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Published in:
Risoe International Symposium on Materials Science. Proceedings

Publication date:
2014

Citation (APA):
Liu, H., Zhang, X., Hansen, N., & Gao, Y. (2014). Numerical investigation of a shot peening process by a finite element approach. Risoe International Symposium on Materials Science. Proceedings, 35, 381-388.

NUMERICAL INVESTIGATION OF A SHOT PEENING PROCESS BY A FINITE ELEMENT APPROACH

Hongsheng Liu[1], Xiaodan Zhang[1], Niels Hansen[1] and Yukui Gao[2]

[1]Danish–Chinese Center for Nanometals, Materials Science and Advanced Characterization-MAC, Department of Wind Energy, Risø Campus, Technical University of Denmark, DK-4000 Roskilde, Denmark
[2]School of Aerospace Engineering and Applied mechanics, Tongji University, Shanghai 200092, P.R. China

ABSTRACT

Shot peening is a surface impact treatment widely used to improve the performance of a metal or a component. The better performance of the shot peened part is controlled by compressive residual stresses resulting from the plastic deformation of the surface layers by impacts of shot. The compressive residual stress is generally measured by X-ray diffraction. However, considerable cost and time are needed for such measurements. For this reason, in this work a 3D finite element (FE) model is introduced for a shot peening process. Through the FE simulations, the effect of process parameters such as damping ratio of material, friction coefficient, shot velocity and shot angle on the magnitude and distribution of the compressive residual stress is examined.

Keyword: Shot peening; compressive residual stress; plastic deformation; finite element method

1. INTRODUCTION

Shot peening is a widely used surface treatment method for improving the resistance of metallic parts which undergoes cycle loading and wear. The shot peening process introduces plastic deformation in the surface layer of a material resulting in a gradient structure with a continuous decrease in grain size as the surface is approached (Zhang, Hansen, Gao and Huang, 2012). Another important effect of shot peening is the introduction of compressive residual stresses in a near-surface layer, which can impede crack initiation and propagation. Modelling of shot peening is typically applied to simulate the magnitude and distribution of compressive residual stresses taking into account processing parameters such as damping ratio, friction coefficient, shot velocity and shot angle. A number of 2D and 3D FE Models have been proposed (Baragetti, 2010, Kim, 2002,Bake, 2003): (i) The 2D FE model of shot peening mainly focus as

In the present model the mesh distribution is optimized: the mesh is the finest in the impact centre and coarser in the region far away from the impact centre as shown in Figure 1(b). In this way the number of mesh can be reduced drastically and the required computation time is reduced. Besides, due to the symmetry, only a half bar is modelled. Furthermore, the material damping ratio also affects the computation time. An appropriate material damping ratio is a prerequisite for obtaining a high convergence rate of simulation results and a reduction of computation time. In the present model, the appropriate material damping ratio is set to 0.3, but a bigger damping ratio can also stabilize the simulation. However, a much bigger damping ratio will lead to a pseudo simulation result. As to the friction condition between the shot and the bar, it influences the stress distribution and the deformation mode for the material near the surface of the bar. A bigger friction coefficient creates a higher friction force on the bar surface and may influence the surface plastic deformation. Therefore, the friction coefficient can significantly affect the residual stress in the radial direction. The shot velocity is another important factor for the shot peening process. For a higher shot velocity, a higher impact energy is absorbed by the material and will result in a severer plastic deformation as well as a higher compressive residual stress as shown in Figure 5. At the same time, the compressive residual stress concentrates in a thin layer near the surface of the bar after the shot impact, a higher shot velocity can create a deeper compressive stress gradient. In addition, a higher shot velocity needs a shorter impact time and therefore creates a higher strain rate. In this way, a high shot velocity is beneficial for obtaining a high compressive residual stress. Nevertheless, too high a shot velocity will result in very severe plastic deformation and the cracks may occur on the surface of the bar after multiple shots. Therefore, there exists an optimum shot velocity for a given material. Introduction of the shot angle in the present model can accurately reflect the real shot peening process. A smaller shot angle results in a larger shot slide and dent on the surface of the bar. As a result, a part of the impact energy is absorbed by the plastic deformation in the radial direction on the bar surface and the amount of plastic deformation is lower in the normal direction. Therefore, with the shot angle decreasing the compressive residual stress leads to reduction in plastic deformation in normal direction to the bar surface. In order to optimize the shot peening process, two important factors such as the shot velocity and the shot angle need to be evaluated overall: (i) A bigger shot angle is appropriate, (ii) A high shot velocity may result in cracks in the material and should not be more than 300 m/s, but a much lower shot velocity cannot create a large plastic deformation and a high compressive residual stress. The large residual stress above 600 MPa has been detected in this modeling and the heavy plastic deformation which improve the strength of this high carbon steel to around 1.4 GPa has been characterized in our previous work (Zhang 2012). The inherent correspondence between the introduced residual stress and the improved strength during shot peening will be validated in near future. Furthermore, our research group will perform some experiments on shot peening to examine the compressive residual stress and the plastic strain distributions after shot peening and validate the present developed 3D FE model. The mechanical properties of the peened material combined with simulations by the 3D model will guide future modelling and the shot peening process design.

5. CONCLUSIONS

A 3D FE model is proposed for the evaluation of residual stress distributions resulting from shot peening with different processing parameters. The simulation results demonstrate that introduction of an appropriate material damping can ensure that the impact energy dissipates immediately after shot impact and therefore the computation time can be reduced. The compressive residual stress almost does not wave for a friction coefficient $\mu \geq 0.3$. It is found that the compressive residual stress and its distribution gradient increase with increasing the shot velocity, and a higher shot velocity results in a higher maximum strain rate during shot peening.

The shot angle significantly influences the compressive residual stress distribution. A lower compressive residual stress distribution and plastic strain distribution in the normal direction to the bar surface result from a smaller shot angles.

ACKNOWLEDGEMENTS

H.S. Liu gratefully acknowledges the support from the Strategic Research Center “REWIND - Knowledge based engineering for improved reliability of critical wind turbine components”, Danish Research Council for Strategic Research, grant no. 10-093966. X.Z. and N.H. gratefully acknowledges the support from the Danish National Research Foundation (Grant No. DNRF86-5) and the National Natural Science Foundation of China (Grant No. 51261130091) to the Danish – Chinese Center for Nanometals.

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