Materials and Design 31 (2010) 3317–3323

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Combined finite element method and dislocation density method solution to residual stress induced by water cavitation peening

B. Han [a], D.Y. Ju [b,*], X.G. Yu [a]

[a] School of Mechanical Engineering and Automation, University of Science and Technology Liaoning, Anshan, Liaoning 114051, China
[b] Department of Material Science and Engineering, Saitama Institute of Technology, Fusaiji 1690, Fukaya, Saitama 369-0293, Japan

ARTICLE INFO

Article history:
Received 7 November 2009
Accepted 2 February 2010
Available online 6 February 2010

Keywords:
Water cavitation peening
Finite element method
Dislocation density method
Residual stress

ABSTRACT

Water cavitation peening is a technique similar to shot peening that induces compressive residual stresses in materials for improved fatigue resistance. Generally, residual stress is of two types: macro-residual stress and micro-residual stress. In this paper, a novel combined finite element method and dislocation density method (FEM/DDM), proposed for predicting macro and micro-residual stresses induced on the material subsurface treated with water cavitation peening, is presented. A bilinear elastic–plastic finite element method was conducted to predict macro-residual stresses and a dislocation density method was conducted to predict micro-residual stresses. These approaches made possible the prediction of the magnitude and depth of residual stress fields in pure titanium. The effect of applied impact pressures on the residual stresses was also presented. The results of the FEM/DDM modeling were in good agreement with those of the experimental measurements.

1. Introduction

Water cavitation peening (WCP) is a surface treatment process that can impose compressive residual stresses on the surface and subsurface layers to enhance the fatigue life of metallic components [1–4]. In the past, most investigations had been concentrated on determining experimentally the mechanical effects including residual stress field, surface morphology, and fatigue performance. Thus far, no theoretical work on the generation of compressive residual stress has been reported. The finite element method (FEM) was initially conducted on other peening processes. For example, in 1999, Meguid et al. conducted a dynamic elasto-plastic analysis of the shot peening process using a single shot to predict compressive residual stresses on the exposed surface layers [5]. Hu et al., and Ding and Ye also proposed finite element analyses (FEA), instead of a complicated experimental procedure, to predict the development, magnitude, and distribution of residual stresses induced by multiple laser shock peening (LSP) [6,7].

Subsequently, similar works were attempted in water jet peening (WJP), which is a surface treatment process similar to WCP. The finite element method was first introduced by Kunaporn et al. to investigate mechanical behavior and to predict residual stresses from water jet-peened materials with a commercial FEA software in 2004 [8]. A proposed mathematical model based on the multiple impacts of the jets was used to estimate the contact pressure and the feasible peening range. The predicted residual stresses by the FEA model was in reasonable agreement with the experimental results at the near-surface region. Attempts were made to investigate the residual stresses induced on materials treated with high-pressure water jet. Rajesh et al. made a transient dynamic finite element analysis, to predict the residual stresses on materials treated with high-velocity water droplets [9]. The impact nature of droplets was simulated by applying impact pressures over a very short duration, estimated using Reichardt's theory and the liquid impact theory. Subsequently, a multidroplet impact model, proposed for predicting residual stresses induced on materials subjected to water jet peening, was presented [10]. This approach considered impact pressure distribution caused by high-velocity droplets impinging on the material surface, instead of the stationary pressure distribution, to predict the residual stresses on water jet-peened surfaces by using transient elastic–plastic finite element analysis. Moreover, Daniewicz and Cummings made a finite element modeling of stationary water jet impinging on an elastic–plastic half-space and performed FEA to characterize WJP processing [11]. Subsurface residual stresses were found to be the result of subsurface plastic deformations.

Generally, residual stress can either be macro-residual or micro-residual [12,13]. In 2009, Han and Ju presented a method to predict residual stress induced on the materials subsurface treated with water cavitation peening [14]. The approach made possible the prediction of the magnitude and depth of residual stress fields in pure titanium. The results indicated that the measured residual stress was in the depth of 0–50 μm, higher than that of the

* Corresponding author. Tel.: +81 48 5856826; fax: +81 48 5855928.
E-mail address: dyju@sit.ac.jp (D.Y. Ju).

0261-3069/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.matdes.2010.02.004