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Short Communication

Compressive residual stress induced by water cavitation peening: A finite element analysis

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ABSTRACT

Water cavitation peening is a recent promising method in surface treatment. It has the potential to induce compressive residual stresses that benefit the fatigue life of components similar to the other peening process. In this paper, a novel method, proposed for predicting residual stress induced on the materials subsurface treated with water cavitation peening, is presented. A bilinear elastic–plastic finite element analysis was conducted to predict to residual stresses. The three-dimensional model was based on the classical bilinear kinematic hardening model that uses two slopes (elastic and plastic) to represent the stress–strain behavior of a material. The approach provided prediction of magnitude and depth of residual stress fields in pure titanium. Effect of applied impact pressures on the residual stresses was also presented. Results of the finite element analysis modeling were in good agreement with that of the experimental measurements.

1. Introduction

Water cavitation peening (WCP) is a surface treatment process that can impart compressive residual stresses in the surface and subsurface layers for enhancing the fatigue life of components [1–4]. In this field, similar method also is referred to as water jet peening (WJP) [5,6]. In those processes, high-velocity water with abundant air bubbles continuously impinges over the surface. These bubbles' blasts produce high peak loads that can cause localized plastic deformation of material and stretching of the layers of the surface. Upon unloading, the elastically stressed sub surface layers tend to recover to original state. But the continuity of material in both elastic and plastic zones does not permit this to happen. Consequently, a compressive residual stress followed by tensile stress is trapped in the treated component. Therefore, it is a force controlled treatment that generates compressive residual stresses in the surface layers without modifying the surface topography.

Most investigations have been concentrated on experimentally determining mechanical effects including residual stress field and surface morphology before. Finite Element Method (FEM) was initially conducted in the other peening process, such as, Meguid et al. conducted dynamic elasto-plastic analysis of the shot-peening process using a single shot to predict compressive residual stresses in the exposed surface layers in 1999 [7]. Hu et al. and Ding and Ye also proposed finite element analyses, instead of a complicated experimental procedure, to predict the development, magnitude and distribution of residual stresses induced by multiple laser shock peening (LSP) [8,9].

FEM is first introduced by Kunaporn et al. to investigate the mechanical behavior and predict the residual stresses from water jet peened materials with a commercial FEA software in 2004 [10]. 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 is in a 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, for predicting the residual stresses on material treated with high-velocity water droplets [11]. Impact nature of droplets was simulated by applying impact pressures over a very short duration, estimated using Reichardt's theory and liquid impact theory. Subsequently, a multidroplet impact model, proposed for predicting residual stresses induced on materials subjected to water jet peening, was presented [12]. This approach considers the impact pressure distribution due to high-velocity droplets impinging on the material surface instead of stationary pressure distribution for prediction of 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

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