Residual stress relaxation of shot peened deformation surface layer on C63020 alloy under applied loading

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Abstract
The relaxation of residual stress in shot peened surface layer on C63020 Ni-Al bronze under static and cyclic loading was investigated. The results revealed that the compressive residual stresses were relaxed under applied tensile stress. The relaxation of residual stresses in longitudinal direction was more obvious than that in transverse direction. And when applied stress was beyond the yield strength of the materials, the relaxation of the compressive residual stress was drastic. Under cyclic loading, the results showed that the relaxation behavior was determined by the applied loading and the number of cycles. And the fast relaxation of the compressive residual stress took place in the first few cycles then became stable gradually. Finally, a model was used to quantitatively predict the compressive residual stress under cyclic loading with different applied tensile stresses.

Keywords: Residual stress relaxation; Shot peening; Applied loading

Introduction

Shot peening (SP) is a widely used cold working process in which the surface of a metal component is bombarded with small spherical shots [1,2]. Each piece of shot striking the material acts as a tiny peening hammer, imparting to the surface a small indentation which is the result of local plastic deformation on the surface [3]. It is well known that fatigue cracking normally initiates at the surface [4,5], and cracks will not initiate or propagate in a compressively stressed zone and the extent of mitigation depends strongly upon the residual stress magnitude and distribution. The maximum compressive residual stress produced at or under the surface of a part by SP treatment is at least as great as half the yield strength of the material being peened [6]. Many materials will also increase the surface hardness due to the cold working effect of SP treatment, and compressive stresses are also beneficial in increasing resistance to corrosion fatigue[7] and stress corrosion cracking[8] hydrogen assisted cracking, fretting, galling and erosion caused by cavitation [9-11]. Unfortunately, any static or cyclic residual stress relaxation during component operation reduces the achievable benefits.

During component operation, the beneficial compressive residual stresses at the surface of the components are often imposed to a cyclic loading with positive mean stress. In this case, it has been found that the rate of residual stress relaxation can be drastic in the early stages of fatigue cycling. It is important to note that the compressive residual stress in the first load cycle can be relaxed by more than 50% [6]. The improvement in the fatigue properties depends mainly on the stability of the residual stresses on the tension-loaded state [12].

Objectives

This short report deals with the relaxation behaviors of the residual stresses in the shot peened surface layer on C63020 Ni-Al bronze under applied tensile loadings. The mechanism of residual stress relaxation and an analytical model for its estimation under various applied loading parameters has been analyzed in details.

Methodology

The widely used Ni-Al bronze C63020 with the chemical composition of 10.0 Al, 4.0 Fe, 3.6 Ni, 0.2 Mn and the balance Cu (wt. %) was employed in the present study. The specimens were cut into dog-bone shape with effective dimensions of 40 × 5 × 2 mm^3 then polished.

The SP treatments were carried out on both sides of the samples by an air blasting machine (Shanghai, Carthing Machinery Company). The diameter of peening nozzle was 15 mm and the distance between the nozzle and the sample was 100 mm. The SP intensity was measured by the arc height of A type Almen specimen, which was determined by jet pressure, SP time and SP medium. In our experiment, the detailed conditions were: 0.50 MPa jet pressures, 60 s SP time, ZrO_2 ceramic beads with 0.25 mm average diameter and under this conditions the SP intensity is 0.18 mmA.
For the applied stress, a micro-tensile tester (Shenzhen, Gopoint Testing Equipment Company) was used in our experiment. In the case of the static tensile loading, the loading along the longitudinal direction was applied from 50 to 450 MPa with a tensile rate of 1.0×10^{-3} s^{-1}. As for the cyclic tensile loading, the applied stresses were 100, 150, 200 and 250 MPa, respectively. At each time after unloading, the residual stresses were measured by an X-ray stress analyzer (LXRD , Canada) with Cu Kα radiation , volt age of 30 kV, and current of 25 mA , Ni filter. The shifts of Cu (420) were detected, and then the residual stress was determined by the $\sin^2\psi$ method. And for the residual stress distribution along the depth, electrochemical polish method was applied to remove the thin surface layer from the top, before stress measurement. In addition, the diffraction patterns of the sample with different conditions were measured by the Rigaku Ultima IV diffractometer with a D/tex 1D high-speed detector, which was operated at voltage 40 kV and current 30 mA with Cu Kα radiation. And the scanning velocity was 2°/min and the step was 0.01°.

Results and analysis
The mechanical properties of C63020 without before shot peeing were estimated from the monotonic tensile stress-strain curve, as shown in Fig. 1. The Young's modulus E and proof yield stress of C63020 are 118 GPa and 258 MPa respectively, which is in accord with the ASTM standard.
The depth distributions of the residual stresses in the deformed layer along longitudinal and transverse directions were presented in Fig. 2. The results reveal that the maximum compressive residual stress values located at the subsurface in two directions, then decreased and finally became the tensile residual stress at the depth of 300 μm. At each depth, the residual stress values were almost the same in two directions.

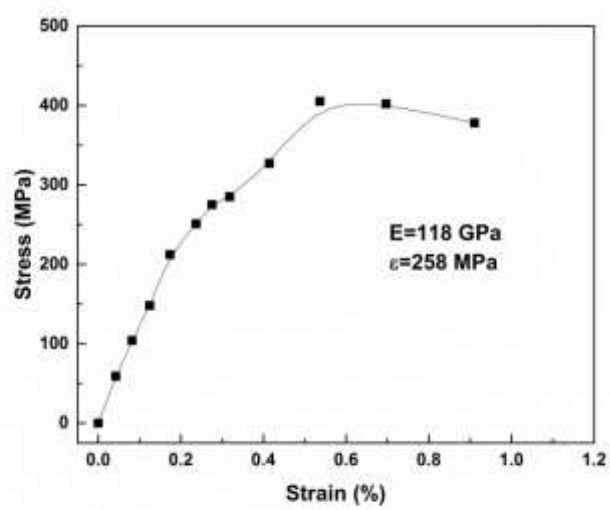

Fig. 1. Stress-strain curve of C63020 alloy before shot peening treatment.

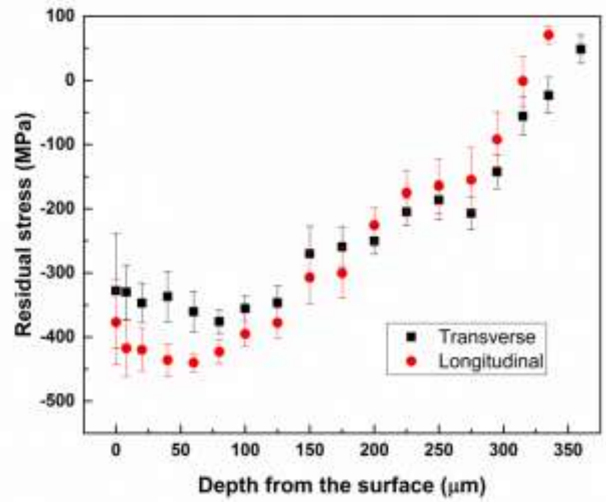

Fig. 2. Longitudinal and transverse residual stresses of shot-peened C63020 alloy under different static loadings.

In principle, the relaxation of residual stress due to mechanical loading occurs when the superposition of applied stress and residual stress reaches the yield point of the materials [13]. And relaxation of the residual stresses was observed under external tensile loadings. The relaxation behaviors of the residual stresses under cyclic loadings are mainly focused on the longitudinal direction [14]. The relaxation behaviors of applied loadings of 100, 150, 200 and 300 MPa along the longitudinal direction were illustrated in Fig. 3. It can be seen that the compressive residual stress relaxation depends on both the applied loading and the cycling number N. Before relaxation the compressive residual stress values were 378 MPa at the surface for all samples. With the cycling number increased, it began to relax and the fast rate of compressive residual stress relaxation took place in the initial stage for all four applied loadings, which is according with previous references [15].

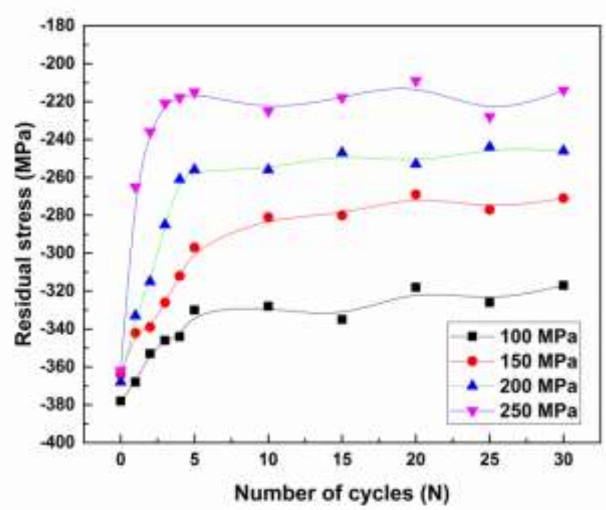

Fig. 3. Variations of residual stress along the longitudinal direction with the magnitude of applied loading and the cycle numbers.

Normally, the cold work produced by shot peening treatment is highest in the surface and decreases through the depth of the materials, because the surface layer subjected to the most severe deformation during the shot peening process. Previous study shows that the tensile cold working can increase the tensile yield strength [16]. The more tensile cold working, the higher the tensile yield strength. Because of the enhanced tensile yield strength, the deformation amount decreases in further cycles. Therefore, after first few cycles, the residual stresses become stable gradually. The residual stress relaxation behavior of C63020 alloy under cyclic loading can be described by the following linear logarithm relationship proposed by Kodama [17].

$$\sigma_N^{RS} = A + m\log N \quad (1)$$

where $\sigma_N^{RS}$is the surface residual stress after N cycles. A and m are materials constants depending on the applied stress amplitude. Using the eq. (1) and the data in the Fig. 3, the relaxation behavior of residual stress along the longitudinal direction under four different applied loadings can be described as: σ_N^{RS} =-360 + 39logN, σ_N^{RS}= 335 +45logN, σ_N^{RS}=-313 + 38logN, and σ_N^{RS}=-257 + 29logN for applied stresses of 100, 150, 200 and 250 MPa respectively. The results reveal that higher applied stress results in faster relaxation of residual stress under cyclic loading.

Conclusions

The compressive residual stress relaxation in the shot peened surface layer of C63020 alloy under static and cyclic loading were systematically investigated. The results showed that the compressive residual stresses in the longitudinal and transverse directions were almost identical in the shot peened layer as well as the surface. The compressive residual stresses were relaxed under applied tensile stresses, and the relaxation behavior was chiefly dependent on the magnitude of the applied tensile stress and the cyclic numbers. The relaxation of the compressive residual stress in the longitudinal direction was more obvious than that in transverse direction. For cyclic loading, the fast relaxation of residual stresses occurred in the initial stage and then became stable gradually. Also, the higher applied tensile stress resulted in the more relaxation of compressive residual stress.

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