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# On the potential applications of a 3D random finite element model for the simulation of shot peening

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ABSTRACT

Shot peening is a cold-working process that is used mainly to improve the fatigue life of metallic components. Experimental investigation of the mechanisms involved in shot peening is very expensive and complicated. Therefore, the Finite Element (FE) method has been recognized as an effective mean for characterizing the shot peening process and several types of FE models have been developed to evaluate the effects of shot peening parameters. However, in most of the existing FE models, the shot peening sequence and impact location were defined *a priori*. It is therefore the purpose of this study to consider the random property of the shot peening process. A novel 3D FE model with multiple randomly distributed shots was developed combining a `Matlab` program with the `ANSYS` preprocessor. The explicit solver `LS-DYNA` has been used to simulate the dynamic impingement process. Several potential applications of this novel model such as: the quantitative relationship of the peening intensity, coverage and roughness with respect to the number of shots have been presented. Moreover, simulations with multiple oblique impacts have been carried out in order to compare with results from normal impingements. Our work shows that such a computing strategy can help understanding and predicting the shot peening results better than conventional FE simulations.

## 1. Introduction

Shot peening is a mechanical surface treatment widely used to improve the fatigue life of metallic components in the aerospace and automobile industries. This process is accomplished by bombarding the surface of a metallic component with shots at high velocities. Each shot acts as a tiny peening hammer, compressing and stretching the metallic surface. An indentation surrounded by a plastic region is created during this impingement. The plastic deformation leads to a residual stress profile through the thickness of the component. This residual stress profile is compressive at the top surface and tensile in the thickness of the component in order to ensure equilibrium. The layer of compressive residual stress reduces the likelihood of premature failure under cyclic loading conditions [27,40,34].

Several studies dealt with the theoretical aspects of shot peening [27,3,23]. Numerical simulation of the process was made possible with the development of the finite element method and the rapid development of computational power. One of the first finite element simulation was carried out by Al-Obaid [2] using 3D isoparametric solid elements with nine layers through the thickness of the target plate. Subsequently, six main types of finite element models have been established to simulate the shot peening process:

(i) Mori et al. [33] introduced an axisymmetric model to simulate the plastic deformation of the workpiece and the shot as shown in Fig. 1a. Levers and Prior [25] performed a 2D dynamic analysis with a deformable component and a rigid spherical shot to study the residual stress profile induced by shot peening. Schiffner and Droste gen. Helling [37] used a similar axisymmetric model for simulating the residual stress profile in an elastic–plastic surface subjected to perpendicular shots with different shot peening parameters. Rouhaud and Deslaef [35] and Rouhaud et al. [36] investigated the influence of the shot and component material properties upon the residual stress profiles with a similar axisymmetric model. Meo and Vignjevic [32] predicted the residual stress profile resulting from the shot peening process with this type of model for welded joints applications.

(ii) Meguid et al. [30] developed a periodic symmetry cell with a square contact surface as shown in Fig. 1b. The main advantage of this model is its ability to simulate multiple impacts with a reduced model size. Majzoobi et al. [26] investigated the effects of shot velocity upon the residual stress profile and the development of the shot peening coverage with this model. Meguid et al. [31] implemented a slightly different

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## Nomenclature

| | |
|---|---|
| $A$ | section area of the target component |
| $\bar{A}$ | shot peening area on the surface of the target component |
| $\mathrm{Ah}(T)$ | reference arc height equation related to peening time |
| $\mathrm{AHf}(N)$ | best fitting arc height equation from the simulated arc heights |
| AHs | simulated arc height of the strip |
| $b, t, l$ | width, thickness and length of the strip |
| $C_{\mathrm{th}}(T)$ | theoretical calculated coverage |
| $\mathrm{Cf}(N)$ | best fitting coverage function from the simulated coverage |
| Cs | simulated coverage |
| $d$ | distance between adjacent shots |
| $E$ | Young's modulus of the target strip |
| $E_{\tan}$ | tangent modulus of the target strip |
| $F_x$, $M_x$ | non-equilibrated force and moment calculated from induced stress |
| $H^1$ | linear strain-hardening parameter of the target component |
| $I$ | moment of inertia of the target component |
| $\dot{m}$ | mass flow rate of shots |
| $N$ | number of random impact shots |
| PV | surface roughness |
| PVs | simulated surface roughness |
| $\mathrm{PVf}(N)$ | best fitting roughness function from the simulated roughness |
| $R$ | rate of creation of indentations (number of impacts per unit area per unit time) |
| $R_{\mathrm{v}}$, $R_{\mathrm{p}}$ | highest peak and lowest valley within the sample length for the definition of PV |
| Rz | reference experimental surface roughness |
| $r$ | radius of shot |
| $\bar{r}$ | average radius of the indentations |
| $T$, $T_{\mathrm{f}}$ | shot peening time and shot peening time to reach full coverage |
| $U_z$ | $z$ direction displacement |
| $v$ | shot velocity |
| $\varepsilon_p$ | von Mises plastic strain |
| $\mu$ | Coulomb friction coefficient between shots and target strip |
| $\nu$ | Poisson's ratio of target strip |
| $\rho_{\mathrm{s}}$, $\rho_{\mathrm{t}}$ | density of shots and target strip respectively |
| $\sigma_x^{\mathrm{ind}}$ | induced stress profile produced by shot peening |
| $\sigma_x^{\mathrm{res}}$ | residual stress profile after deformation of the strip |
| $\sigma_{\mathrm{y}}$ | yield stress of target component |

cell that consists of 5 simple unit cells to study the relaxation of peening residual stresses due to cyclic thermo-mechanical overload.

(iii) Schiffner and Droste gen. Helling [37] created a 3D model with an equilateral triangle impact surface and three symmetry surfaces to investigate the effect of adjacent shots, as shown in Fig. 1c. Their results showed that the interaction between adjacent shots should be taken into account.

(iv) Edberg et al. [11] simulated multiple impingements between shots and a surface using a 3D model with two symmetry surfaces as shown in Fig. 1d. Meguid et al. [28,29] used this kind of model to study the residual stress profiles resulting from single and twin indentations. The effect of the separation distance between two impinging shots on the equivalent stress contours and residual stresses was presented. Deslaef et al. [9] and Guagliano [14] employed a similar model with four impacts (being equiva-

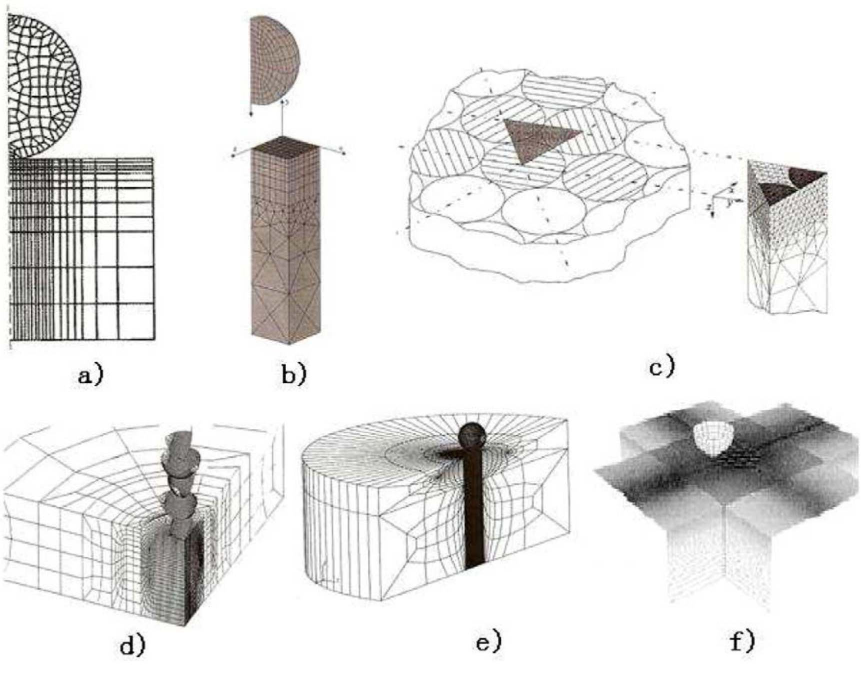

**Fig. 1.** Six types of existing models for simulating the shot peening process: (a) 2D axisymmetric model [33]; (b) 3D model with four symmetry surfaces [30]; (c) 3D model with three symmetry surfaces [37]; (d) 3D model with two symmetry surfaces [14]; (e) 3D model with one symmetry surface [5]; (f) 3D model without symmetry [38].