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Shot peening modeling and simulation for RCS assessment

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Abstract

The application of shot peening to components and structures induces residual compressive stresses (RCS) on the surface. It has also been identified that fatigue, corrosion fatigue (CF) and stress corrosion cracking (SCC) are lifted by RCS. However, failures still occur in local areas of shot peened components under service conditions at stresses below the yield strength of the material. This calls for a real assessment of the distribution of stresses in the shot peened component for enhanced prediction of induced RCS. This report is the first part of an ongoing research aimed at establishing a simplified methodology for a realistic simulation of the shot peening process and the accompanying residual stress by combined DEM-FEM approach. In this paper, the authors have replaced the transient analysis used in past DEM-FEM approach with a simpler static structural analysis. The results obtained are validated with similar experimental results available in literature. This will serve as a reliable tool for more accurate analysis/prediction of the service life of shot peened components and for enhancement of shot peening application as a life-extension remedy to critical engineering components.

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Keywords: discrete element method(DEM), finite element method(FEM), modelling and simulation, residual compressive Stress (RCS), shot peening (SP).

1. Introduction

The shot peening (SP) process is a mechanical surface treatment in which the creation of a beneficial residual compressive stress state is produced by an imposed cold working with accompanying tiny surface dents due to

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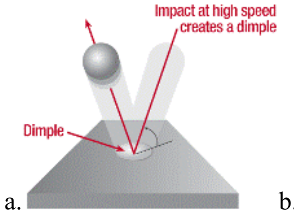
random impact of small balls as shown in figure 1 below. Its application results in improved fatigue / corrosion fatigue resistance, by eliminating / reducing steady tensile stress at the surface of the component when load is applied. This reduces severe causes of cracking by fatigue, corrosion fatigue and stress corrosion cracking. Generally, there is an enhanced service life of the component. As a result of the highlighted benefits indicated above much experimental work, analytical and numerical modeling has been carried out to attempt the optimization of the SP process, and to proffer better understanding of its stochastic nature. Yet questions as to what extent the SP parameters influence the depth/magnitude of the induced compressive stress/surface hardening, and how stable is the RCS under service conditions are still not clear. Also the issue of coverage when complex geometry such as the root of a turbine blade is shot peened and how it affects the service performance of the component are yet to be answered.



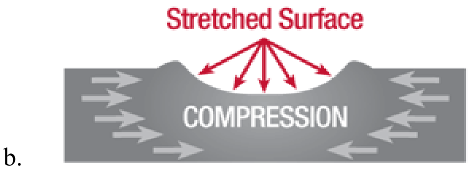


Fig. 1. (a) Interaction of shot peening ball and a metallic surface; (b) resulting compressive stress and deformation of target surface.

Nearly all fatigue and stress corrosion failures originate at the surface of a part, but cracks will not initiate or propagate in a compressively stressed zone, as represented schematically in Fig. 1. Due to overlapping dimples from shot peening, a uniform layer of compressive stress is created at metal surfaces, thus enhancing service life of the component, however, shot peened components still fail at operating conditions below their fatigue strength. There are other related surface enhancement processes such as laser peening and low plasticity burnishing which induces deeper greater residual compressive stresses without the associated pitfalls with shot peening application, notwithstanding shot peening is still the most economical and practical method of ensuring surface residual compressive stresses, especially with large components.

Research and development for shot peening is focused on two areas. The first area is devoted to researching the effects of coverage, saturation, and intensity on the fatigue behaviour of a shot peened structure and surface forming capability. The second is prediction and measurement of the residual stress via analytical, numerical or experimental research. Coverage is simply the fraction of area peened during a specified time. Saturation is reached when doubling the shot peening time does not result in more than 10% increase in arc height (deflection of a metal strip). The intensity is directly related to the energy of the shot stream. An intensity measurement corresponds to how much a standard metal strip, known as an Almen strip, will deflect (bow) depending on the chosen parameters such as pressure, shot velocity and size. An understanding of the influence of these parameters on the SP process is needed for its optimization and control in the manufacturing of components.

A large number of studies have been performed on shot peening experimentally [1, 2]. In this approach, parts are shot peened with a set of peening parameters for a certain coverage. Then these parts are subjected to fatigue testing. If the fatigue performance is adequate, then the subsequently manufactured parts are also subjected to the same peening conditions. However, the determination of peening parameters needs to be repeated through further experimentation if the part does not meet the expected fatigue life, which is very expensive. This made way for analytical study of the process [3,4]. These analytical methods involve complex mathematical analysis which are less expensive but difficult to implement due to much simplified assumptions which compromises their effectiveness when applied to complex geometry. Good enough, with numerical simulations making use of computers, the shot peening process has become a very attractive subject leading to a vast number of proposed models [5-9], with better understanding of the complex phenomenon. Very recently, wonderful attempts have been made [8,10] to bring these models and their simulation very close to reality. It is therefore the objective of this paper to further simplify previous DEM-FEM approaches [7,8] by replacing the transient structural analysis with a static structural analysis. This effort which is the first part of an ongoing research will easily make way for further analysis of shot peened components and structures during their manufacture, and implementation of life-extension strategy