile test and the modulus of elasticity was evaluated to use in finite element analysis. The maximum tensile strength after carburizing was (1065 MPa) with strain (0.0075) while the tensile strength as received condition was (708 MPa) with strain (0.00815).Because the hardness of the case increased after carburization.

Figure (7) investigates the experimental load – deflection curves with different beams width (12, 14 and 16) produced by bending test .the deflection increase with increase load and the maximum deflection (61 mm) at load (6.5 KN) at (b=12). The deflection will decrease with increase beams width at constant load.

Figure (8)shows the finite element load – deflection curves with different beams width, is the same as for experimental curves and the maximum deflection(68 mm) at load(6.5 KN) at (b=12).

Figure (9) investigates Relationship between the experimental and finite element load–deflection curves with (b=14mm). In general the finite element deflection results is slightly greater than the experimental results is clearly appear.

Figure (10) presents the relationship between flexural strength and width of beam for carburized condition for 5 hours at (900 ºC) for the experimental and finite element results the flexural strength increase with increase beams width and the maximum flexural strength was (1810 MPa).

Figure (11) illustrates relationship between maximum shear stress and width of beam for the experimental and finite element results ,the shear stress increase with increase beams width slightly difference between experimental results and FEM .

Figure (12) shows the relationship between maximum strain and beams width for the experimental and finite element results. The maximum strain increase with increase beams width. The maximum experimental strain was (0.0083).

Figure (13) shows the maximum strain with different beams width for carburized condition for 5 hours at (900 ºC) beams of the bending analysis 3D model by Ansys11. The strain distribution on the beam is clearly showed and the maximum strain (0.0087 at b=16) at middle span.

Figure (14) investigates the shear stress with different fiber volume fraction for carburized beams by Ansys11. It shows the 3D beam shear stress distribution and the maximum shear stress (127 MPa at b=16).

6 Conclusion

The study involved the bending analysis of the rectangular beam of the carburized condition for 5 hrs at (900 ºC) of low carbon steel beams, by using finite elements techniques compared with experimental method.

The main conclusion of result is:

1. The micro hardness decreases from maximum value at the outer surface of case depth to normal value at depth (0.9 mm) the core direction.
2. The experimental modulus of elasticity and increased with the carburized low carbon steel.
3. The maximum deflection (61 mm) at load (6.5 kN) at width (12). The deflection will decrease with increase beams width at constant load in experimental result and from Ansys11 is (68 mm) at the same width. The deflection will decrease with increase beams width at same load.
4. The experimental and finite element flexural strength, maximum strain and shear stress results increase with carburized low carbon steel.
5. The maximum difference between the numerical and experimental results for flexural strength (3.3%) was, the shear stress was (3.4%) at width (16 mm) and the maximum strain was (6%) at width (14 mm).
6. The experimental, finite element and analytical results obtained for the bending analysis are approximately agreement.

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Nomenclature

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

Eb = 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).

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

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

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

Figure (1) Tensile test apparatus

Figure (2) Bending test apparatus

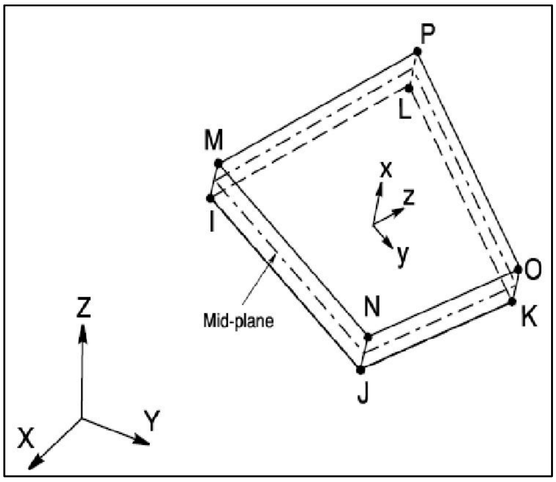


Figure (3): The solid element 8-node

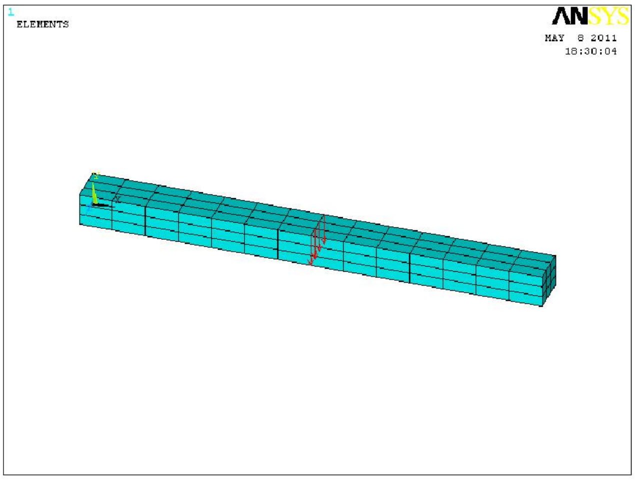


Figure (4): The mesh of the 3D beam

Table (2): The tensile strength, modulus and Vickers micro hardness.

	Tensile strength	Experimental modulus of elasticity	Experimental bending modulus of elasticity	Vickers micro hardness
As received condition	708 MPa	196 GPa	193 GPa	210
carburized for 5 hrs at 900 ºC	1065 MPa	207 GPa	201 GPa	525

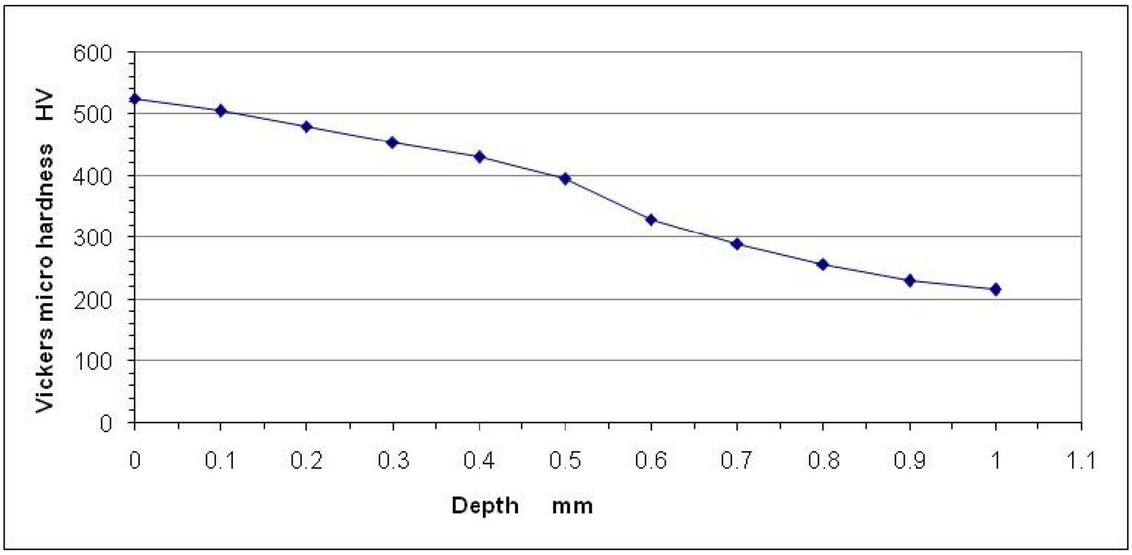


Figure (5): The relation between Vickers micro hardness and the case depth of the carburized surface.

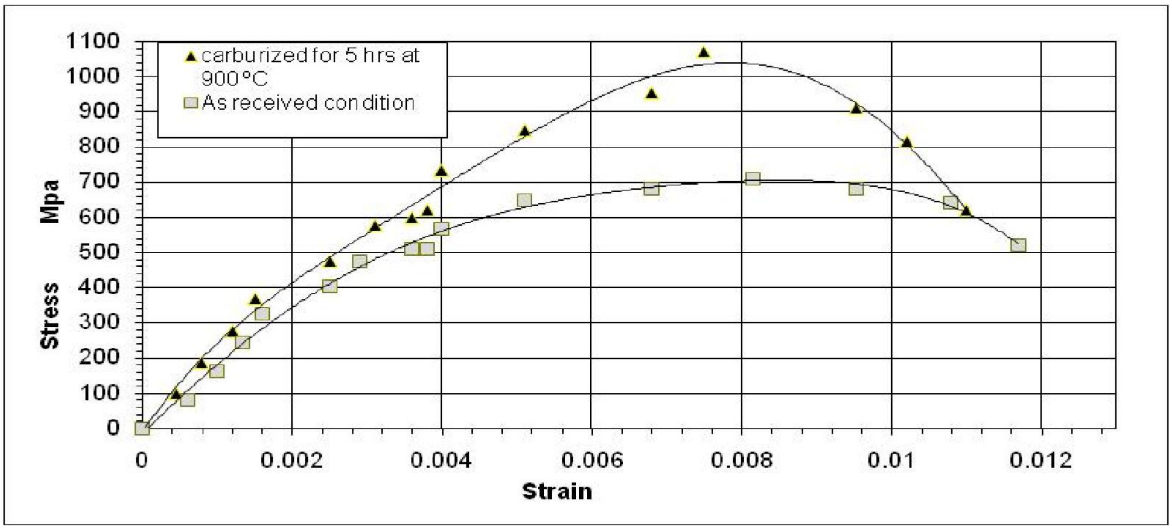


Figure (6): The stress – strain curves for thermo-chemical heat treatment (carburizing) of low carbon steel.

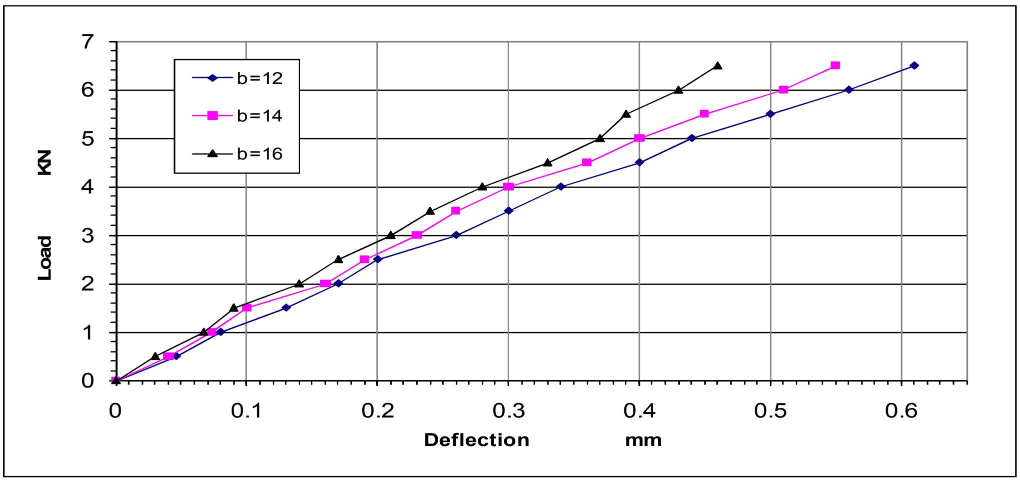


Figure (7): Shows the experimental load – deflection curves .

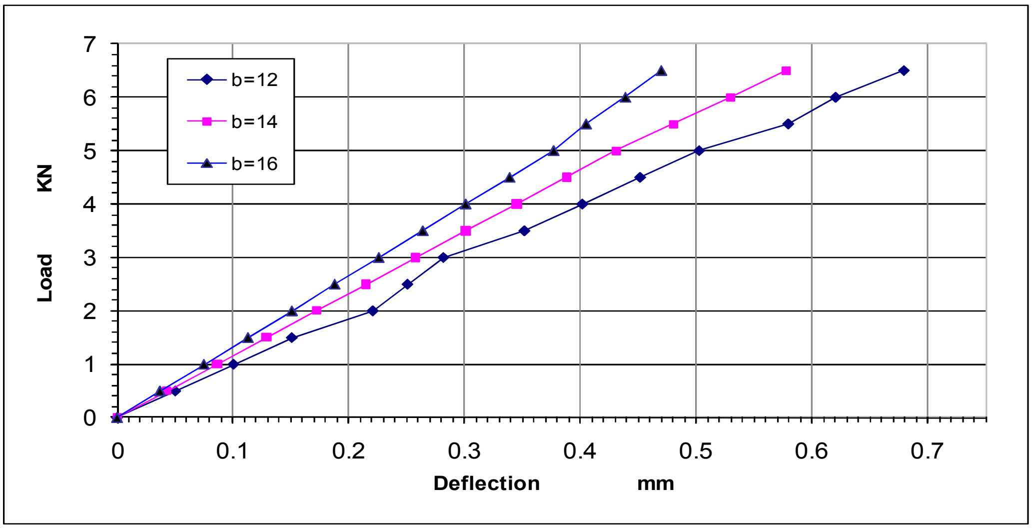


Figure (8): Shows the FEA load – deflection curves .

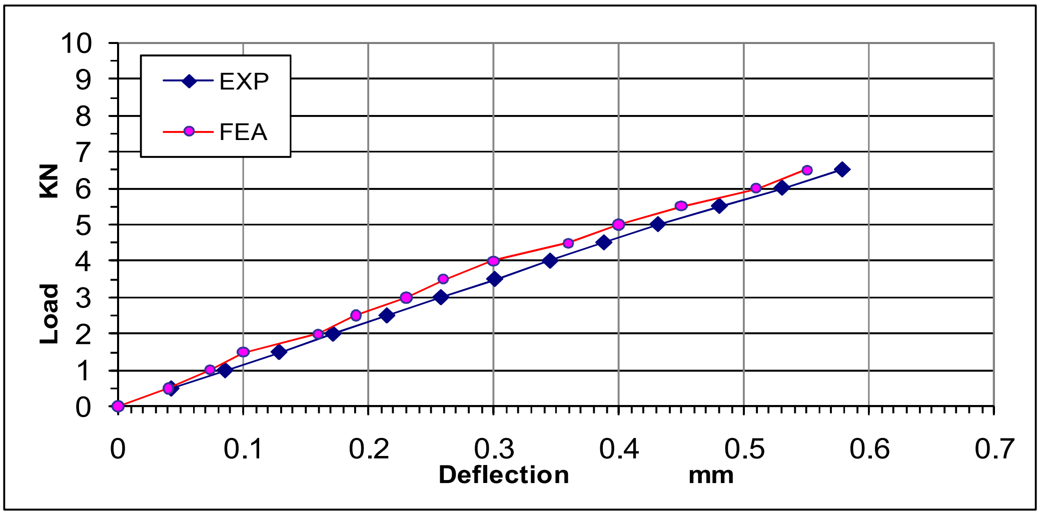


Figure (9): Relationship between the experimental and F.E.M. load – deflection curves At width (14mm)

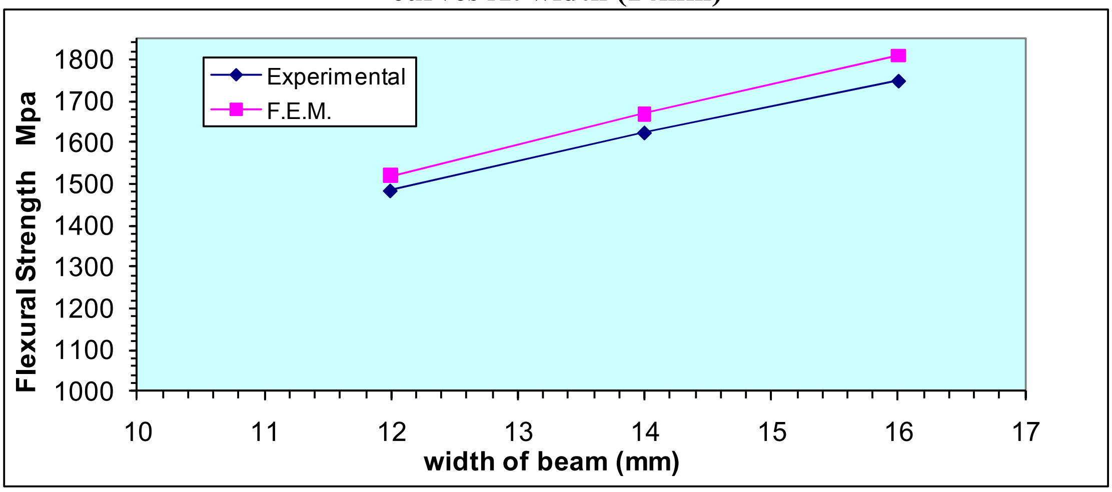


Figure (10): Relationship between Flexural strength and width of beam.

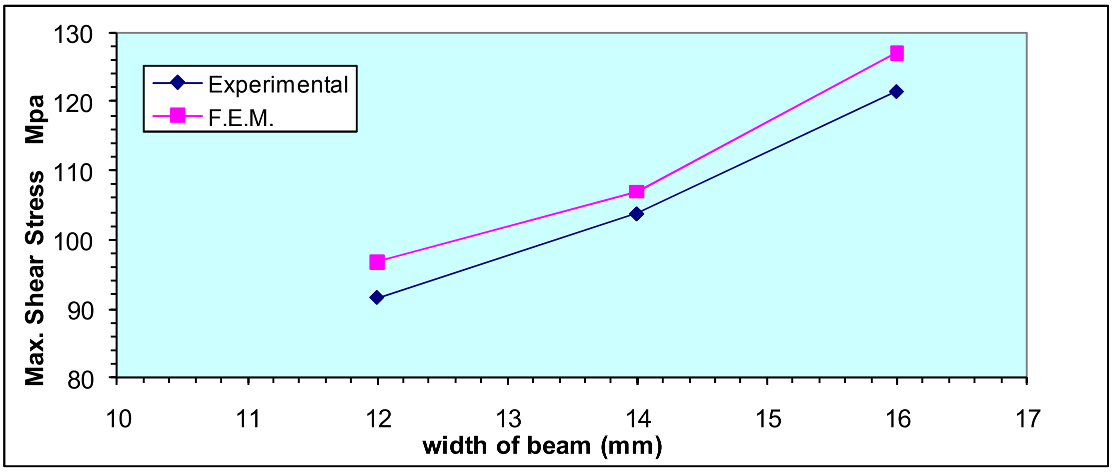


Figure (11): Relationship between maximum shear stress and width of beam.

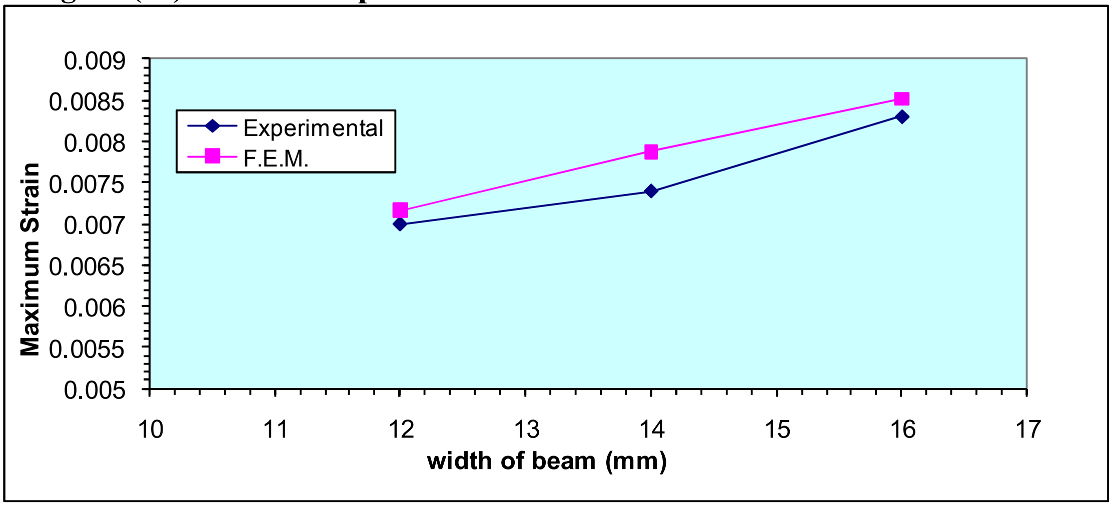
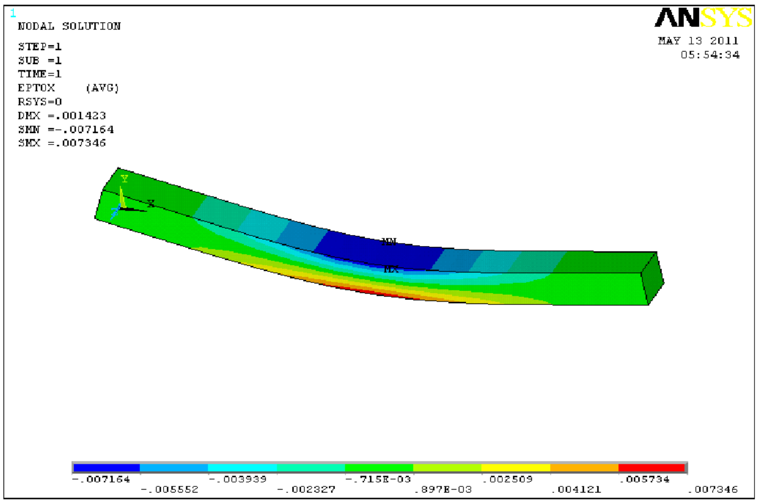
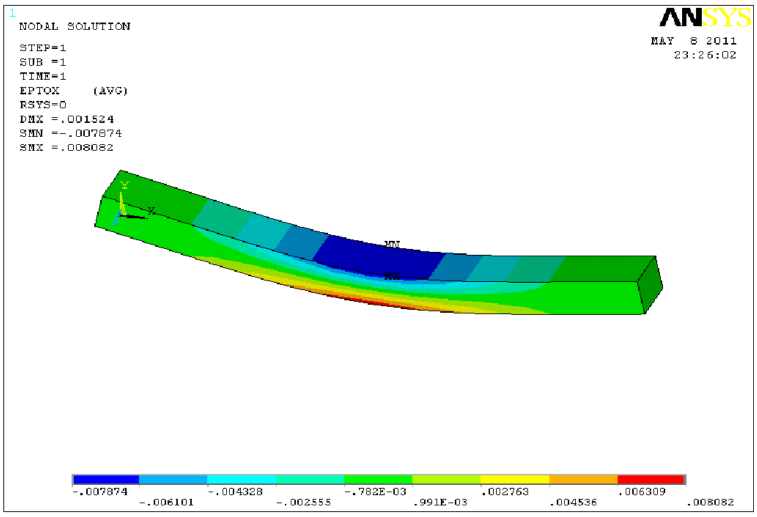


Figure (12): Relationship between maximum strain and width of beam.



b=12



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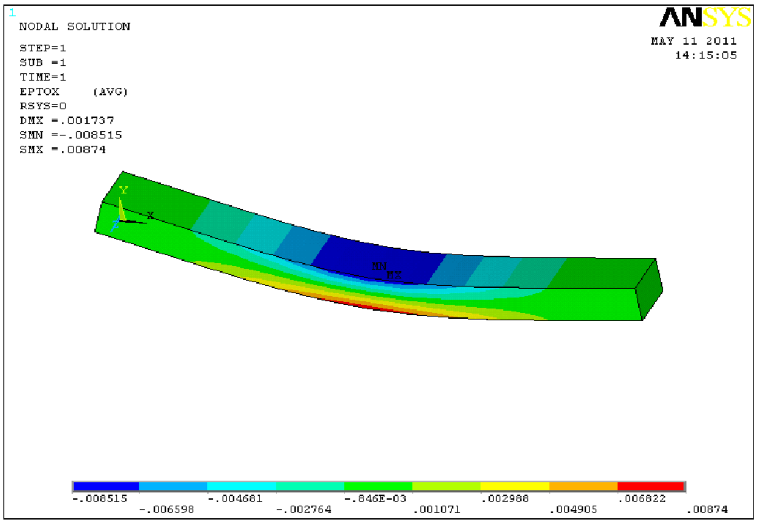
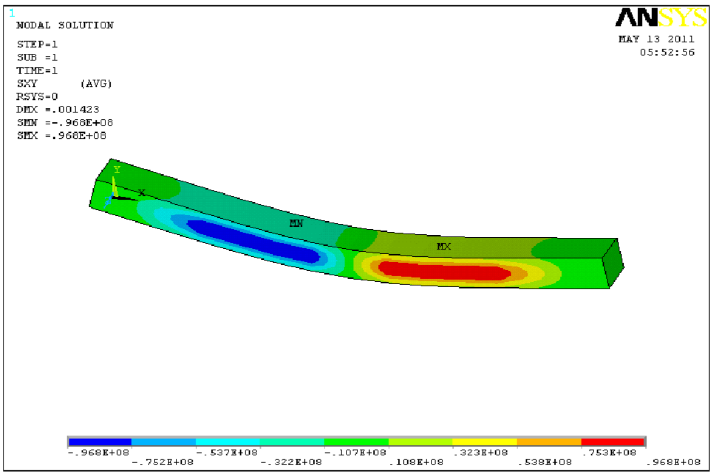
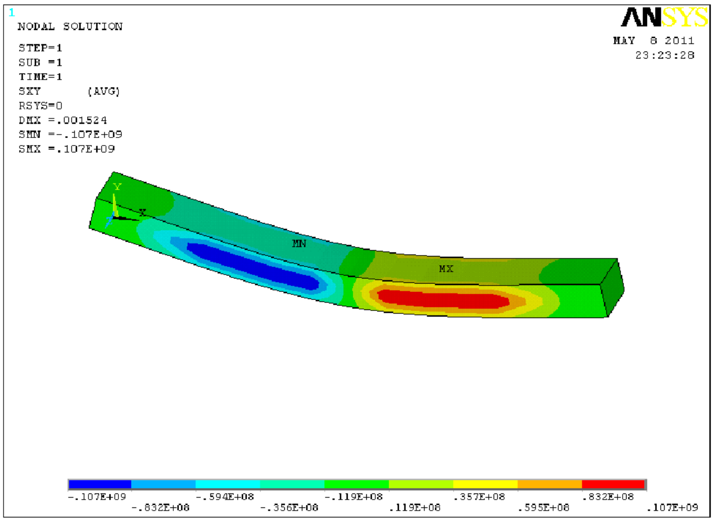


b=16

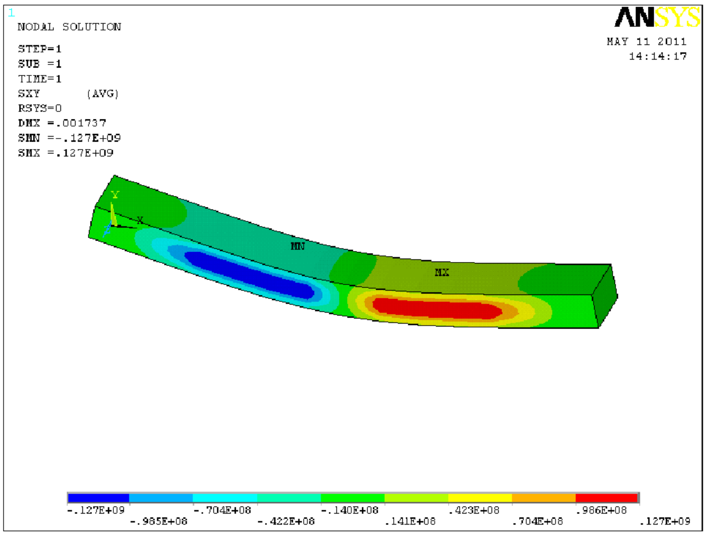
Figure (13): The maximum strain with different width of beams by Ansys.



b=12



b=14



b=16

Figure (14): The shear stress with different width of beams by Ansys.