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Influence of Shot Peening on 70/30 Brass Residual Stresses Using Plasticity Theory

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Abstract

Residual stresses play an important role in the behavior of structures subjected to static and dynamic loads. The main aim of this study is to estimate experimentally the residual stresses in 70/30 brass material tested in bending and torsion using the plasticity theory. The influence of shot peening process on the tensile residual stresses is discussed. It is shown that the shot peening strongly influences the residual stresses, i.e. shot peening will reduce the tensile residual stresses by 13.6% of the yield strength in bending tests. While will reduce the tensile residual stresses by 22% of shear yield stress in torsion tests.

Keywords: 70/30 brass material, residual stresses, shot peening, plasticity theory

تأثير القذف بالكريات على الاجهادات المتبقية لسبيكة البراص 30/70 باستخدام نظرية اللدونة

الخلاصة

الاجهادات المتبقية تلعب دورا مهماً في تصرف التراكيب المسلط عليها أحمال ثابتة ومتحركة. الهدف الرئيسي من هذه الدراسة هو تقييم الاجهادات المتبقية عملياً في مادة البراص 70/30 تمت فحوصات الانحناء والالتواء باستخدام نظرية اللدونة. تأثير عملية القذف بالكريات على الاجهادات المتبقية تمت مناقشته . حيث تمت ملاحظة بأن القذف يالكريات سوف يؤثر على الاجهادات المتبقية بشكل ملحوظ وهذا يعني إن القذف بالكريات سوف يقلل من الاجهادات المتبقية الشدية بنسبة 13.6% نسبة لاجهاد الخضوع في فحوصات الانحناء بينما سوف يقلل هذه الاجهادات المتبقية الشدية بنسبة 22% من إجهاد الخضوع القصي في فحوصات الالتواء

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Introduction

Mechanical surface treatments such as shot peening is commonly used in industrial application to improve the mechanical properties and fatigue behavior. This treatment lead to surface layer properties of the work piece different from those in the bulk, for example , the yield stress in near-surface regions increase, due to cold work and resulting high dislocation densities [1].

Brass is widely used in industry for fabrication of structural components, in which strength and toughness are important design requirements. It features good performance when under cyclic loads, retaining good fatigue strength while developing high tensile strength in heat treated condition. One of the most used techniques to improve surface fatigue strength under such conditions is to create a compressive residual stresses. Researches have been developed in recent years showing that coatings with materials like nickel, chromium, tungsten carbide, Zn-Ni, Zn-Co and Zn-Fe are effective to increase the residual stresses, wear and corrosion resistance of aeronautical components [2 – 8].

Therefore, the use of effective methods to improve fatigue strength must be considered [4]. One of the known ways to improve mechanical properties and fatigue resistance is by using the shot peening process to induce compressive residual stress in the surface layers, making propagation of cracks originated in ferrous and nonferrous materials [9]. The compressive residual stress is obtained due to surface plastic deformation and is responsible for increasing the strength in mechanical components. Usually, fatigue cracks nucleate and propagate from the surface due to surface texture and defects like stretches, but Torres and Voorwald [5] presented some cracks nucleation originated in sub surface layers, under the compressive residual stress field due to shot peening treatment, indicating that such stress acts as a barrier to crack propagation. The compressive residual stress field induced by shot peening is dependent on various parameters like shot intensity, stream energy, shot material and dimensions.

The objective of this paper is to study the evaluation of residual stresses in shot peened and unshot peened brass specimens subjected to bending and torsion tests using the plasticity theory.

Experimental Procedures

This investigation is performed on 70/30 brass, tensile test were performed on shot and unshot cylindrical specimens having gage length and diameter of 100 mm and 19 mm, respectively. Tensile properties are listed in table (1), while torsion properties are given in table (2).

Figure (1) and (2) show the behavior of 70/30 brass material in tension and torsion for shoted and unshoted specimen.

After machining the gauge length of all specimens are polished to become smooth surface (0.5 μm) and then shoted. The details of shot peening are described elsewhere. [1]

Residual Stresses Evaluation Using Plasticity Theory (Tension test)

Figure (3) shows the concept of plasticity theory using tensile test showing elastic unloading process from any load conditions. The details of this theory are given elsewhere [10].

When materials are loaded beyond the yield point the resulting deformation does not disappear completely when load is removed and the material is subjected to permanent deformation. When beams are subjected to moments will produce partial plasticity, i.e., part of the beam section remains elastic whilst the outer fibers yield, this permanent deformation associated with the yielded areas prevents those parts of material which are elastically stressed from returning to their unstressed state when load is removed. Residual stresses are therefore produced. In order to determine the magnitude of these residual stresses, it is normally assumed that the unloading process, from either partially plastic or fully plastic states, is completely elastic as shown in Fig. (4)

Figure (5) shows the brass specimens tested under bending for initial yield load p = 14.66 kN, L = 0.5 m, h = 0.05 m and d = 0.025 m.

Residual Stresses Evaluation Using Plasticity Theory (Torsion)

The method of treatment of shafts subjected to torques sufficient to initiate yielding of the material is similar to that used for plastic bending of beams. It is usual to assume a stress-strain curve for the shaft material of the form shown in Fig.(6)

Results and Discussion

Plasticity theory application (bending tests)

Fig.(5) shows a rectangular beam loaded until the yield stress has just been reached in the outer fibres. The beam is still completely elastic and the bending theory applies

$$M_E = \frac{bh^3}{6}\sigma_y \qquad \text{....... (1)}$$

Where M_E: elastic bending moment

σ_y : yield stress in tension

b, h : beam section dimensions

If loading is then increased, it is assumed that instead of the stress at the outside increasing still further, more and more of the section reaches the yield stress σ_y

Partially plastic moment (M_{pp}) see Fig. (4-b)

$$M_{PP} = \frac{b\sigma_y}{12}\left[3h^2 - h_1^2\right] \quad \text{.. (2)}$$

When loading been continued until collapse, the bending moment required to produce this fully plastic state can be obtained from the following equation, since h_1 is then zero

Fully plastic bending moment,

$$M_{FP} = \frac{bh^2\sigma_y}{4} \qquad \text{... . (3)}$$

Table (3) shows the results of depth of plasticity and residual stress according to plastic theory for shoted and unshoted beam specimens

Table (3) and Fig.(9) shows the variation of tensile residual stress at the surface with the partially plastic moment. The magnitude of the residual stress on the surface is of the order 4.288 to 64.38 Mpa for the unshoted brass specimens or about 2.436- 37 % of the 70/30 yield strength of the 176 Mpa. While the magnitude of residual stress is of the order 4.326 to 40.384 Mpa for the shoted brass specimens or about 2.47-23% .Table (4) gives the results of unshoted and shoted brass specimens

Plasticity theory application (Torsion test)

Consider, the cross-section of the shaft shown in Fig.(6) with its associated shear stress distribution. Whilst the shaft remain elastic, the latter remains linear , as the torque increases the shear stress in the outer fibers will eventually reach the yield stress in shear of the material τ_y. The torque at this point will be the maximum that the shaft can withstand whilst it is completely elastic.

From the torsion theory

$$T_E = \frac{\pi R^3}{2} \tau_y \qquad \text{........ (4)}$$

Where T_E: elastic torque
R : radius of the shaft
τ_y : yield stress in shear

Therefore partially plastic torque

$$T_{PP} = \frac{p\ t_y}{6}\left[3R^3 - R_1^3\right] \qquad \text{....(5)}$$

Where T_{PP}: partially plastic torque
R_1: radius of elastic portion

The torque has now been increased until the whole cross-section has yielded, i.e., become plastic. The torque required to reach this situation is then easily determined from equation (5) since $R_1 = 0$

Fully plastic torque

$$T_{FP} = \frac{2p}{3} R^3 t_y \qquad \text{....(6)}$$

Table (4) and Fig.(10) present residual stresses resulting from the torsion test for unshoted and shoted brass shafts (specimens). The residual stress is shown as a function of the depth of plasticity shaft. Results are interesting, and show large tensile residual stresses, reaching nearly 32 Mpa or about 32% of the yield strength of 100 Mpa for the unshoted brass specimens. The residual stresses are of the order 3.798 to 32.1 Mpa for the unshoted material while the residual stresses are of the order 0.67 to 10.106 Mpa, or about 0.67% to 10 % of the typical shear yield strength for shoted specimen.

Conclusions

1- surface tensile residual stresses of about 65 Mpa (9.47 ksi) are present for unshoted 70/30 brass material tested in bending.
2- The above surface tensile residual stresses are reduced to 41 Mpa (5.97 ksi) for shoted 70/30 brass material in bending.
3- Shot peening will reduce the tensile residual stresses by 13.6% of the 70/30 typical yield strength of 176 Mpa.
4- Surface tensile residual stresses of about 132.1 Mpa (4.679 ksi) are present for 70/30 brass material rested in torsion.
5- Surface tensile residual stresses of about 10.106 Mpa (1.473 ksi) are present for shoted 70/30 brass material.
6- Shot peening will reduce the tensile residual stresses by

22% of the brass shear yield stress of 100 Mpa.

Acknowledgment

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Table (1) Mechanical properties of brass specimen in tension

Mechanical properties	Unshoted	Shoted
Modulus of elasticity (Gpa).	116	130
Percentage elongation (%)	21	20
Percentage reduction in area %	24.7	23
Nominal stress at fracture Mpa.	247	261
Actual stress at fracture Mpa	328	362
Ultimate stress Mpa (σu)	289	332
Yield stress Mpa (σy)	176	200
Poisson's Ratio	0.25	0.25
Modulus of rigidity (Gpa).	46.5	53

Table (2) Mechanical properties of brass in torsion.

	Shear yield stress (τy) Mpa	Ultimate shear stress (τu) Mpa
Unshoted	100	165
Shoted	122	190

Table (3) Depth of plasticity and residual stress according to plastic theory in bending.

P (KN)	14.66	15	15.5	16	17	18	20
M_{pp} (N.m)	1833	1875	1937	2000	2125	2250	2500
h1 (unshoted) (mm)	-	48.8	47	45.2	41.3	36.93	26.11
h_1 (shoted) (mm)	-	-	-	-	48.89	45.82	38.72
R.S unshoted (Mpa)	-	4.28	10.3	16.3	28.33	40.35	64.38
R.S shoted (Mpa)	-	-	-	-	4.32	16.34	40.38
Depth of plasticicity (unshoted) (mm)	-	1.2	3	4.77	8.7	13.07	23.88
Depth of plasticicity (shoted) (mm)	-	-	-	-	1.102	4.175	11.27

Table (4) Results of unshoted and shoted shaft brass specimens

T_{PP} (N.m)	530	550	600	650	680	700
R_1 (unshoted) (mm)	-	14.4	12.67	10.25	7.97	5
R_1 (shoted) (mm)	-	-	-	14.91	14.17	13.63
R.S unshoted (Mpa)	-	3.79	13.23	22.67	28.33	32.1
R.S shoted (Mpa)	-	-	-	0.67	6.33	10.10
Depth of plasticicity (unshoted) (mm)	-	1.2	4.65	9.48	14.05	20
Depth of plasticicity (shoted) (mm)	-	-	-	0.164	1.646	2.724

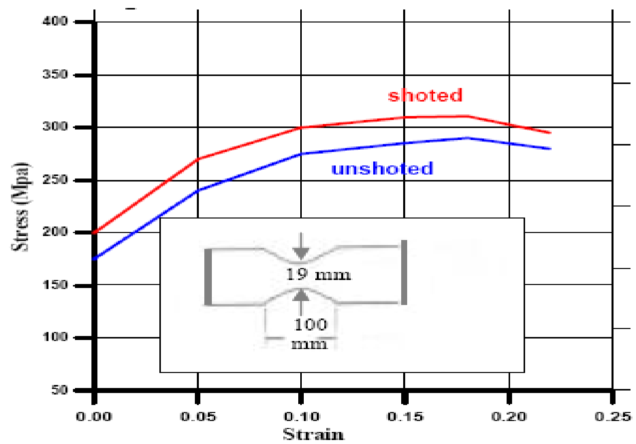

Figure (1) stress – strain diagram for brass material (Tensile test) for shoted and unshoted specimens.

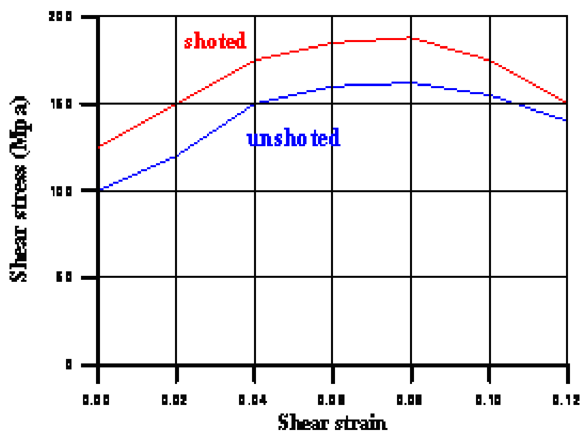

Figure (2) Shear stress against shear strain (Torsion test) for shoted and unshoted specimens.

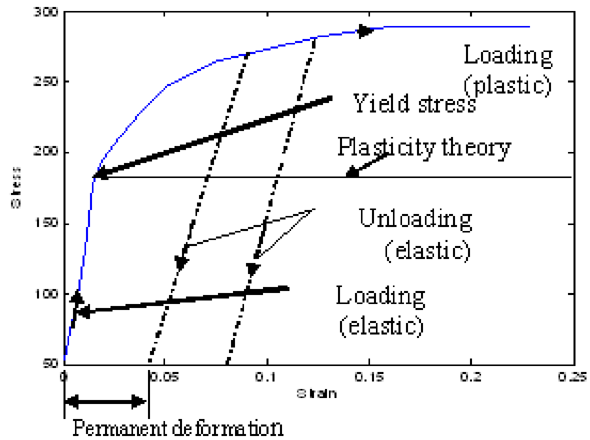

Figure (3) Tensile test stress – strain curve showing elastic unloading process from any load condition [10].

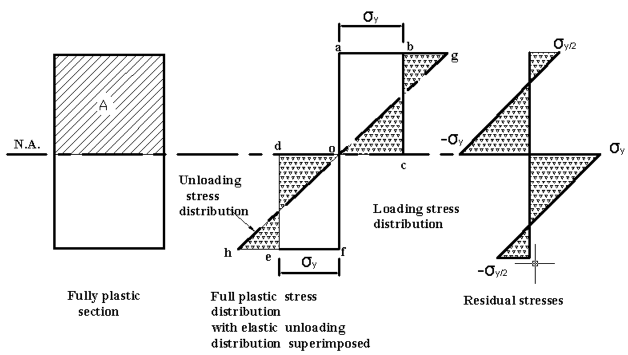

Fig.(4-a).Residual stresses produced after unloading a rectangular-section beam from a fully plastic state.[10]

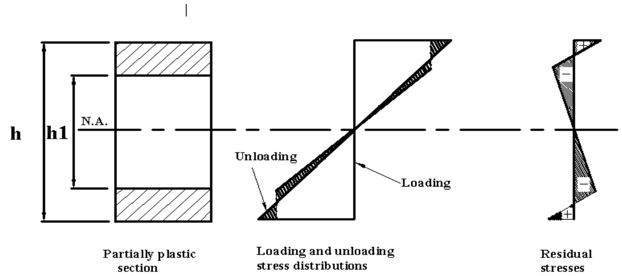

Fig.(4-b).Residual stresses produced after unloading a rectangular-section beam from a partially plastic state.[10]

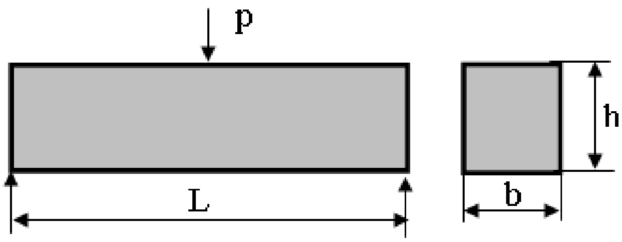

Figure (5) Brass specimen under bending .

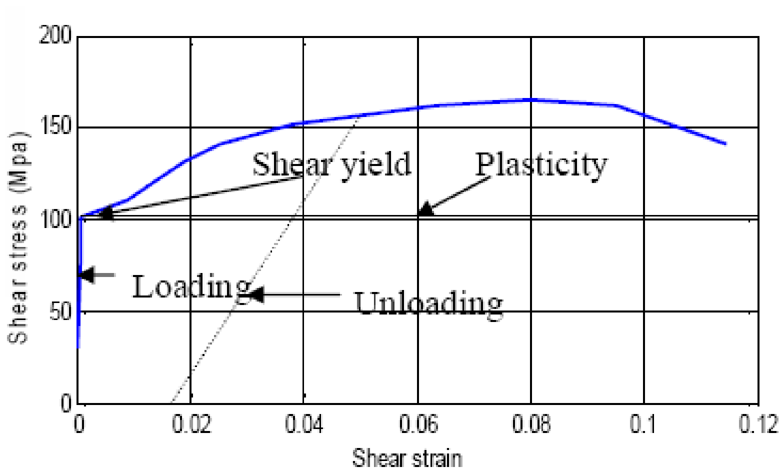

Figure (6) Plastic torsion of a circular shaft [10]

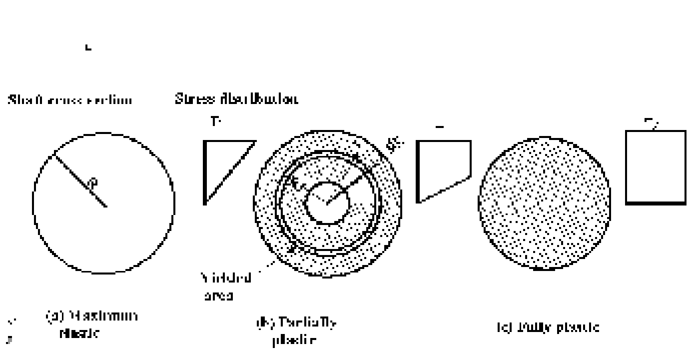

Figure (7) Shear stress against shear strain (Torsion test).

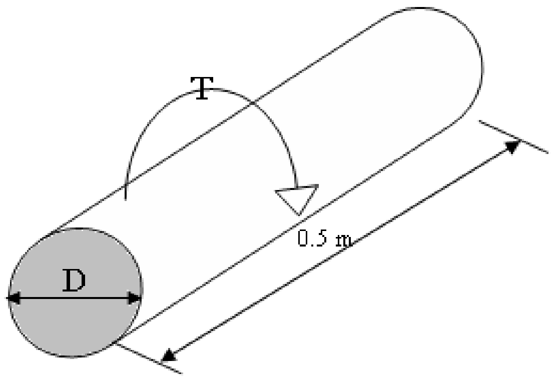

Figure (8) Brass shaft specimen in torsion .

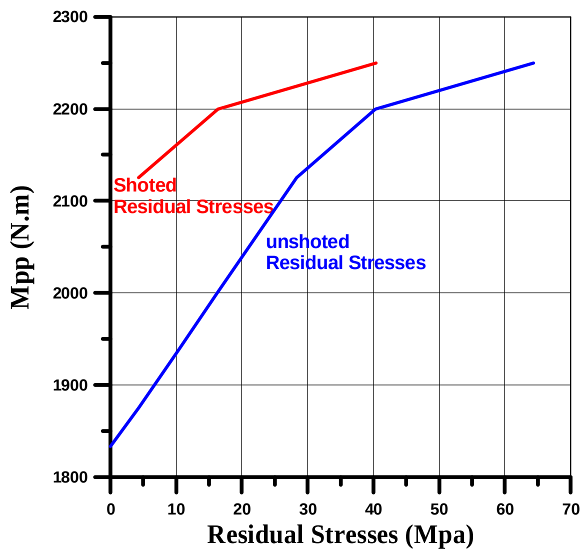

Figure (9) Shot peening effect on residual Stresses

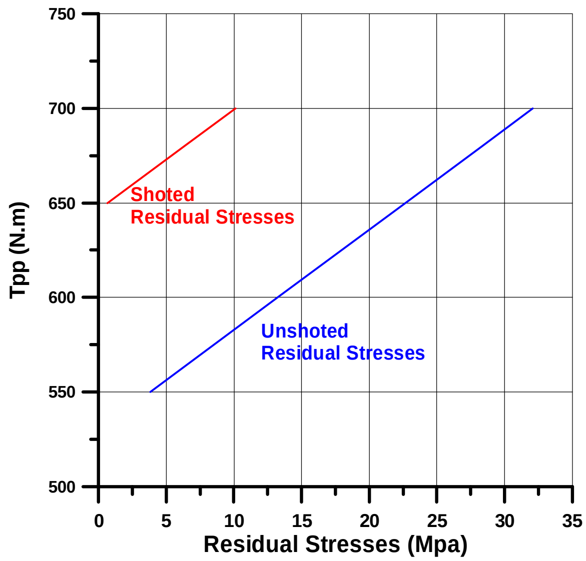

Figure (10) Resulting of Residual Stresses from torsion tests