

Experimental And Numerical Study Of Buckling For Carburized Low Carbon Steel Columns

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Abstract :

Experimental work and finite element techniques were used to analyze the tensile and buckling characteristics of carburized low carbon steel columns for different diameters.

The back of carburization consists of hardwood charcoal mixed with barium carbonate as the energizer. The specimens were carburized using (30%) of energizers at temperature equal to (900°C) for 5 five hours.

The modulus of elasticity as measured experimentally was used in FEM (ANSYS) to calculate the buckling load. The results of the study showed that the Vickers micro hardness increased from (HV=210) to (HV=525), the tensile strength increased from (708 MPa) to (1065 MPa) and critical buckling load increased from (18.37 kN) to (19.6 kN) for d=8mm. Also critical buckling load increased from (5.8 kN) to (19.2 kN) as the diameter of the carburized low carbon steel column increased from 6mm to 8mm respectively for FEA analysis.

Keywords: low carbon steel, carburization, tensile, buckling

دراسة عملية عددية لانبعاج أعمدة الفولاذ منخفض الكربون المكرين

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الخلاصة :

تضمنت الدراسة الجانب العملي و تقنية العناصر المحددة لتحليل الشد و الانبعاج للفولاذ المنخفض الكربون المكرين وبأقطار مختلفة للعمود.

أن وسط الكربنة مكون من مسحوق الفحم النباتي مع كاربونات الباريوم كمادة منشطة وأن العينات يتم كربنتها باستخدام نسبة (30 %) من مادة التنشيط وعند درجة حرارة (900°C) ولمدة خمسة ساعات.

النتائج العملية لمعامل المرونة استخدمت في تقنية العناصر المحددة (برنامج انيسيز) بينت النتائج أن الصلادة المجهريية للسطح المكرين تزداد من (HV=210) الى (HV=525) ومقاومة الشد تزداد من (708 MPa) الى (1065MPa) والحمل الحرج للانبعاج يزداد من (18.37 kN) الى (19.6 kN) بعد الكربنة للنتائج العملية لقطر

6mm. و كذلك يزداد الحمل الحرج من (5.8 kN) الى (19.2 kN) بزيادة قطر العمود من 6 mm الى 8mm على التوالي.
الكلمات المفتاحية: الفولاذ منخفض الكربون، الكربنة، الشد، الانبعاج.

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. Note that this method will only allow hardening on the surface, but not in the core, because the high carbon content is only on the surface.

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.

P.O. Atanda^[1] reports an investigation of the effect of carburizing variables – temperature, time and percentage of energizer –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 energizer. 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.

Jaykant Gupta^[2] studied the investigation of the mechanical and wear behaviors of mild steels carburized at different temperature range of 850, 900 and 950 °C and it is found that the simple heat treatment greatly improves the hardness, tensile strength and wear resistance of the mild steels.

Sung, Dong and Chai^[3] investigated the postbuckling capabilities of stiffened and un stiffened steel compression plates 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^[4] 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.

F.Alami^[5] established the relationship between buckling Load and natural frequency of several types of structures. The buckling loads for different kinds of structures under various loading and boundary conditions are often expressed using approximate simple formula. Sometimes more accurate results based on finite element approach are commonly employed.

The main objective of this work is to study experimentally and theoretically the effect of the carburization and changing column diameter on the analysis of the tensile and the buckling characteristics of low carbon steel columns.

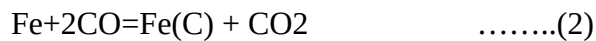
Theoretical Analysis

a. Solid Carburization:-

The solid or pack carburization involves heating the steels parts embedded in powdery mixture of 70% coal and 30 % BaCO₃ 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.



The atomic carbon enters the steel through the following reaction.



The addition of BaCO₃ enhances the carburizing effect. BaCO₃ decomposes and evolves CO₂ which react with coal to form carbon monoxide.



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.

b. Critical load:-

Column fails by buckling when the axial compressive load exceeds some critical load ^[6].

The compressive stress can be well below the material yield strength at the time of buckling depending on the factor that determines if a column is short or long which is column slenderness ratio (S), where:

$$S = L/r \quad \text{.....(4)}$$

$$\text{Where } r = \sqrt{\frac{I}{A}} .$$

That:

r: is radius of gyration.

L: is the length of the column.

A: Area of cross section.

I: is moment of inertia.

A short column is usually defined as one whose slenderness ratio is less than about (10) ^[7].

The critical load of the long column can be calculated from Euler equation as follows:

$$P_{cr} = C \frac{p^2 EI}{L^2} \dots\dots\dots(5)$$

Where:

C: is the end condition number. When both ends are free pivots use (C=1).

Experimental work

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).

The carbon content is (0.14 %) from (Sky Ray Instrument cs-168 type infrared carbon &Sulfur analysis instrument),where The chemical composition of low carbon steel by (wt %) is given as follows C-0.14, Mn-0.43, Si-0.06, Ni- 0.03, Cu-0.01, Cr-0.02, S-0.04, P-0.1, and Fe.

A carburizer consisting from hardwood charcoal mixed with barium carbonate as the energizer. 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 energizers at temperature equal to (900°C) 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 °C and then the samples are water quenched so that a fine ferrite/bearlite/ martensite structure is obtained. Second refine the case by heating to 750 °C and then quenched to give refine-grained martensite in the case, finally, the samples are tempered at 220 °C 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 apparatus is shown in **Figure. (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 experimental modulus of elasticity results used as input data in ANSYS to calculate buckling load.

The buckling samples for different columns diameter (6,7and 8mm) buckled by the apparatus (Microcomputer Control Electronic Universal Testing Machine, Time Group Inc.,Model:WDW-50E) as shown in **Figure (2)**.



Fig. (1) Tensile test apparatus

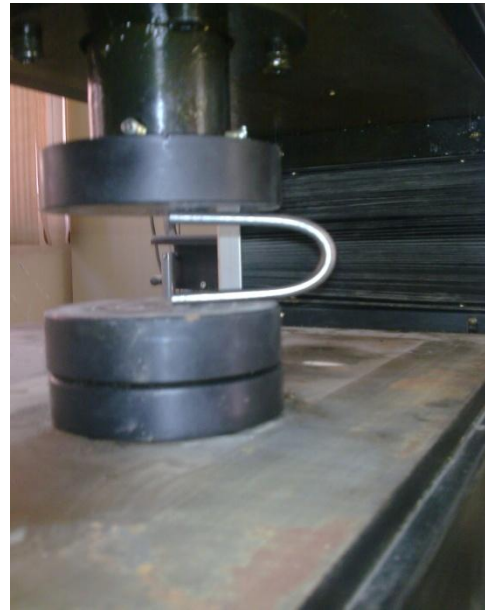


Fig. (2) Buckling test apparatus

The load deflection curves for all samples with different diameters as received and carburized are shown in figures (8, 9, and 10). The sample dimension in (mm) was (length=150, diameter=6, 7 and 8). Where slenderness ratio ($S=100, 86$ and 75) respectively calculated from Eq. (4) so that the sample is long column.

Finite Element Analysis

The finite element analysis carried out as a part of this work was performed using Ansys package in the buckling analysis of column to determine the critical load at which the structure become unstable. The column is constructed of isotropic material.

In 1970, the finite element method became more affected and used in a wide range to solve numerical engineering problems ^[8].

Eigenvalue And Eigenvector

For the finite element method analysis of the buckling of the column problem, the ANSYS11package program is adopted. This program has very efficient capabilities to perform finite element analysis of most engineering problem.

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 and obtain the static solution in this step defined the analysis type and options, applied load (displacement and force), specify load step options, meshing of the problem and begin the finite element solution.

3. Obtain the Eigen value buckling solution: this step requires files from the static analysis. Also, the database must contain the model geometry data to obtain the Eigen value buckling solution.
4. Expand the solution: this step is used to review the buckling mode shapes.
5. Review the results: it consists of buckling load factors, buckling mode shapes, and relative stress distributions.

The eigenvalue and eigenvector problem needs to be solved for mode-frequency and buckling analyses. It has the form of ^[9]:

$$[K] \cdot \{\psi_i\} = \lambda_i \cdot [M] \cdot \{\psi_i\}$$

Where:

$[k]$ = Total structure stiffness matrix.

$$= \sum_{m=1}^N [K]^e$$

$\{\psi_i\}$ = i th eigenvector of displacements.

λ_i = i th eigenvalue.

$[M]$ = total structure mass matrix

$$= \sum_{m=1}^N [M]^e$$

N = Number of elements.

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

$[M]^e$ = element mass matrix.

For model analyses, the $[K]$ matrix includes the stress stiffness matrix $[S]$. For eigenvalue buckling analyses, the $[M]$ matrix is replaced with the stress stiffness matrix $[S]$.

Element Selected

From the ANSYS 11 element library ^[10] the beam 3 (2D-elastic beam) adopted to perform this type of analysis. This element is used to model the column. This element is a uniaxial element with tension, compression, and bending capabilities. The element has three degree of freedom at each node translations in the nodal x and y directions and rotation about the nodal z-axis. The geometry, node locations and the coordinate system for this element are shown in **Figure (3)**. The mesh generation of the column represents in **Figure (4)**. The column is simply supported at points (1) and (2) and the load is applied axially on the point (2) that this point moved in direction of point (1) and can be rotated about the nodal z-axis and

rotated about the nodal y-axis in point (2). This method is simple and gives accurate critical load (FREQ.) results when compared to experimental result.

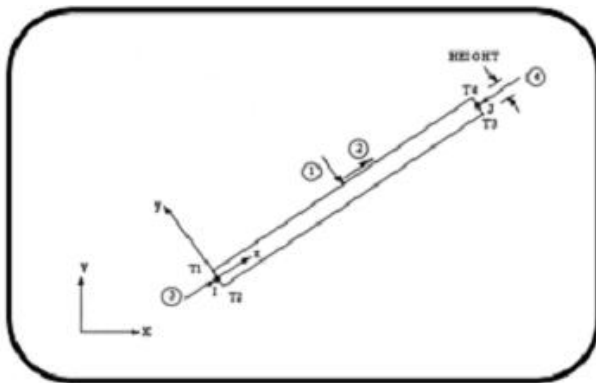


Fig. (3) 2-D Elastic Column ^[10].

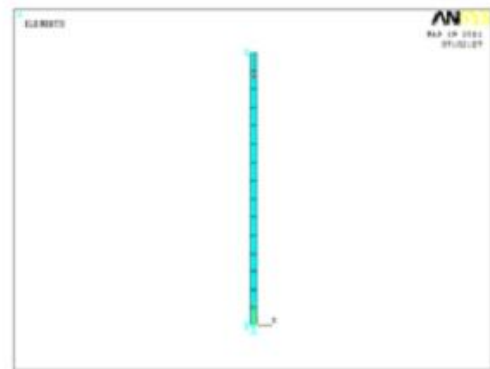
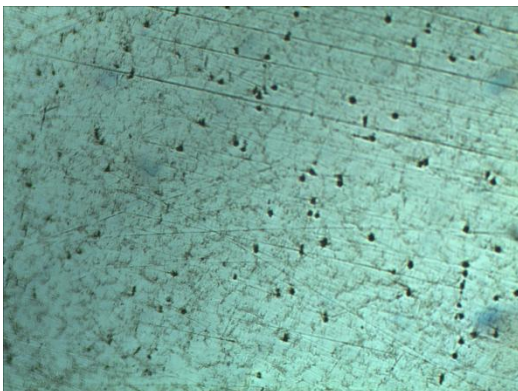


Fig. (4) The mesh of the column

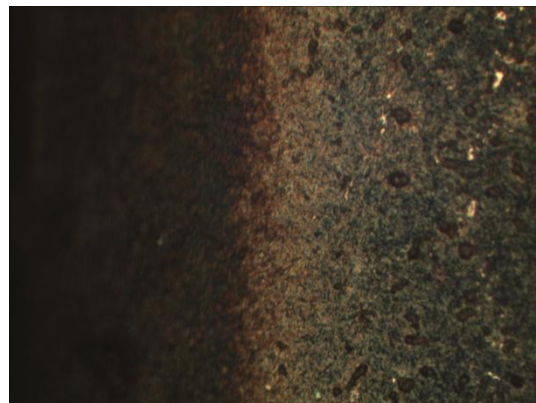
Results and Discussion

The results obtained from the experimental work and theoretical equations and the finite element analysis of the tensile and buckling of the column are discussed here.

Figure (5) shows the microstructure of low carbon steel magnification at 200X from the carburization deduce that the total layers of the case depth of the outer case surface is the tempered martensite and small ratio of retained austenite .The retained austenite decrease from the outer surface to the core because the carbon content of the outer surface decreases gradually.



(a) As received conditions



(b) Carburized for 5 hrs. at 900 °C.

Fig. (5) The microstructure of low carbon steel magnification at 200X.

Table (1) shows the values of tensile strength and experimental modulus of elasticity and Vickers micro hardness all these values increases when the low carbon steel carburized

for 5 hrs. at 900 °C and this return to increase of the hardness of the case after carburization that the ratio of increase of tensile strength (33%) the ratio of increase of modulus of elasticity (5.6%) the ratio of increase of micro hardness (150%).

Table (1) The values of the tensile strength, experimental modulus of elasticity and Vickers micro hardness.

	tensile strength	experimental modulus of elasticity	Vickers micro hardness
As received condition	708 MPa	196 GPa	210
carburized for 5 hrs at 900 °C	1065 MPa	207 GPa	525

Figure (6) the relation between Vickers micro hardness and the 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.

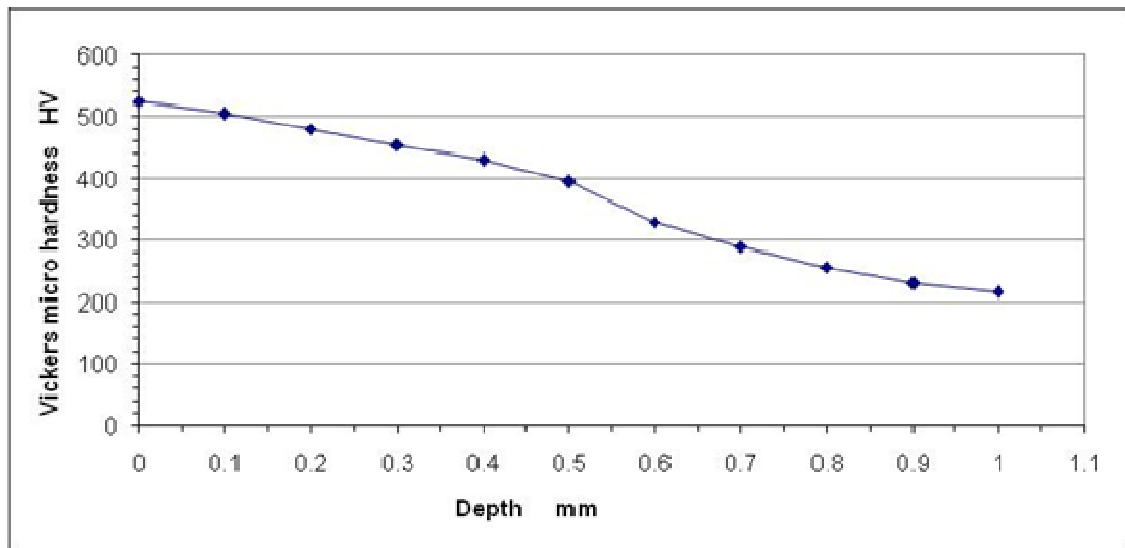


Fig .(6) The relation between Vickers micro hardness and the case depth of the carburized surface.

Figure(7) 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 of low carbon steel increased after carburization.

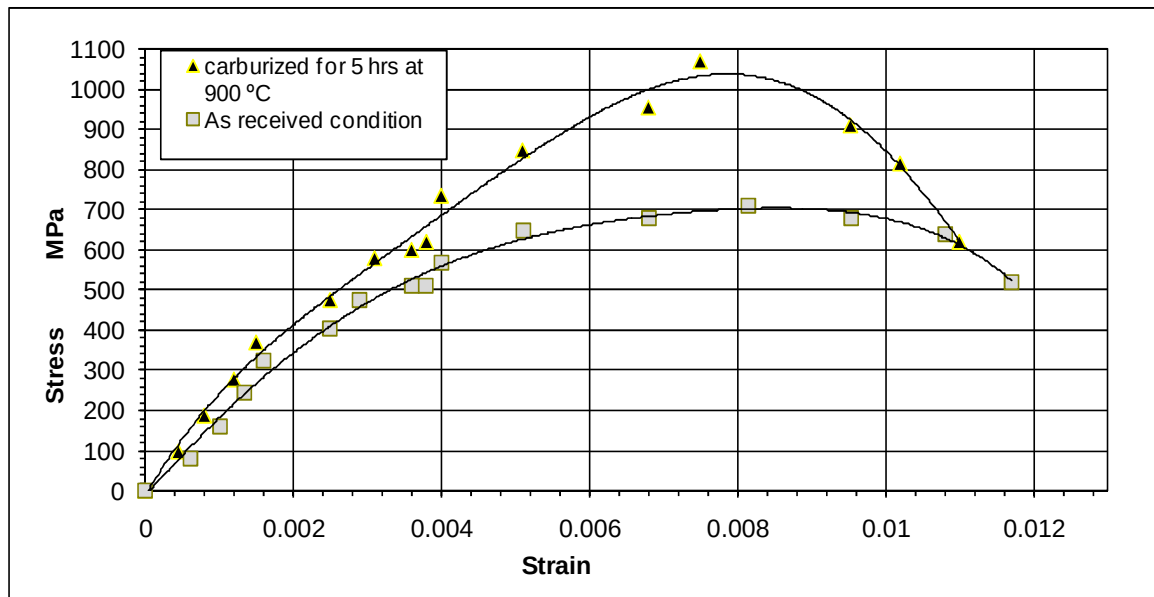


Fig .(7) The stress – strain curves for thermo-chemical heat treatment (carburizing) of low carbon steel.

Figure (8) shows the critical load – deflection curves for different diameters (as received condition). The buckling load increase from (5.58 kN) at ($d=6\text{mm}$) to (18.37 kN) at ($d=8$) with same deflection (1.1 mm).

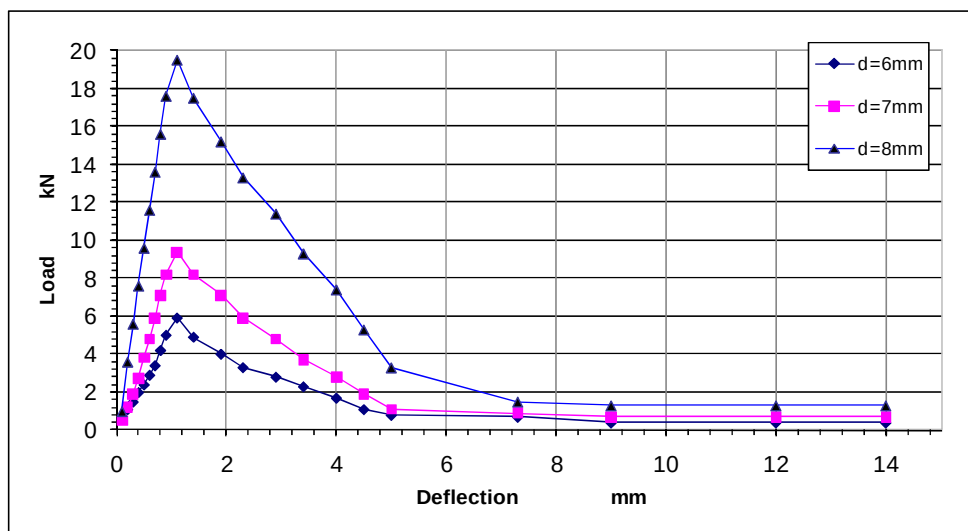


Fig .(8) The critical load – deflection curves for different column diameters (as received condition).

Figure (9) shows the critical load – deflection curves for different diameters carburized for 5 hrs at 900 °C. The buckling load increases from (5.9 kN) at (d=6mm) to (19.6 kN) at (d=8mm) with same deflection (1.1 mm).

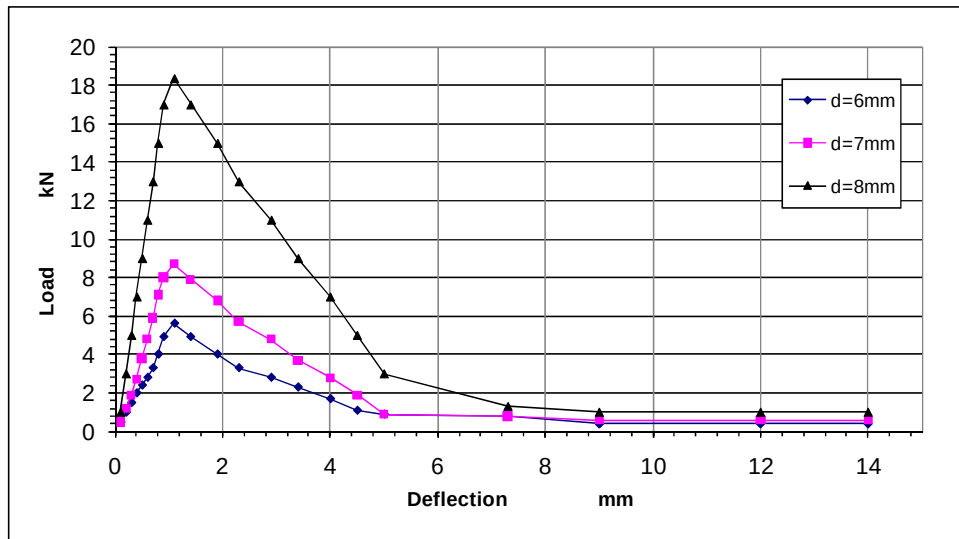


Fig .(9) The critical load – deflection curves for different column diameters (carburized for 5 hrs at 900 °C).

Figure (10) Shows the critical load – deflection curves for the column diameter (7mm) (as received condition and carburized at 900 °C). The buckling load affected by the surface hardness of case from carburization that increased from (8.71kN) to (9.37 kN) with same deflection and the ratio of increase of critical buckling load was (7%) where the ratio of increase of critical buckling load at (d=6mm) was (5%).

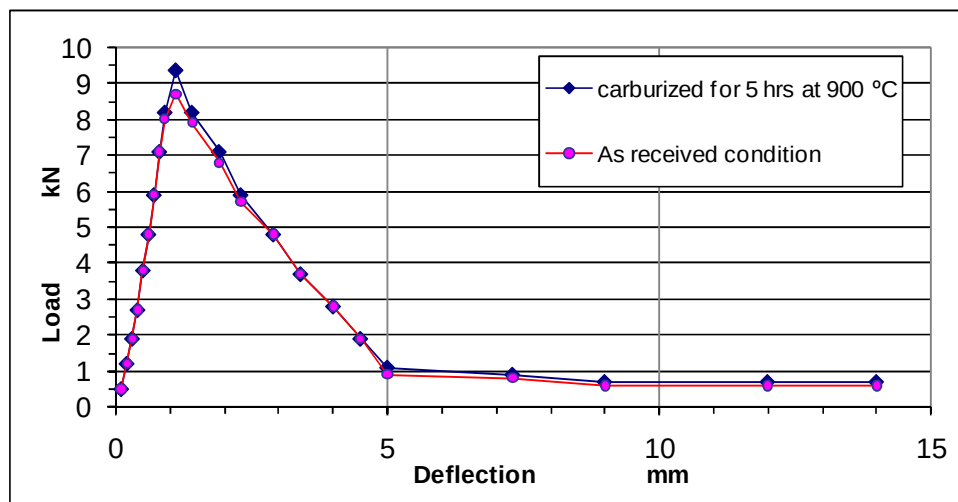
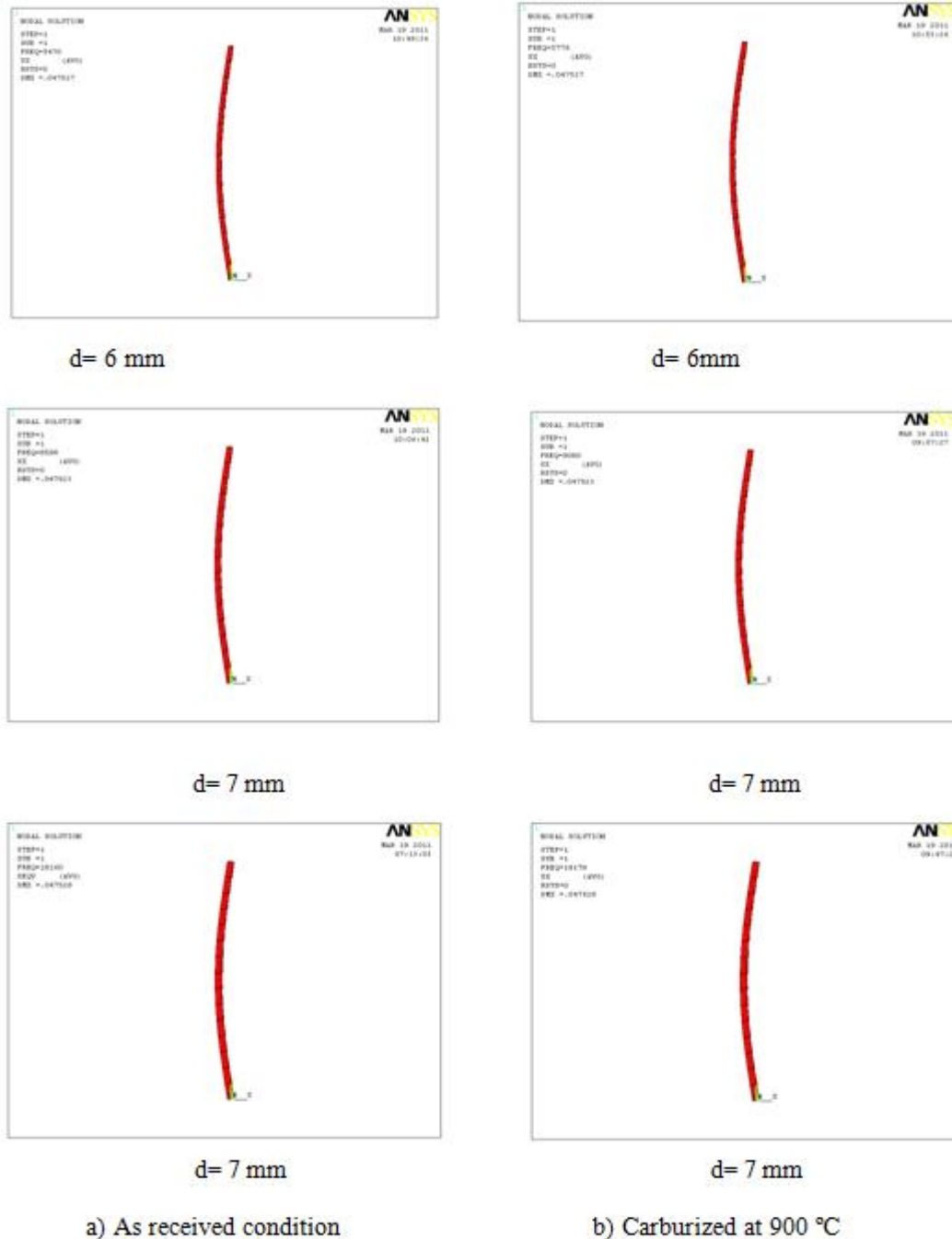


Fig .(10) The critical load – deflection curves for the case (d=7mm).

Figure (11) shows the critical load (as received condition and carburized at 900 °C) for different column diameters by Ansys. For all These columns at same diameter the FEA shows the buckling load(FREQ) increased when carburized low carbon steel because it depend on the value of modulus of elasticity and this value increased by carburizing.



d	mm	a)buckling load (As received) N	b)buckling load (Carburized at 900 °C) N
6		5470	5776
7		8598	9080
8		18160	19179

Fig .(11) The variation of the critical load with different column diameters.

Figure (12) shows the variation of the critical load for different column diameters. It is clear that the critical buckling load as calculated by FEA (Ansys) is less than the corresponding experimental value at same diameter as received and carburized conditions the experimental critical load (19.6 kN) while critical load by (Ansys) was (19.179kN) at (d=8mm) for carburize columns and this emphasizes that the difference between the experimental results and (Ansys) results is very small, while this difference increases when the column diameter is increased.

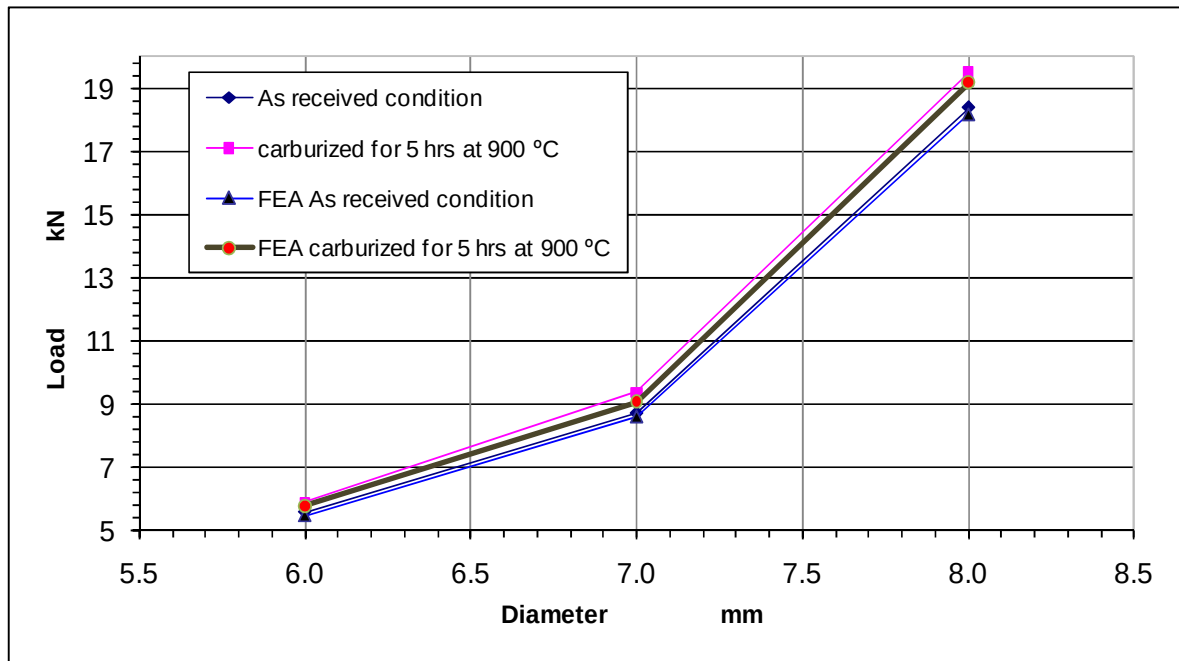


Fig .(12) The variation of the critical load with different column diameters (as received condition and carburized at 900 °C).

Conclusion

The study involved the tensile and the buckling analysis of the columns made from low carbon steel as receive and carburized condition, by using finite elements techniques compared with experimental method.

The main conclusions of tensile and buckling result are:

1. The experimental values after carburization was increased that the ratio of increase of tensile strength (33%), the ratio of increase of modulus of elasticity (5.6%) and the ratio of increase of micro hardness (150%) of tensile strength.
2. The critical buckling load of the low carbon steel column increases by the effect of carburization and the maximum ratio of increase was (7% at d=7mm).
3. The finite element results for the buckling load are slightly less than the experimental results and the maximum difference (2.1 % at d=8mm) indicating conservation in the theoretical predictions by the FEA.

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