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An approach to relate shot peening finite element simulation to the actual coverage

S.M.H. Gangaraj [a,*], M. Guagliano [a], G.H. Farrahi [b]

[a] Politecnico di Milano, Dipartimento di Meccanica, Via La Masa, 1, 20156 Milano, Italy
[b] Materials Life Estimation and Improvement Lab., School of Mechanical Engineering, Sharif University of Technology, Tehran, Iran

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ABSTRACT

Coverage is one of the most important parameters which is always used in practice to characterize a shot peening process. At the same time however, it is the most missing parameter in the finite element simulations of this process. This study aims to relate shot peening simulation to the actual coverage that is developed during the process. Accordingly, two important models from literature are re-simulated and their capability to predict an actual coverage is assessed. Results of this study illustrate that full coverage situation is not captured by these models. Thereafter, a random finite element simulation along with a step by step examination of the treated surface is adopted in order to present an actual coverage evolution. Application of Avrami equation in order to adopt an appropriate number of impingements in simulation to achieve a given coverage for a given target area is examined. According to the result, application of this equation in simulation leads to an overestimation of impingement numbers at full coverage level unless the radius of treated are is at least ten times of the radius of a single indentation.

1. Introduction

Among the common fatigue life improvement techniques, shot peening is widely used due to its simplicity, economical cost and applicability to variety of targets. Shot peening is carried out by firing small spherical shots with a velocity of 20–100 m/s against a target surface. Tensile residual stress developed during the manufacturing process can be completely converted to a compressive one by shot peening and stress rising due to notches could be fully counterbalanced using optimum process parameters.

The beneficial effects of shot peening on fatigue life are attributed to compressive residual stress and surface work hardening [1–3]. With the variety of processing parameters in shot peening however, selection of the most suitable and optimum ones to achieve a given degree of improvement is always a matter of question in the designers' mind. An accurate analytical or numerical assessment could be an inexpensive and at the same time reliable method to answer.

“There is still a huge lack of knowledge. We are only just entering the area of mechanics of shot peening.” Al-Hassani used these words at the end of his analytical analysis of a target impinged upon by a single sphere, three decades ago, to emphasize on the complexities of the process involving many disciplines of static and dynamic elasticity and plasticity [4]. At that era shot peening was not known to everyone and also very limited works and researches were available. His simple formulas and those published by Al-Obaid [5,6] were the first relations which correlated depth of plastic zone and residual stress to density of shot, velocity of impact, thickness and hardness of the target.

Noteworthy differences of dent shape and residual stress in static and dynamic indentation test [7] demonstrated that dynamic effects of shot peening cannot be ignored. This issue increases the complication of analytically analyzing the process. Numerical methods such as finite element, thanks to rapid progress of computer power in the last decade, have been efficiently utilized for analyzing of involved process. Simulation of one spherical shot Impingement on an elasto-plastic target has been widely used for determination of the shot peening induced residual stress [8–13]. A cube of 7R width (R is the shot radius.), 4R height and 5R breadth [8] and a cylinder of 8R radius and 3R height [13] have been proposed as suitable geometries of an arbitrary target upon which impingement of one shot takes place. Although these single shot impingement models could not simulate a realistic peening, they drew a preliminary good perception of shot velocity and size effects on plastic zone development, its growth and unloading residual stress. Examination of twin spherical indentation using the finite element model [14] revealed the significant effect of separation distance between two shots upon residual stress field which in turn introduced multiplicity of shots as a serious topic to be considered in finite element simulations. Situation of a large number of identical shots impinging a metallic target has been envisaged by symmetry cell approach [15]. The dimensions of the proposed symmetry cell were $C \times C \times H$ where C is one half of separation distance between adjacent shots and could be considered as representative of the coverage in the peening. Shot peening of the symmetry cell can be regarded as the impingement of identical shots with a symmetry layout inside each row. These rows were further combined in series of four rows that in each impingement

* Corresponding author. Tel.: +39 02 23998667; fax: +39 02 23998202.
E-mail address: seyyed.hassani@mail.polimi.it (S.M.H. Gangaraj).

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upon the target surface one single shot comes into contact with one corner of the symmetry cell. A general realistic residual stress induced by shot peening has been successfully and efficiently calculated [16] by application of the four impacts symmetry cell combined with the idea of averaging the nodal residual stresses at each depth. Using another shot sequence, Majzoobi et al. [17] developed a nine impacts symmetry cell model and studied the variation of in depth residual stress profile in different points of the target. Increasing the number of impacts, they found that a uniform state of in depth residual stress could be achieved in different points of target at particular number of shots. However, this particular number of shot impact is certainly a problem dependent parameter and would change for different peening conditions. More recently, a random location of shots in finite element model has been utilized to simulate nano-crystallization by shot peening [18]. Good agreement between simulated and experimentally measured residual stress distribution affirmed that random locations for shot can be a good alternative for simulation of more realistic shot peening process.

A brief look on the way in which numerical simulation goes through as compared by that of practical shot peening, discloses a lack of straightforward terminological correlation between simulation and practice. Numerical simulators are presenting their own results in terms of shot velocity and size while shot peening industries are more interested in other parameters. There are two important practical parameters that have been universally accepted and adopted by engineers in order to ensure repeatability of the process: I) intensity and II) coverage. Intensity is an index of transferred kinetic energy from stream of shots to the target and coverage indicates the amount of target surface that is treated by shots. If a reliable selection of shot peening parameters to meet a given function is supposed to be a mission of numerical simulation, there is no escape but incorporation of intensity and coverage into numerical simulation of shot peening.

A procedure to relate the values of Almen-scale, which is indicator of intensity, to the residual stresses in metal parts have been established [19]. Such a correlation can guide the designer towards the optimal selection of process parameters while minimizing the cost of necessary experimental assessments. Such an incorporation however, for the other important parameter i.e. coverage has not been investigated yet. In fact most of the 3D multiple impact simulation models, recently developed, did not focus on coverage but on the general understanding of how the stress state develops during successive impacts [18].

Coverage, the most important measurable variable of shot peening, the most important parameter in the so called severe shot peening [18] and one of the most affective parameters on fatigue life of treated parts, either improvement or deterioration, is at the same time the most missing one in the finite elements simulations. It is therefore the purpose of this study to first examine if the former finite element models can take coverage into account and then to characterize a suitable random simulation to accommodate coverage.

2. Finite element models

Reviewing all finite element models published so far is neither in the scope of the paper nor necessary. As far as shots are interested, shot peening simulations can be classified into prior and random positioning of shots. When target is regarded, there are one symmetry plane [12,13], two symmetry planes [19] and four symmetry planes [15–17,20]. Among these kinds of targets, more attention was given to those containing four planes of symmetry, in another words symmetry cells. Therefore, two main symmetry cells Meguid & Kim [15,16] and Majzoobi [17] that made an effort to simulate a realistic shot peening have been selected from literature. A finite element re-simulation of them is carried out in this section. These models are considered to be a representative of prior shot positioning since both of them have assigned prior positions to shots. The capability of these models to capture a realistic peening is evaluated and discussed. A random finite element simulation of shot peening is also developed and presented in this section in order to overcome the inadequacies of former models.

2.1. Symmetry cell#1 (Meguid & Kim)

Kim et al. [16] applied the idea of area average solution on a symmetry cell to obtain a realistic distribution of shot peening residual stress. In this approach the average nodal residual stress in all nodes forming the cross section at specific depth, is introduced as the amount of shot peening induced residual stress at that depth. The impingement of four shots on each corner of a symmetry cell target which was developed by Kim is re-simulated in this work. However, on behalf of a

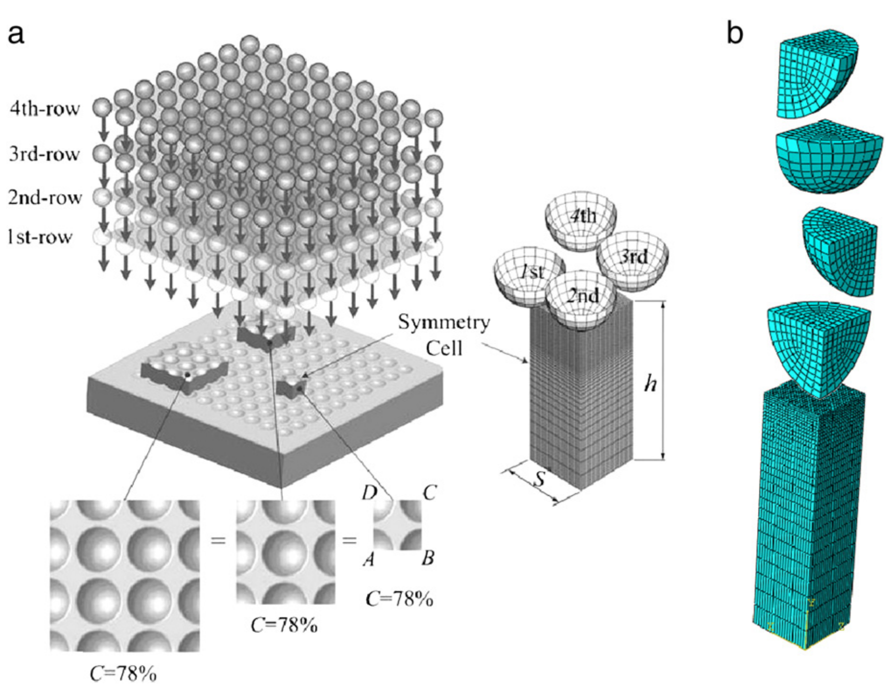

Fig. 1. a) Symmetry cell used by Meguid & Kim [16]. b) Finite element mesh of Meguid & Kim symmetry cell used in the present study.

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