Determination the Optimum Shot Peening Time for Improving the Buckling Behavior of Medium Carbon Steel

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ABSTRACT

The purpose of this paper is to estimate the optimum improvement of surface treatment on the dynamic buckling behavior of CK35 steel alloy due to shot peening based on the experimental results. Rotating circular column buckling test machine was used to evaluate the buckling life of column under compression and combined loading. The experimental results obtained show a favorable influence of shot peening treatment on mechanical properties and dynamic buckling behavior. A maximum significant life obtained at 25 min SPT (shot peening time) under dynamic buckling. The results showed that shot peening change the type of column from long to intermediate one based on Euler and Johnson formulas.

Keywords: Shot Peening Treatment, Dynamic Buckling, Columns, CK35 Steel Alloys.

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الخلاصة

هدف البحث هو لتحديد التحسين الأمثل للمعاملة السطحية بطريقة القذف بالكريات المسبق على تصرف الانبعاج الجانبي لسبيكة الفولاذ CK35 معتمدا على النتائج العملية. تم استخدام ماكنة فحص الانبعاج الجانبي الدوار لعمود دائري المقطع لتقييم عمر الانبعاج للمركب تحت الحمل ألانضغاطي. حيث أن النتائج العملية المستخرجة أوضحت تأثير قيم معاملة القذف بالكريات على الخواص الميكانيكية وتصرف الانبعاج الجانبي الديناميكي. لوحظ الحصول على أعلى عمر اشتغال تحت تأثير الانبعاج الديناميكي كان عند زمن تصليد بالقذف بالكريات هو 25min. اظهرت النتائج بان السفع بالكريات غيرت العمود من طويل إلى متوسط استنادا لنظريتي اويلر وجونسن.

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Nomenclature	Definition	Units
A	cross – sectional area	mm2
C_c	Column's constant	
D	Diameter of column	mm
E	Modulus of elasticity	GPa
G	Modulus of rigidity	GPa
I	Moment of inertia of cross section	mm4
I%	improvement percentage in strength	
k	Hardness constant	MPa
K	End condition coefficient	
L	Length of column	mm
L_{eff}	Effective length of column	mm
N	Hardness index	
Nf	Number of cycle before failure	Cycle
R	Radius of gyration	mm
Ra	Roughness parameter	µm
Rt	Roughness parameter	µm
SPT	Shot peening time	Min
S.R.	Slenderness ratio	
σult	Ultimate stress	MPa
σy	Yield stress	MPa

INTRODUCTION

The structure or member fails by yielding of material when a load is greater than the yield load of a given material. This is a fact for shorts members or bars. But if the bar is long (strut), the failure becomes from buckling phenomena or elastic instability. The strut (column) deflected drastically at a certain critical load and then collapses suddenly [1]. Thus, a column fails by buckling at a load lower than the yield load of the column material. The objective of column analysis methods is to estimate the load or stress at which a column would become unstable and buckle [2]. A strut may be horizontal, inclined or vertical. But a vertical strut is known as a column. The machine members that must be investigated for column action are piston rods, valve push rods, connecting rods, screw jack, side links of toggle jack, etc. [3]. 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 is by using 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 etc. [4][5]. 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. The effects of shot peening on fatigue strength have been studied quantitatively and reported in the literature [6]. Donzella et. al. [7] proposed the effect of shot peening treatment on Sintered steels plates were analyzed in terms of micro-structural and mechanical properties and residual stress profiles, residual stresses after the treatment were measured by means of the hole drilling technique and related to the mechanical properties and the surface densification of both steels, varying the nominal density. The obtained results showed the presence of the principal residual stresses for each specimen, there were expected in shot-peened components. G.H. Majzoobi et. al. [8] used a numerical simulations; which was LS-DYNA finite element code; the modelling of shot peening process was accomplished by simulation of multiple shot impacts on a target plate at different velocities, the results showed that, residual stress distribution was highly dependent on impact velocity and multiplicity, impact velocity significantly influenced the residual stress profile, and the increase of velocity improved the residual stress distribution up to a particular point. On the other hand, they showed that the increase in the velocity may reduce the maximum residual stress. Also Ref. [8] showed that when the reducing the shooting velocity it will be reduced the peek residual stresses.
However, only a few investigations have considered the effects of shot peening on dynamic buckling loads and lives. This paper examines the effect of shot peening on the dynamic buckling of columns subjected to compression and compression-bending loads, of medium carbon steel (CK35) material by series of columns with and without shot peening at different times.

THEORY

Euler and Johnson formulas

For long columns, Euler equation can be used to determine the critical load as [9]:

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

It is clear that the critical buckling load (Pcr) is not dependent on the mechanical properties of the material except the modulus of elasticity. But the critical load is directly depend 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 [10]. For intermediate column, when the slenderness ratio (S.R.=Leff/rmin) is less than the column constant ($C_c = \sqrt{\frac{2\pi^2 E}{\sigma_y}}$), then the column is intermediate and Johnson formula can be applied. This formula may be written as [11]

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

The critical load (Pcr) 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.

EXPERIMENTAL WORK

Material

The material used in this work was a rod of CK35 steel alloy. This alloy is widely used in many applications where better properties than those for mild steel are required. Some typical examples are in the manufacture of connecting rods and railway couplings [1]. During the manufacture of the specimens, carefully lathe controlled was performed to produce a good surface finish and to minimize tensile residual stresses at the surfaces due to machining. The material was received as a rod of 3m in length and 12mm in diameter. The chemical composition of the steel alloy; tested in engineering centre for testing and recondition in Al-Saydiyah; is listed in Table (1) and the relevant mechanical properties; tested in University of technology at room temperature (25Co); in Table (2).

BUCKLING SPECIMEN PREPARATION

Buckling specimens (columns) with different slenderness ratio (S.R.=Le/r) were chosen for the present test program. It was designed to use different slenderness ratio (S.R.) to differnate between intermediate and long buckling columns behaviour. Table (3) gives the main buckling parameters with the buckling specimens dimensions as D=9mm, r=2.25mm, I=322.06mm4 and A=63.62mm2. The critical load is estimated according to Euler formula for the long column, while for intermediate is estimated according to Johnson formula. Table (4) shows the S.R. with the column constant (Cc) for all the buckling specimens used.

DYNAMIC BUCKLING TEST RIG

Figure (1) illustrates the main systems which are torsion, compression and bending. These systems operate simultaneously or alone. The high speed is 34 r.p.m. (0.567Hz) and low speed of 17 r.p.m. (0.284Hz). The counter which measures the number of turn with 9999.9 digits. More details about the test rig can be found in Refs.[1, 12].

Failure definition

Under the controlled load, failure may be defined as the instance when the specimen deformed laterally to about (1%) of specimen effective length, i.e. the total laterally deflection (δ_{final} =1% of the effective length) [12].

Shot peening technique

To improve the surface characteristics of components, the control of the surface residual stress is of almost importance. The shot peening technique has been extensively applied in the industry for this purpose [13]. The details of shot peening process are given in Table (5).

All the shot peening tests were carried out at the Institute of Technology of Alsaklawaya.

RESULTS AND DISCUSSION

Tensile results under different shot peening time (SPT)

Figure (2) shows the value of yield stresses and ultimate stresses for different shot peening time (SPT). It is clear that, increasing the SPT will increase the ultimate stress (σult) and yield stress (σy) up to 25 SPT and then this value is reduced because of the reducing in hardness and increasing in surface roughness according to Ref. [14]. Table (6) gives the σult and σy with the improvement percentage, I%.

Based on the above results, in Table (6), the best improvement percentage in tensile and yield stresses are appeared at (25 SPT). In general, it is well known that the shot peening treatment produces an increasing in surface hardness at the surface layers of the surface specimens. Increasing the surface hardness up to 25 min SPT creates a compressive residual stresses on the surface, usually improves the strength and resistance of the dynamic column buckling. The reason of this phenomena is that the compressive residual stress field can significantly decrease the crack growth rate at the surface and therefore inherently causing the life extension of shot peening column.

Dynamic shot peening buckling column results

Table (7) presents the conditions of shot peening time, slenderness ratio and column constant for 25 columns tested under compression and combined loading. It is clear that, after shot peening, the buckling performance is increased clearly in the 25min SPT but no further improvement in the buckling behavior is observed in 30min SPT and 35min SPT. The roughness increase gradually with increasing the SPT as shown in Table (8).

The above data are an average of eight readings, the surface hardness was increasing proportionally with SPT, because of the amount of cold working and plastic deformation of the metal surface. This finding was in good agreement with Ref. [15]. It may be concluded that the improvement in buckling behavior exhibited by the shot peening specimens (columns) is attributed to an increase in hardness at the surface and compressive residual stress layer. It is possible to observe in Figure (3) that greater life occurred at 25min SPT in which the max compressive stress happened at this time of shot peening, after that the hardness of the surface slightly tends to reduce. It is clear that the compressive residual stress on the surface is also function of the shot used. In addition to that, the life of specimen was very small when applied combined stress compared to that life when applied compression stress only.

For a given slenderness ratio, the best SPT is 25 min. as shown in Figure (4). Shot peening greatly increases the life of columns subjected to dynamic buckling. This beneficial effect is attributed to the compressive residual stresses induced by shot peening in the surface layer. After 25 min SPT the life of the column is reduced as shown in Figure (3) and Figure (4). Shot peening may change the type of column based on the Johnson formula in which yield stress plays a major role in this formula. Columns classify as intermediate after shot peening treatment as shown in Table (7). It is clear that, column No. 20 changed from intermediate to long because shot peening increase the yield stress which in terms reduces the column constant Cc leads to become long column.

CONCLUSIONS

In this work, the effect of shot peening on dynamic buckling performance was investigated on CK-35 and the following conclusions can be drawn

1. Shot peening increases the ultimate and yield stresses improvement percentage and the max. improvement percentage was occurred at 25 min SPT as 9.75% and 12.12% respectively.

2. A significant improvement was appeared in dynamic buckling due to shot peening at 25 min SPT After that the improvement tends to be reduced.
3. The hardness and surface roughness were increased proportionally with the SPT up to 25 min SPT.
4. Shot peening may change the type of column to become long while it was intermediate before shot peening.
5. When Cc is greater than S.R., the Johnson formula is valid and the column is intermediate, while when S.R. is greater than Cc, the Euler formula is valid and the column is long.

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Table (1) Chemical Compositions of CK35 Steel Alloy (wt%).

CK35	C	Mn	Si	S	P
Standard (DIN50114)	0.32-0.39	0.5-0.8	0.15-0.35	0.035	0.035
Experimental	0.33	0.75	0.25	0.024	0.013

Table (2) Mechanical Properties of CK35 steel alloy.

CK35	σult (MPa)	σy (MPa)	E (GPa)	G (GPa)	Poi. ratio (μ)	N	k
Standard (DIN50114)	550-700	<392	201	79	0.3	0.5	590
Experimental	660	400	205	80	0.28	0.4	580

Table (3) Dimensions of specimen with type of loading.

No	L(mm)	Leff*(mm)	S.R.	type of loading **
1	270	189	84	Combined
2	270	189	84	Combined
3	270	189	84	Combined
4	270	189	84	Combined
5	270	189	84	Combined
6	170	119	52.89	Combined
7	170	119	52.89	Combined
8	170	119	52.89	Combined
9	230	161	71.55	Compression
10	230	161	71.55	Compression
11	230	161	71.55	Compression
12	230	161	71.55	Compression
13	230	161	71.55	Compression
14	150	105	46.67	Compression
15	150	105	46.67	Compression
16	150	105	46.67	Compression
17	300	210	93.34	Compression
18	300	210	93.34	Compression
19	300	210	93.34	Compression
20	330	231	102.67	Compression
21	330	231	102.67	Compression
22	330	231	102.67	Compression
23	340	238	105.78	Compression
24	340	238	105.78	Compression
25	340	238	105.78	Compression

* Leff was concluded by Leff=K*L where K is the end condition coefficient; which was fixed-pinned ends; it is equal to 0.7. **Combined means compression and bending loads.

Table (4) Slenderness ratio (S.R.) in comparison with the column constant (Cc).

No.	S.R.	Cc	Type of column
1	84	100.6	Intermediate
2	84	98.6	Intermediate
3	84	95.7	Intermediate
4	84	96	Intermediate
5	84	97.7	Intermediate
6	52.89	100.6	Intermediate
7	52.89	98.6	Intermediate
8	52.89	95.7	Intermediate
9	71.55	100.6	Intermediate
10	71.55	98.6	Intermediate
11	71.55	95.7	Intermediate
12	71.55	96	Intermediate
13	71.55	97.7	Intermediate
14	46.67	100.6	Intermediate
15	46.67	98.6	Intermediate
16	46.67	95.7	Intermediate
17	93.34	100.6	Intermediate
18	93.34	98.6	Intermediate
19	93.34	95.7	Intermediate
20	102.67	100.6	Long
21	102.67	98.6	Long
22	102.67	95.7	Long
23	105.78	100.6	Long
24	105.78	98.6	Long
25	105.78	95.7	Long

Table (5) Main parameters of shot peening technique used.

Ball steel size (mm)	Standoff distance (mm)	Ball hardness Hv	Average blasting press. Bar	Ball speed m/s	Coverage
1	100	48-50	12	40	100%

Table (6) Illustrates the values of σult and σy for different SPT.

SPT (min)	σy (MPa)	σult (MPa)	I% in σy	I% in σult
0	400	660	--------	--------
5	410	679	2.5	2.87
10	416	691	4	5.16
15	416	707	4	7.12
20	438	721	9.5	9.24
25	442	740	10.5	12.12
30	439	733	9.75	11.06
35	424	702	6	6.36

Table (7) Dynamic shot peening buckling column results.

Specimen No.	SPT min)	S.R.	Cc	Nf (cycle)
1	0	84	100.6	73
2	15	84	98.6	99
3	25	84	95.7	131
4	30	84	96	109
5	35	84	97.7	82
6	0	52.89	100.6	92
7	15	52.89	98.6	121
8	25	52.89	95.7	162
9	0	71.55	100.6	232
10	15	71.55	98.6	271
11	25	71.55	95.7	321
12	30	71.55	96	318
13	35	71.55	97.7	271
14	0	46.67	100.6	309
15	15	46.67	98.6	348
16	25	46.67	95.7	385
17	0	93.34	100.6	102
18	15	93.34	98.6	132
19	25	93.34	95.7	159
20	0	102.67	100.6	82
21	15	102.67	98.6	117
22	25	102.67	95.7	135
23	0	105.78	100.6	77
24	15	105.78	98.6	105
25	25	105.78	95.7	129

Table (8) The values of the roughness and hardness for different SPT.

SPT (min)	Ra(μm)	Rt(μm)	Hardness(HRC)
0	0.554	5.207	17
5	2.189	10.643	18
10	2.87	12.41	21
15	3.196	14.68	23
20	2.291	12.173	24
25	2.466	12.817	25
30	2.885	13.36	23
35	3.367	14.69	20

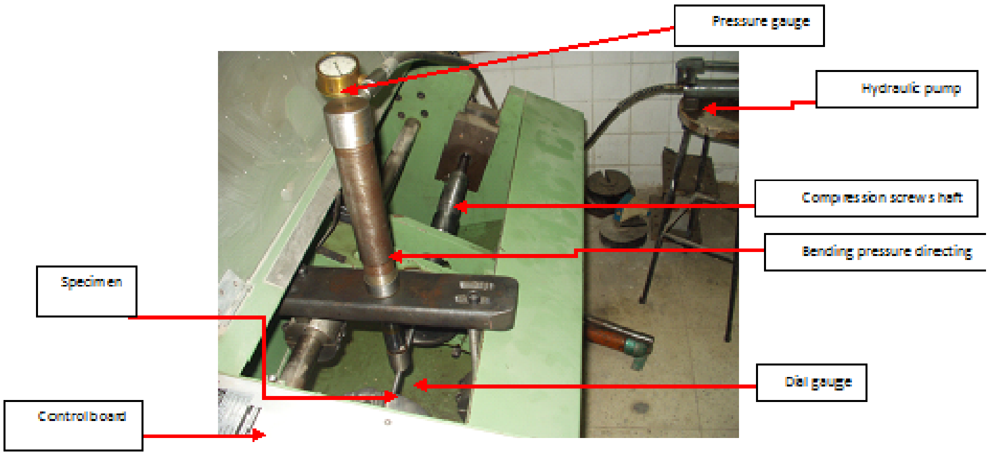

Figure (1) the dynamic buckling test rig.

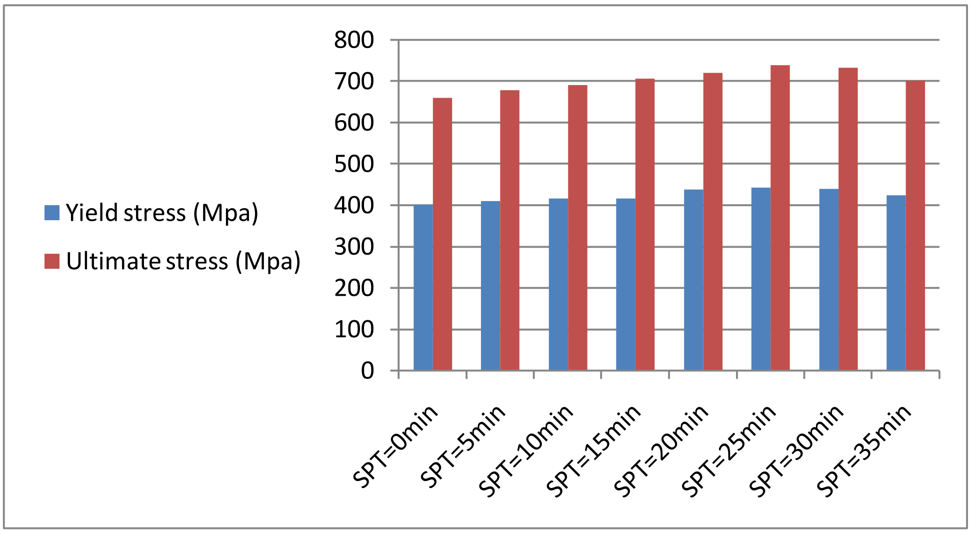

Figure (2) Yield and ultimate stresses for different shot peening time.

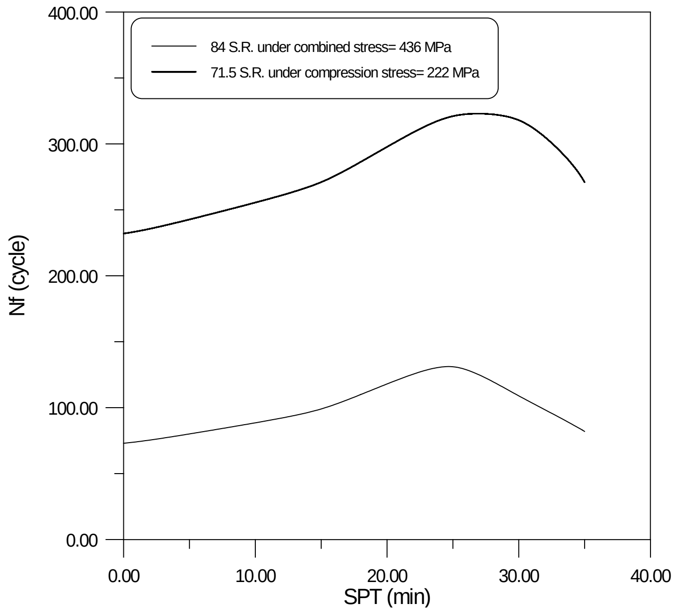

Figure (3) SPT against buckling life.

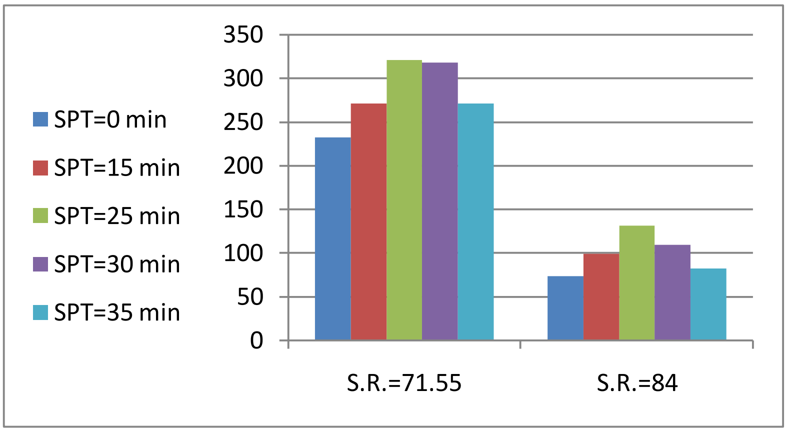

Figure (4) The buckling life (cycles) under different SPT for two type of slenderness ratios.