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Research Article

Study the Influence of Shot Peening Time on Buckling Behavior of Medium Carbon Steel (CK 35) under Dynamic Loading (Experimentally and Numerically)

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Abstract

A study of dynamic buckling behavior (experimentally and numerically) under increasing load has been conducted on medium carbon steel (CK35) specimen. 24 specimens were tested under compression loading, 12 specimens are long and others are intermediate. All these specimens were tested under four shot peening times (SPT) (0, 15, 25, 30) minutes. It was concluded that the best buckling behavior was appeared at (25 min) SPT and the comparison between the experimental and numerical results showed good agreement between these results.

Keywords: *shot peening time, buckling behavior, dynamic load, CK35 steel alloys.*

Introduction

Shot peening is a cold-work process in which the surface of a component is bombarded with small spherical media called shot. The compressive residual stress field is an important factor for improving the strength of parts peened (YU-KUI GAO *et al*, 2002).The current tendency in the field of critical automotive components is to increase the performance while reducing material and processing costs such as machining, forging or hardening treatments. The current guideline is rather to use carbon steels for which buckling strength performance has to be increased by an optimized surface hardening. The process is known to offer some advantages with respect to other surface treatments such as carburizing, shot-peening, burnishing or rolling. One of the main features of induction surface treatment is the strength improvement. It is also viewed as a cleaner process than carburizing because it uses less toxic products than those used in carburizing or nitriding. Induction treatment can also be integrated into a production line because surface hardening is achieved in a few seconds (Dominique C. *et al*, 2008).

A column is a structure member that carries an axial compressive load and that tends to fail by elastic instability or buckling, rather than by crushing the material. Elastic instability is the condition of failure in which the shape of column is insufficiently rigid to hold it a straight under load. Then, if the load is not reduced, the column will collapse and this kind of catastrophic failure must be avoided in structures and machine elements (H.J. Mohamed Al-alkawi*et al*, 2007).

Buckling plays a very important role in the design of slender columns. Linear buckling of column structures is an important design constraint, especially where weight is a major concern (Y. Pekbey*et al*, 2007).

To improve design metals and alloys for many applications, investigations are aimed to strengthen mechanisms. Surface treatments of shot peening on steel have been extensively used in the automotive, aerospace and petro-chemical fields. One of the known ways to improve the strength of materials by the shot peening technique. Shot peening is an effective way of surface treatment in engineering components widely used for introduction of compressive residual stresses and improving the strength to buckling failure, corrosion, fatigue and fatigue-creep interaction. Various surfaces strengthen methods, such as shot peening, laser shock peening and hold cold expansion, are utilized in the aircraft industry to increase components lives. Among these surface treatments, shot peening is widely used due to its ease of operation, good surface integrity obtained (Al-alkawi H. J. M. *et al*, 2014).

(V. Azar *et al*, 2010) investigated the influence of shot peening treatment on hardness, fatigue and corrosion behavior of 316L stainless steel in Ringer's solution, Hardness, fatigue and electrochemical tests were performed on each specimen before and after shot peening treatment. The concluding remarks observed that shot peening treatment increases the surface hardness and fatigue resistance. (A.R. Rahai*et al*, 2008) formulated the buckling analysis of tapered column members. The calculation of the buckling loads was carried out by using modified vibrational mode shape (MVM) and energy method. This study was shown that this phenomenon was

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Table (1) Experimental results for buckling behavior of medium carbon steel (CK 35)

No.	L (mm)	SPT (min)	S.R.	C_c	Type of column	$\delta_{initial}$ (mm)	δ_{cr} (mm)	N_f (cycle)	$P_{cr.}$ (N)
1	500	0	155.56	100.58	Long	0.33	5.4	1.8	4946
2	500	15	155.56	99.82	=	0.2	5.2	1.9	5230
3	500	25	155.566	98.22	=	0.3	5	2.2	5440
4	500	30	155.56	96.71	=	0.45	5.1	2	5300
5	370	0	115.11	100.58	=	0.3	3.7	2.5	8831
6	370	15	115.11	99.82	=	0.27	3.8	2.5	9538
7	370	25	115.11	98.22	=	0.24	3.5	2.9	10032
8	370	30	115.11	96.71	=	0.3	3.6	2	9185
9	330	0	102.67	100.58	=	0.3	3.3	2	11304
10	330	15	102.67	99.82	=	0.3	3.1	2.3	12434
11	330	25	102.67	98.22	=	0.24	3.1	2.5	12717
12	330	30	102.67	96.71	=	0.22	3.2	2.3	12293
13	310	0	96.44	100.58	Intermediate	0.21	3	2.2	13424
14	310	15	96.44	99.82	=	0.15	3.1	2.3	14130
15	310	25	96.44	98.22	=	0.2	3	2.6	14483
16	310	30	96.44	96.71	=	0.23	3.2	2	14342
17	270	0	84	100.58	=	0.3	2.7	2.7	16250
18	270	15	84	99.82	=	0.27	2.5	2.8	17309
19	270	25	84	98.22	=	0.26	2.6	3.3	18369
20	270	30	84	96.71	=	0.31	2.6	3	17804
21	250	0	77.778	100.58	=	0.17	2.7	2.6	19076
22	250	15	77.778	99.82	=	0.14	2.6	3.4	19782
23	250	25	77.778	98.22	=	0.18	2.5	3.5	20277
24	250	30	77.778	96.71	=	0.21	2.6	3.1	19429

used to estimate the vibrational mode shapes of taper columns. In turn, these mode shapes were incorporated to evaluate their buckling loads. (H.A. Hussein, 2010) investigated buckling of square columns with different lengths under effect of liquid nitriding was investigated by using the analytical and experimental approach of materials carbon steel alloys. It had been showed experimentally that the use of the nitride case hardening increases the buckling resistance. The study showed also experimentally that the use of Euler's theory is limited for long columns and the tangent modulus for an inelastic range.

This paper examines the effect of shot peening on the dynamic buckling of columns subjected to combined compression-bending loads, of medium carbon steel (CK35) material experimentally and analytically by finite element model, and compare between the result of these two method, also determine the deflection shape and critical deflection with number of cycles at failure.

Theory

The column which has the slenderness ratio (S.R.=L_{eff}/R) is large than the column constant ($C_c = \sqrt{2\pi^2 E/\sigma_y}$), then the column is being long and Euler formula is used to determine the critical buckling load (Al-alkawi H. J. M. *et al*, 2014)

$$P_{cr} = \frac{\pi^2 EI}{(L_{eff})^2} \tag{1}$$

Where L_{eff}=K*L where K is the end condition coefficient; which was fixed-pinned ends; it is equal to (0.7) (Al-alkawi H. J. M. *et al*, 2014).

If the slenderness ratio (S.R) is less than column constant (C_c), then the column is intermediate and Johnson formula can be applied. This formula may be written as (Al-alkawi H. J. M. *et al*, 2014)

$$P_{cr} = A\sigma_y \left[1 - \frac{\sigma_y (S.R)^2}{4\pi^2 E}\right] \tag{2}$$

The value of critical load (P_{cr}) in equation (1) is not dependent on the mechanical properties of the material except the modulus of elasticity. But the critical load is directly depending on the dimensions of the column. The material strength is not involved in the above equation. For the above reasons, it is often of no benefit to specify a high strength material in a long column application. While the critical load (P_{cr}) in equation (2) is directly affected by material strength in addition to its modulus of elasticity. While strength is not a factor for a long column when Euler formula is used (Al-alkawi H. J. M. *et al*, 2014).

Finite Element description

Buckling loads are critical loads where certain types of structures become unstable. The buckling of column problem can be solved by Ansys program (version 11), after choice a suitable element which is BEAM3. This element is a uniaxial element with tension, compression, and bending capabilities. The element has three degrees of freedom at each node: translations in the nodal x and y directions and rotation about the nodal z-axis as shown in Fig. (1) shows the geometry, node locations, and the coordinate system for this element. The element is defined

Table. (2) Two known methods with the experimental reading

No.	L (mm)	SPT (min)	$P_{cr.}$(N) Exp.	δ_{cr}(mm) Exp.	$P_{cr.}$(N) Theory	$P_{cr.}$(N) Numerical	δ_{cr}(mm) Numerical
1	500	0	4946	5.4	5319.34	5332	4.3
2	500	15	5230	5.2	5449.04	5462	4.211
3	500	25	5440	5	5604.7	5618	4.152
4	500	30	5300	5.1	5397.14	5410	4.231
5	370	0	8831	3.7	9713.91	9737	2.7
6	370	15	9538	3.8	9950.83	9975	2.67
7	370	25	10032	3.5	10235.14	10260	2.63
8	370	30	9185	3.6	9856.1	9880	2.68
9	330	0	11304	3.3	12211.52	12241	2.29
10	330	15	12434	3.1	12509.27	12539	2.26
11	330	25	12717	3.1	12866.67	12898	2.226
12	330	30	12293	3.2	12390.13	12420	2.27
13	310	0	13424	3	13749.33	13871	2.1
14	310	15	14130	3.1	14113.87	14120	2.06
15	310	25	14483	3	14563.12	14616	2.03
16	310	30	14342	3.2	14041.34	14074	2.07
17	270	0	16250	2.7	16572.48	18286	1.7
18	270	15	17309	2.5	17094	18732	1.671
19	270	25	18369	2.6	17834.69	19267	1.65
20	270	30	17804	2.6	17392	18553	1.68
21	250	0	19076	2.7	17838.47	21329	1.51
22	250	15	19782	2.6	18431.44	21849	1.49
23	250	25	20277	2.5	19301.85	22473	1.47
24	250	30	19429	2.6	18895.76	21641	1.5

by two nodes, the cross-sectional area, the area moment of inertia, the height, and the material properties. It can be predicts the theoretical buckling strength of an ideal elastic structure by classical Euler buckling analysis. It computes the structural Eigen values for the given system loading and constraints.

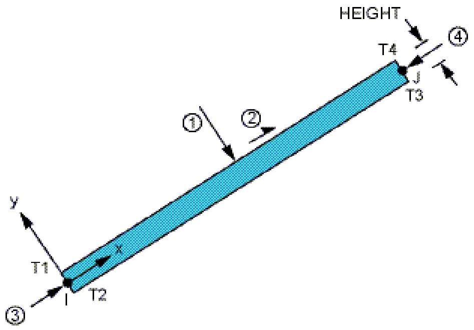


Fig (1): Beam element geometry and loading.

Experimental work

The material used was medium carbon steel alloy CK35 which is widely applied in industry materials. The chemical composition of the above material alloy is given elsewhere (Al-alkawi H. J. M. *et al*, 2014).

While shot peening device and all specimens manufacturing process was done in the General Company for Mechanical Industries in Al-Eskandria using CNC machine illustrated in (Al-alkawi H. J. M. *et al*, 2014).

In the other hand, the details of buckling test rig were described in (K. H. AL-Jubori, 2005).

Results and Discussion

Table (1) shows the properties of dynamic buckling test of columns obtained experimentally in laboratory have the geometry properties D=9mm & R=2.25mm, it can seen that the best time of shot peening was 25 min which gave the highest lives for long and intermediate columns, also the optimization improvement in buckling strength can be observed at this time. While above this time a slightly reduction in the buckling strength can be observed. This finding agreed well with the conclusion of (S. S. Murdhi, 2013) for stainless steel metal.

Table (2) shows the comparison of buckling properties between experimental results with theoretical solution and numerical analysis. It can be seen from this table that the difference of the results of P_{cr}between the theoretical and numerical, for intermediate columns, were more than that of long columns, that is because using Euler theory in the analysis for all types of columns (long and intermediate) in the numerical solution, while the Euler is valid for long column only and Johnson is more accurate for intermediate columns as finding theoretically.

Euler and Johnson methods have been shown to be satisfactory for predicating the critical buckling load at failure; for long and intermediate columns respectively; under different conditions of SPT compared with the experimental data.

Fig. (2) shows the comparison between experimental and numerical results. This comparison between buckling properties under different SPT; such as (0, 15, 25 & 30) min; can be observed a good agreement between experimental and numerical results.

Figures (3) & (4) show comparison between buckling force with deflection at failure for experimental and numerical analysis for intermediate and long column respectively.

It is clear from these figures (2), (3) & (4) the buckling occurs in the intermediate column required larger force at lower deflection from the long column according Euler and Johnson formulas. Figures (2), (3) & (4) show the numerical solution by Ansys program analysis gave good correlation with experimental results but so conservative due to ideal analysis for numerical solution and neglected the initial deflection of columns which obtained experimentally due to surface finish processes of the specimens.

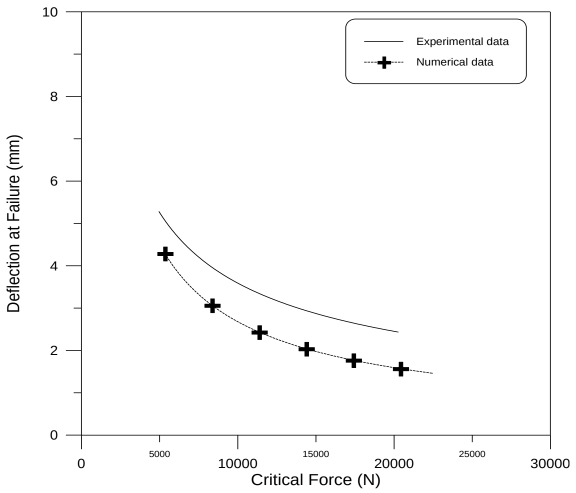
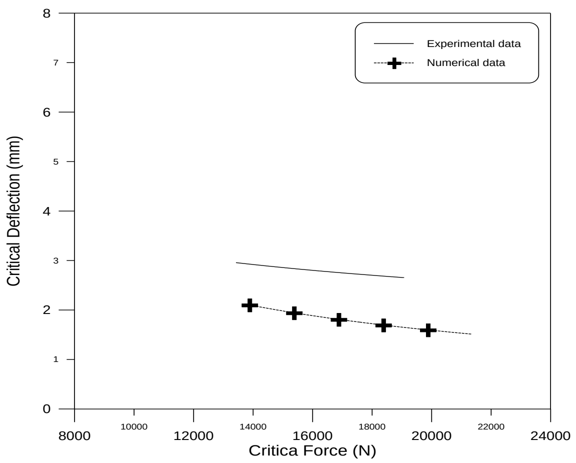
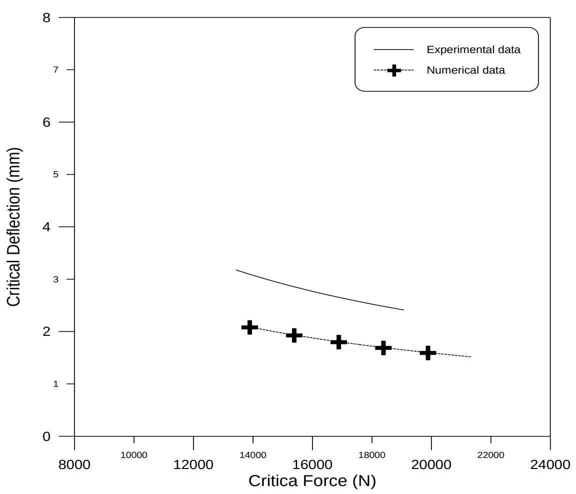


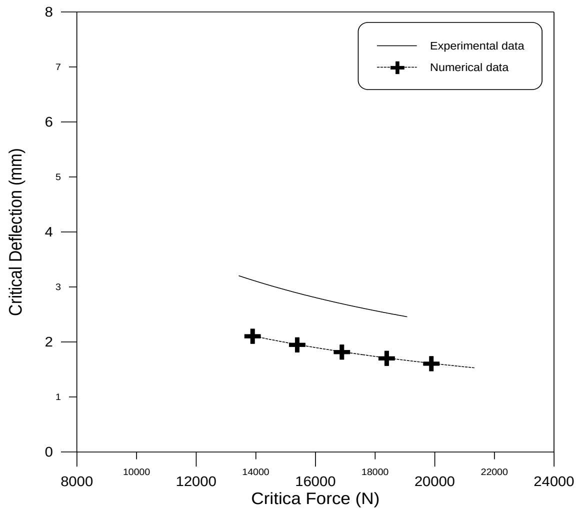
Fig. (2) Comparison between experimental, theoretical and modeling data for buckling force with deflection at failure.



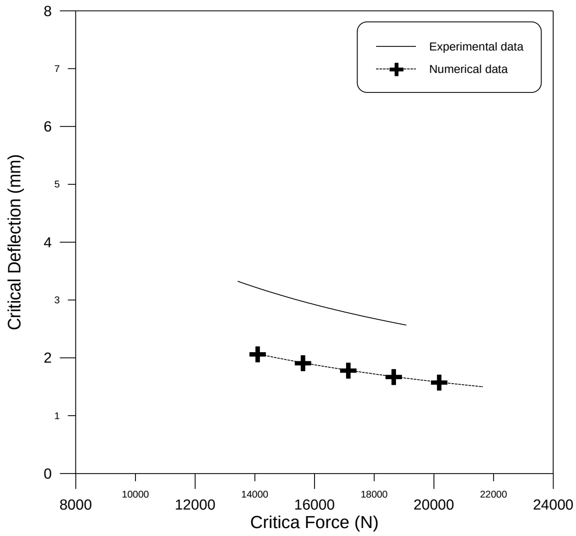
(a) SPT=0 min.



(b) SPT=15 min.

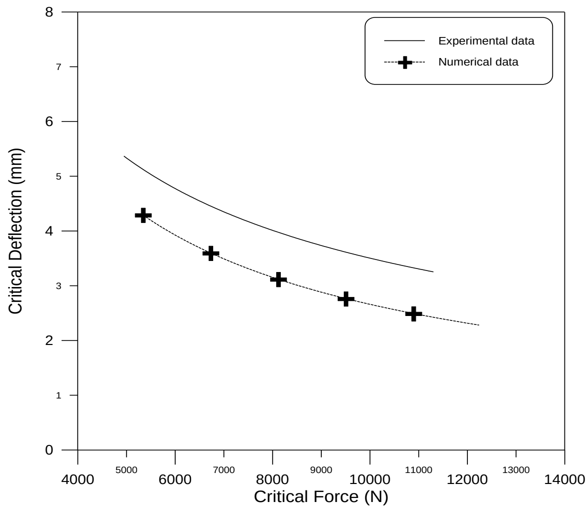


(c) SPT=25 min.

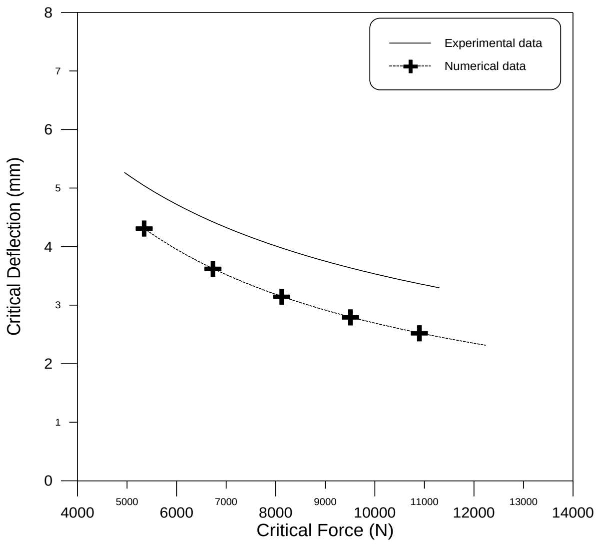


(d) SPT=30 min.

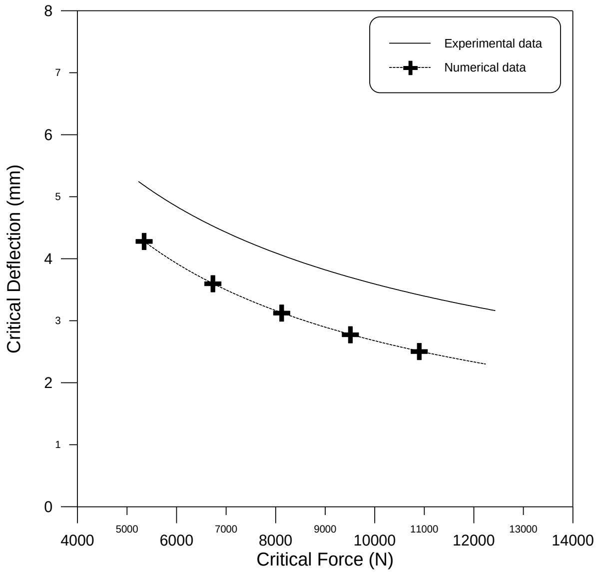
Fig. (3) Critical force with critical deflection for intermediate column.



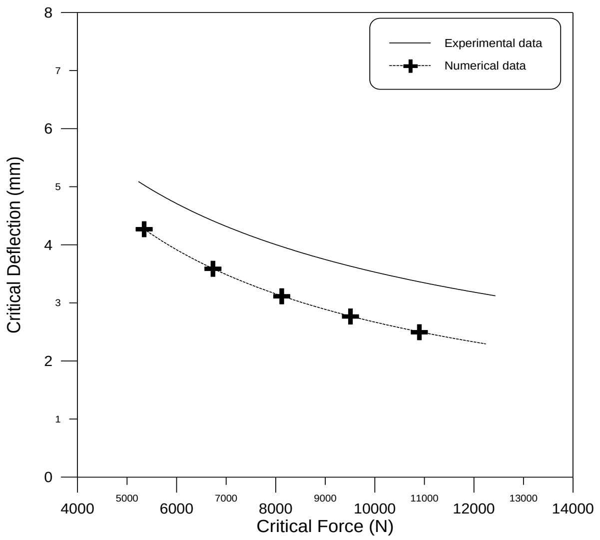
(a) SPT=0 min.



(b) SPT=15 min.



(c) SPT=25 min.



(d) SPT=30 min.

Fig. (4) Critical force with critical deflection for long column.

Fig. (5) shows the relationship between the buckling force and the number of cycles to failure for intermediate and long column, this figure shows the intermediate column required larger buckling force and higher number of cycles to failure, also this figure shows the long columns required less time to reach the failure by buckling because intermediate column stronger from long column.

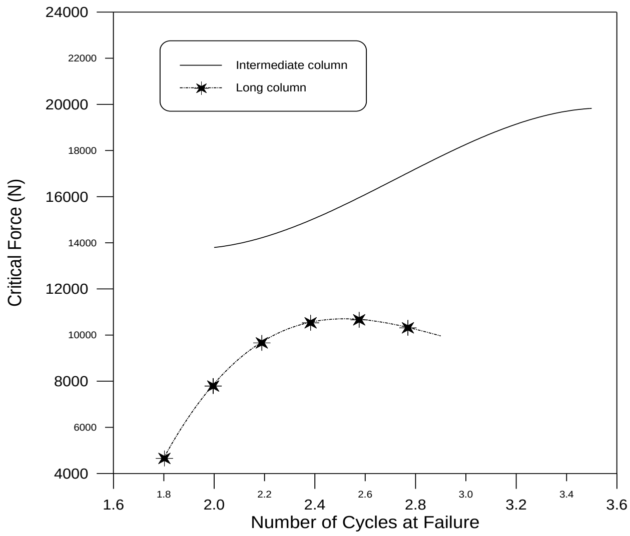


Fig. (5) Buckling force with number of cycles to failure for intermediate and long column.

Table (3) shows the comparison for buckling load between theoretical, numerical and experimental results and the percentage differences between them where

$$Icr\% = \frac{(experimental\ Load - theorical\ or\ numerical\ Load)}{experimental\ Load} * 100 \qquad (3)$$

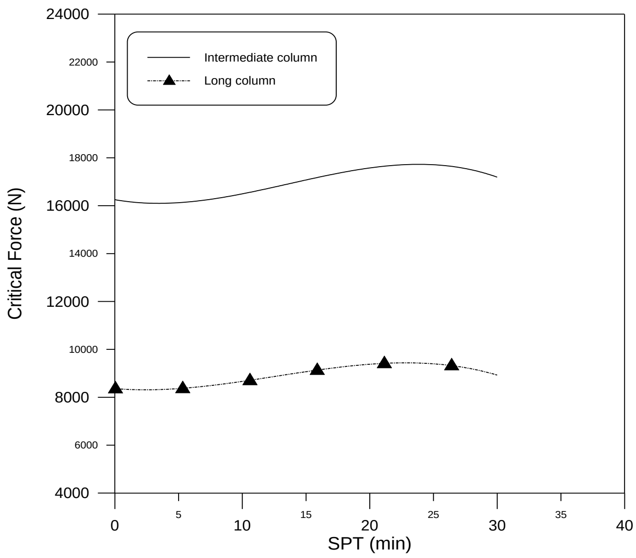
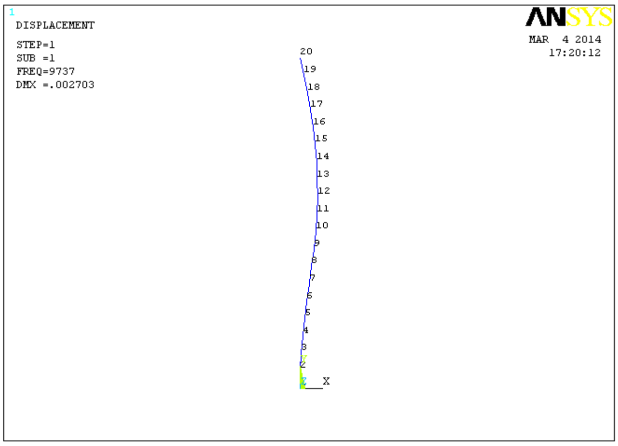


Fig. (6) Buckling force with shot peening time for intermediate and long column.

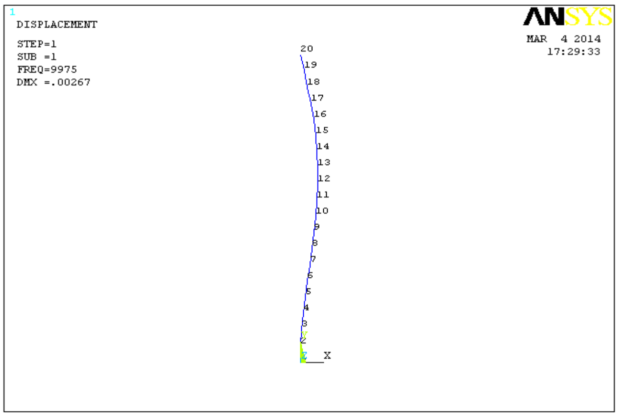
It is clear that, the (P_{cr}) theory (P_{cr}) numerical are always close to the experimental load (P_{cr}) experimental,. The percentage increase or decrease in (P_{cr}) is limited within (0-12)%.the difference could be related to the assumptions of Euler and Johnson formulas and the Ansys applications

Table (3) the difference between experimental with theoretical and modeling results

No.	L (mm)	SPT (min)	Pcr.(N) Exp.	Pcr.(N) Theory	Icr%	Pcr.(N) Numerical	Icr%
1	500	0	4946	5319.34	-7.54832	5332	-7.80429
2	500	15	5230	5449.04	-4.18815	5462	-4.43595
3	500	25	5440	5604.7	-3.02757	5618	-3.27206
4	500	30	5300	5397.14	-1.83283	5410	-2.07547
5	370	0	8831	9713.91	-9.99785	9737	-10.2593
6	370	15	9538	9950.83	-4.32827	9975	-4.58167
7	370	25	10032	10235.14	-2.02492	10260	-2.27273
8	370	30	9185	9856.1	-7.30648	9880	-7.56668
9	330	0	11304	12211.52	-8.02831	12241	-8.2891
10	330	15	12434	12509.27	-0.60536	12539	-0.84446
11	330	25	12717	12866.67	-1.17693	12898	-1.42329
12	330	30	12293	12390.13	-0.79012	12420	-1.03311
13	310	0	13424	13749.33	-2.4235	13871	-3.32986
14	310	15	14130	14113.87	0.114154	14120	0.070771
15	310	25	14483	14563.12	-0.5532	14616	-0.91832
16	310	30	14342	14041.34	2.09636	14074	1.868638
17	270	0	16250	16572.48	-1.98449	18286	-12.5292
18	270	15	17309	17094	1.242128	18732	-8.22116
19	270	25	18369	17834.69	2.908759	19267	-4.88867
20	270	30	17804	17392	2.314087	18553	-4.20692
21	250	0	19076	17838.47	6.487366	21329	-11.8107
22	250	15	19782	18431.44	6.827217	21849	-10.4489
23	250	25	20277	19301.85	4.809143	22473	-10.83
24	250	30	19429	18895.76	2.744557	21641	-11.385

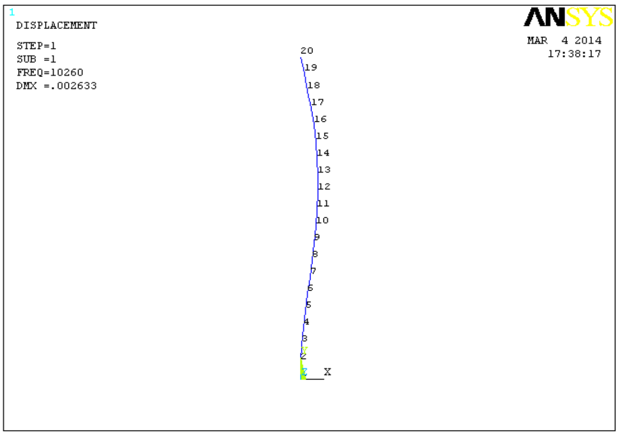


(a) SPT = 0 min.

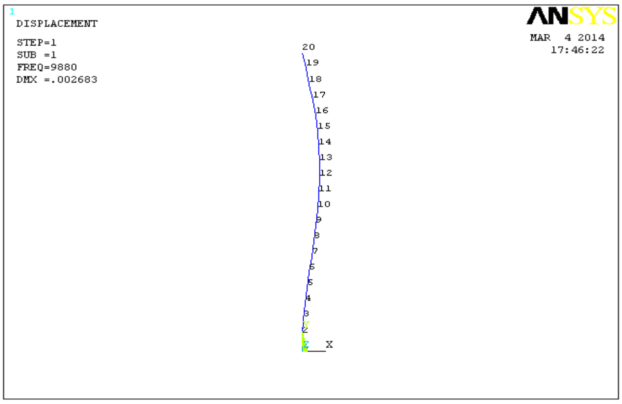


(b) SPT = 15 min.

Fig.(7 a, b) the deflection shape for fixed – hinged ends with different shot peening time.



(c) SPT = 25 min.



(d) SPT = 30 min.

Fig. (7 c, d) the deflection shape for fixed – hinged ends with different shot peening time.

and some error can be obtained in the experimental work. Also there are some difference between experimental and theoretical solutions, this because in the experimental solution may be find some defect and initial deflection due to surface finishing as shown previously, while in theoretical solution these problems not finding. Fig. (6) gives the relationship between buckling force and shot peening time for intermediate and long column, and this indicated for the same column material with the same shot peening conditions the buckling force was higher for intermediate column from long column and the maximum buckling resistance at 25 min SPT.

Fig. (7) gives the deflection shape for a column buckling with geometry properties where diameter=9mm & length=370mm for different shot peening time were 0min, 15min, 25min & 30min respectively, and the ends of column were fixed – hinged ends. This shows the critical deflection was decrease laterally with increase the shot peening time (SPT) until reach 25 min due to increase the strength of buckling, and this deflection increased when increase SPT above 25 min because of increase the roughness of surface layer of specimen and increasing the stress concentration regions at the surface of specimen. Finally, this figure shows that the failure occurs at first mode shape.

Conclusion

The following conclusions could be remarked from this study:

1. The best SPT was 25 min which gives higher resistance against buckling and increasing the buckling life at this time.
2. In buckling test, prediction the critical buckling load and critical deflection with the effect of different SPT ; which was (0, 15, 25, 30) min; had been studied experimentally, theoretically and numerically.
3. A good agreement between experimental and numerical results was obtained with no more of percentage difference of 12%.
4. The buckling failure occur at first mode shape.

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