Effect of prestressed shot peening on residual stress and microhardness of C63020 alloy

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Abstract

Residual stress and microhardness on surface deformed layer of C63020 nickel aluminum bronze alloy after shot peening with different prestress states were investigated. The results showed that the compressive residual stress and microhardness were improved significantly after stress shot peening. The values of compressive residual stress depended on both the prestress state and the measurement directions. Based on these investigations, it was concluded that the stress shot peening is superior to conventional shot peening in improving the surface properties of NAB alloy.

Keywords: Pre-stress shot peening; Residual stress; Nickel aluminum bronze

Introduction

Nickel aluminum bronzes (NAB) are widely used range from seawater pumps, valves and propellers to landing gear bearing and bushings due to their unique combination of high strength, good damping capacity, excellent wear and corrosion resistance [1]. However, these alloys can also be subjected to selective phase corrosion and stress corrosion cracking when they working in seawater or other extreme conditions due to their complex phases and inhomogeneous distribution of residual stresses [2].

In most cases, the surface is more likely to be failure than the central part. Hence a number of studies have been carried out recently to enhance the surface mechanical properties and the corrosion resistance including friction stir processing [3] and laser cladding [4]. These techniques can refine the grains or homogenize the microstructure [5]. In comparison, shot peening (SP) as one of the mostly used methods to improve the surface properties of components, can simultaneously refine the microstructure and induce the compressive residual stress (CRS) into the surface layers. As we know that CRS can also enable the components have excellent resistance against the stress corrosion cracking. In order to further enhance the helpful effect of CRS, the prestress treatment is usually used during SP process. Other investigations have also confirmed that the prestress can introduce higher CRS than that of traditional SP [6,7]. However, the effect of SP on the nickel aluminum bronze with prestress treatment has not enough been investigate.

Objectives

This study is aimed to evaluate the influence of prestress on the residual stress and microhardness of shot peened nickel aluminum bronze and explore the optimal parameters used to improve the surface properties of it.

Methodology

NAB samples used in this study were C63020 plates with effective dimensions of 20 mm×10 mm×10 mm. All samples were ground to 1000-grit SiC before the treatment and tests. The untreated group was used as reference for comparing with other groups subjected to SP with different prestress states. A traditional air blast machine was employed to carry out the peening treatment. The shot medium was ZrO_2 ceramic beads and the stand-off distance was 100 mm. The different intensities were confirmed as 0.10 and 0.15 mmA, respectively. The coverage of all peened samples were ensured no less than 100%.

The residual stress information was collected by X-ray stress analyzer (LXRD, Proto, Canada, Cu-Kα radiation, 30 kV, 25 mA) and calculated using $\sin^2\psi$ method. Ni filter was selected and the shift of Cu

(420) diffraction profile was detected during the measurement. The value of prestress were also determined before SP treatment. Surface hardness of samples with and without SP was measured by Digital Microhardness Tester (DHV-1000, Beijing), with the loading force of 1.98 N and the holding time of 15 s. The average value of five points measured at each layer was determined as the final result. In-depth profile variations were determined by electrochemical corrosion method [8]. Before stress peening, the samples were pre-stressed by three point bending method along longitudinal direction (LD). The magnitudes of pre-stresses were 100, 150, 200 and 250 MPa, respectively.

Results and analysis

Residual stress distributions

The distribution of residual stresses along the depth of shot peened NAB alloy with different prestress states were illustrated in Fig. 1. The directions which both parallel and perpendicular to the tensile prestress were investigated. It can be seen that CRS increased to the maximum point then dropped with the increasing depth. The CRS and the position at which it had the maximum value both increased with the raising prestresses. However, the excessive prestress or peening intensity were likely to induce the micro-cracks in the surface [9-10]. Stress shot peening could improve the CRS and the depth of shot peening influence zone without enhancing of shot peening intensity [11]. The variation trends with different measurement directions were similar. The rate of improvement along longitudinal direction was larger than that of traverse direction. This can be attributed to the larger elastic recovery along longitudinal direction after prestress released. CRS at the surface and the position at which had the maximum value along both directions with different prestresses were listed in the Tables 1 and 2. Before shot peening, the applied loading was along the longitudinal direction, and the elastic deformation caused by tensile stresses along the longitudinal direction was larger than the transverse direction. After shot peening and prestress was released, the larger elastic deformation was recovered and the higher CRS were induced along the longitudinal direction, which was in accord with previous Refs. [12,13].

Table 1. Surface compressive residual stresses with different prestresses along the longitudinal and transverse directions, the deviation statistics were also shown in the brackets.

	0 Mpa	100 Mpa	150 Mpa	200 Mpa	250 Mpa
Longitudinal direction	-256 (±42)	-285 (±30)	-300 (±32)	-346 (±27)	-393 (±29)
Transverse direction	-211 (±32)	(-272±31)	-289 (±35)	-323 (±33)	-342 (±34)

Table 2. The maximum compressive residual stresses with different prestresses along the longitudinal and transverse directions, the deviation statistics were also shown in the brackets.

	0 Mpa	100 Mpa	150 Mpa	200 Mpa	250 Mpa
Longitudinal direction	-456 (±13)	-543 (±27)	-568 (±19)	-553 (±19)	-585 (±14)
Transverse direction	-447 (±13)	(-463±27)	-458 (±19)	-486 (±19)	-473 (±24)

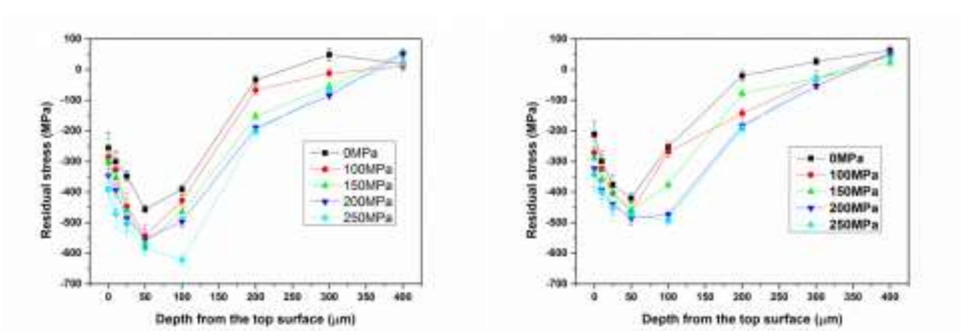

Fig. 1 Residual stresses distributions of NAB alloy with different prestresses as a function of depth. (a) Longitudinal direction and (b) transverse direction.

The beneficial effect brought by shot peening derived mainly from the generation of a stable CRS profile and refined microstructure in near surface region. In conventional shot peening CRS and microhardness can be improved by increasing the peening intensity [14]. However, it may produce some microcrack on the surface with a high shot peening intensity, which was detrimental to the fatigue properties of materials. For stress shot peening, at the same shot peening intensity, the compressive residual stress and microhardness could be effectively improved by increasing the prestress value before shot peening. One of very important effect of stress shot peening was to prevent the generation and growth of microcrack, namely, appropriate prestress can reduce the damage of micro-indentation. As a result, in our experiment the prestresses were chosen as 100, 150, 200 and 250 MPa for reducing micro-indentation effect in an appropriate range. In this way, the optimized residual stress field and microhardness can be obtained after stress shot peening, which was beneficial in improving the mechanical properties and stress corrosion cracking resistance of NAB alloys.
Fig. 2 showed the microhardness distributions of C63020 NAB alloy after stress shot peening. The significant increments of microhardness in surface deformed layers had been observed after shot peening with different prestress states. The results revealed that the microhardness values of all these samples reached the maximum at the top surface and then gradually decreased along the depth. On the top surface, under different prestresses of 0, 100, 150, 200 and 250 MPa after shot peening, the values of microhardness reached 286, 297, 301, 316 and 331 HV respectively, which were more than 40% higher than that of the substrates' value at 250 μm. At the same depth, the values of microhardness were increased with the increasing prestress.
The values of microhardness were influenced by work-hardening, plastic deformations and high CRS, which were determined by the microstructures of the deformed surface. Shot peening was an essential process of work-hardening which would induce high CRS, refined domain sizes and high density of dislocations. Furthermore, some study showed [14] that nano-crystalline layer can be formed after shot peening, and the nanocrystalline layer had much higher microhardness because of higher dislocation density. In the process of stress shot peening, the materials were in the stress state directly after peening but before unloading, subsequently, after unloading the prestress, elastic deformation induced by tensile stress loaded before shot peening was recovered, which introduced higher CRS and more severe deformation layer. For NAB alloy, accordingly, the further increments of microhardness for the pre-stressed samples were mainly ascribed to the higher CRS, smaller domain size and higher dislocation density in the deformed layer.

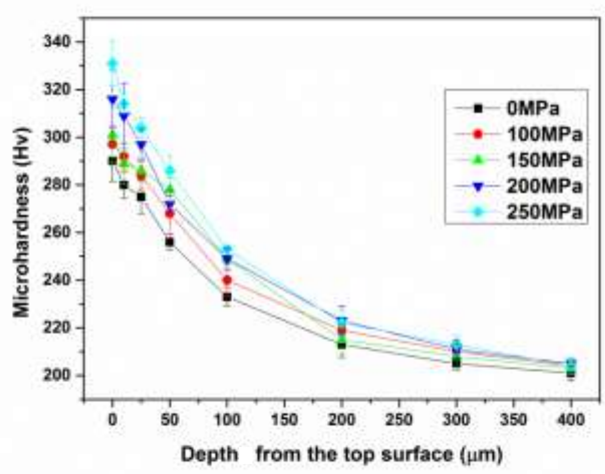

Fig. 2 Microhardness distributions along the depth with different stress peening treatments.

Conclusions

The effect of stress shot peening on the residual stress and microharndess of C63020 alloy was investigated. The results revealed that CRS was improved significantly after stress shot peening, and the increment of CRS was proportional to the pre-stress. The value of CRS reached maximum when the prestress was 200 MPa. The investigation of CRS values with different measurement directions showed that the improve rate of CRS along longitudinal direction was bigger than that in transverse direction which resulted from the larger elastic recovery along longitudinal direction after prestress release. Moreover, the microhardness of the surface was improved significantly by stress shot peening. The further increment of hardness was mainly due to higher compressive residual stresses, smaller domain size and higher value of dislocation density/microstrain induced by stress shot peening. Based on above investigations, it can be seen that stress shot peening was an effective way to improve surface properties of NAB alloys.

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