A 3-D NUMERICAL STUDY OF SHOT PEENING PROCESS USING MULTIPLE SHOT IMPACTS

G.H. Majzoobi* and R. Azizi*

*Mechanical Engineering Department, Faculty of Engineering, Bu-Ali Sina University, Hamadan, Iran

ABSTRACT

LS-DYNA code was employed and validated for the numerical simulations in this work. The modeling of shot peening process was accomplished by simulation of multiple shot impacts on a target plate at different velocities and angles. From the simulations, the compressive residual stress profiles were obtained and the effects of shot angle, velocity and multicipility were investigated. The results showed that, residual stress distribution was highly dependent on these parameters. A uniform state of stress was achieved at a particular number of shots. Impact velocity significantly influences the residual stress profile. The increase of velocity improves the residual stress distribution up to a particular point. Further increase in the velocity may reduce the maximum residual stress. A close agreement between the numerical residual stress profiles obtained in this work was achieved with the experimental profiles reported by Torres and Voorwald. The deviation of impact angle from 90^o must be compensated by the increase of shot velocity.

SUBJECT INDEX

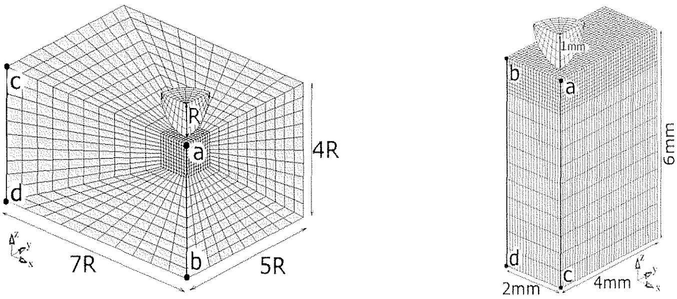
Shot peening, finite element, residual stress, impact, numerical simulation

1- INTRODUCTION

Shot peening is a hybrid process involving many disciplines of static and dynamic elasticity and plasticity. Kobayashi *et al* [1] showed that in the static tests, compression residual stress was created near the centre of the ball indentation mark. In the dynamic tests, however, tensile stress was created near the centre of the ball indentation mark and compression residual stress was created outside of the indentation. The disadvantages of experimental works along with the appearances of powerful finite element codes have attracted the attention of the researchers to numerical simulation of shot-peening process. Meguid et al [2] developed a three dimensional finite element model of dynamic single and twin shot impacts using rigid spherical shots and metallic targets. Their results indicated that the effect of shot parameters were more profound than the strain-hardening rate of the target. In another work, Meguid [3] conducted a comprehensive nonlinear dynamic elasto-plastic finite element analysis of shot-peening process. Their results revealed that multiple shot impacts result in a more uniform residual stress and plastic strain distribution and that the separation distance between shots significantly influences the residual stress field. The numerical simulation of single and multiple shot impacts carried out by Al-Hassani [4] verified the significant role played by non-linear work hardening and strain rate dependency of the target on residual stress profile and extent of surface hardening. In the present work, LS-DYNA [5] was employed for numerical simulations.

2 LS-DYNA VALIDATION

Two single balls with diameters of 3 and 5.5 mm were fired against a flat steel plate of dimensions 20x300x300 mm at velocities in the range of 100 to 400 m/s using explosive actuated gun launcher. The profiles of indentations created on the target plate by the impact of the projectiles (balls) were used for validation. In order to obtain the profile, the indentations were molded with an acrylic wax material. The moulds were then examined by optical microscopy and the profiles of the indentations were obtained. The Johnson-Cook model, $\sigma = (A + B\varepsilon^{n})(1 + C\,Ln\dot{\varepsilon})(1 - T^{*})$ [6] in which A, B, n, C and m are material constants and are measured by experiment, was designated for the simulations. Having ignored the temperature effects, the strain and strain rate constants, A, B, n and C were measured from a number of tensile tests. The tests were conducted for low strain rates using the universal Instron tensile testing machine and Flying Wedge testing apparatus [7] for higher rates. From the stress-strain curves obtained by experiments, the material constants for Johnson-Cook model were found to be: A= 320MPa, B= 420MPa, n= 0.47, C= 0.018. Two finite element models of the impact of a single shot on the target plate are illustrated in Fig. 1.



(a) (b)

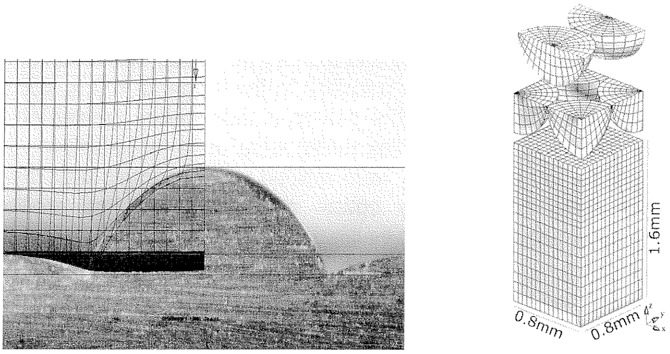
Fig. 1: Finite element models for single-shot impact simulations.

In order to validate the LS-DYNA finite element code, the profiles of the indentations created by the experiments with those predicted by numerical simulations were compared. A typical result is shown in Fig. 2(a). For more clarity, the deformed and undeformed finite element meshes were superimposed on the indentation profile obtained from the experiments as explained above.

A reasonable agreement between the experimental results and numerical prediction can be seen in Fig. 2(a). It is interesting to notice that even the rounded protuberances surrounding the indentations have been fairly predicted by the simulations.

3 MULTIPLE SHOT IMPACTS MODELLING

The simulations of shot-peening process in this work were carried out using the models consisting of 4, 6, 8, 9, 13, and 25 shots. The shot radius of 0.4 mm, the target plate dimensions of 0.8x0.8x1.6 mm and the friction coefficient of 0.1 remained constant throughout of the simulations.



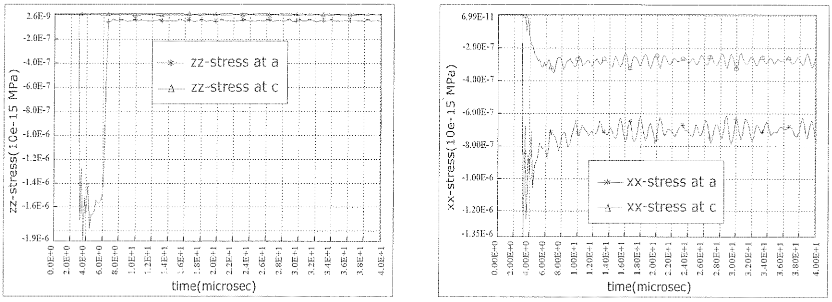
(a) (b)

Fig 2: (a) Comparison between the experimental and numerical indentation profiles (V=360 m/s, indentation depth=1.25mm, shot dia. =5.5 mm) , (b) 6-shots model.

The Material properties of the shots were: ρ=7800kg/m^3, E= 210 GPa and ν =0.3. The target plate was made of AISI 4340 steel. This material, as used by Torres and Voorwald [8], had the following particulars: ρ = 7800kg/m^3, E= 210 GPa, ν =0.3, σ_y = 1500 MPa, H (plasticity modulus) = 1600 MPa. The Cowper-Symonds material model [5 & 8], $\sigma=\sigma_0\left[1+(\dot{\varepsilon}/C)^{1/p}\right]$ with C=2x10^5, p=3.3 and σ_0= 1500 MPa was employed for the simulations. The simulations were carried out at impact velocities in the range of 50 to 100 m/sec. In order to shorten the paper only the model for 6 shots is shown. Fig. 2(b), in which the arrangement of the shots for successive impacts can be observed. Because of symmetry, in the first impact only 1/8 of each shot and in the subsequent impact, only 1/4 of each shot have been considered for the simulations.

3-1 Stress wave effects

In shot peening process where the impact velocity is of order of several hundreds m/sec, the stress waves play a significant role in the deformations.



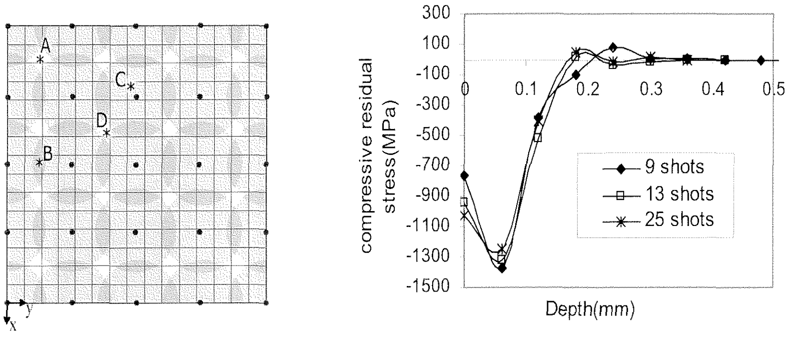
(a) (b)

Fig. 3: stress time-histories at points a and c in (a) z direction and (b) x direction

Because of three dimensionality of the process, the stress wave propagation and their interactions are very complicated. The finite element model of a single shot impact is shown in Fig. 1(b). The stress time-histories of two distinct points, a (where the shot and the target plate meet for the first time) and c (where the shot and the target plate never meet) are illustrated in Fig. 3. As it can be seen, the stress waves produced by the impact of the shot on the target plate has negligible effect on the stress time-history of the point c, located away from the point of the impact, in z direction, while the stress-time history in x-direction is significantly influenced by the stress waves.

3-2 Numerical Simulation of Multiple Shot Impacts

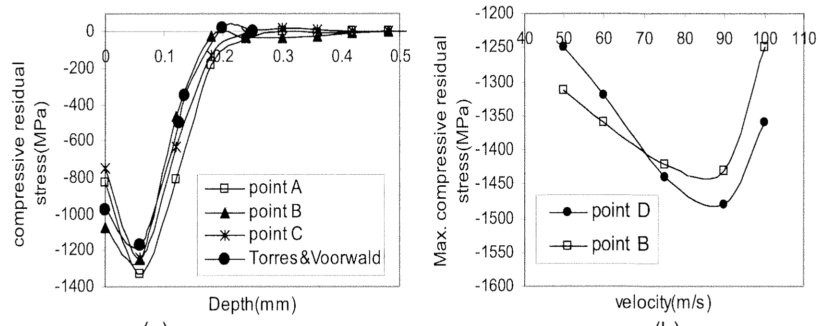
It is evident that the each point on the surface of the target plate would experience a different residual stress distribution. The variation of residual stress profile versus impact velocity has been studied at four distinct critical points on the target plate (see Fig. 4(a). The points are: (1) Point A, which is exposed to the first contact with a shot; (2) Point B, which is located in the region where some indentations, caused by successive impacts, overlap; (3) Point C, which is located at the centre of an indentation, which is created upon the first impact of the shots on the target plate; (4) Point D, which is a random point of the plate.



(a) (b)

Fig. 4: (a)The target plat e with indentations created by shot impacts. (b) Residual stress profiles at point D for 3 different shot models at a velocity of 50 m/s.

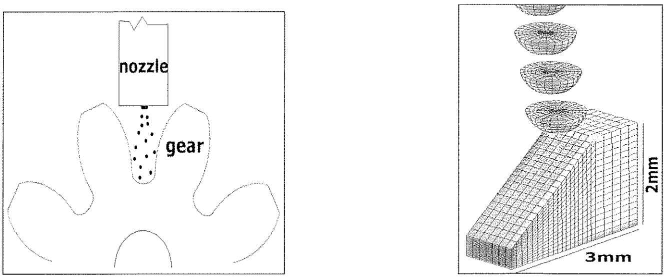
The results not shown here imply that the profile of residual stress changes rapidly as the number of shot impacts increases. The results provided in Fig. 4(b) indicate that the residual stress profiles for 13 and 25 shots models nearly coincide implying that a state of uniform stress has been reached. The residual stress profiles were obtained from the numerical simulation at point D and at the velocities of 50, 75, and 100m/sec. The variation of maximum residual stress versus impact velocity is depicted in Fig. 5(a). The figure implies that the maximum compressive residual stress rises as the velocity increases up to a point thereafter it begins to decline. Although, the maximum residual stress-velocity curve varies for different points on the target plate, but the trend of the curves is the same for all the points. The numerical predictions of residual stress profile for 25-shots model at various points are compared with the experimental profiles reported by Torres and Voorwald [8] in Fig. 5(b). As the figure indicates, the numerical and experimental results are very close. The differences can be attributed to the material model, numerical approximation and measurements.



(a) (b)

Fig. 5: (a) Variation of maximum residual stress versus impact velocity and (b) A comparison between the numerical and experimental residual stress profiles.

Some mechanical parts such as gears are shot-peened at oblique angles to their surfaces (see Fig. 6(a)) which often are of non-regular shapes. The evaluation of residual stress distribution in these cases is relatively complicated. In this work only a simple oblique surface as shown in Fig. 6(b) has been considered for numerical simulations.



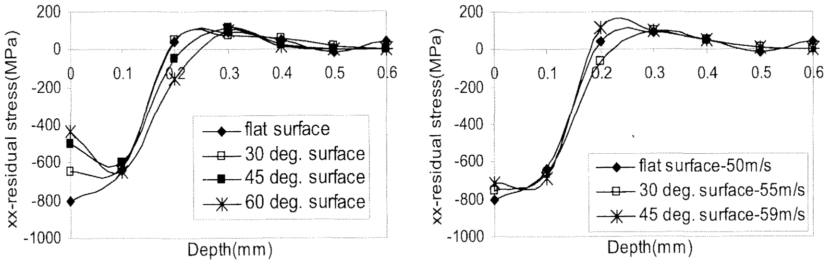
(a) (b)

Fig. 6: (a) Gear shot-peening, (b) finite element model for anoblique shot impact of 45^o.

The residual stress profiles of flat and oblique surfaces for 30, 45 and 60 degree are depicted In Fig. 7(a). As observed in the figure, when the oblique and horizontal surfaces are shot-peened under the same condition, the maximum stress for oblique surface is less than horizontal one. The magnitude of this difference depends on the surface angle and becomes more profound as the angle increases. Therefore, the reduction in impact angle from 90^o must be compensated by the impact velocity. The residual stress profiles shown in Fig. 7(b) indicate the increase of the impact velocity will result in the increase of the maximum residual stress until the profiles coincide with that obtained for a flat surface.

4- CONCLUSIONS

(i) Shot peening process can successfully be simulated by LS-DYNA finite element code providing a proper material model is selected. (ii) A uniform state of stress is achieved at a particular shots number. (iii) Impact velocity significantly influences the residual stress profile. The increase of velocity improves the residual stress distribution up to a particular point. Further increase in the velocity may reduce the maximum residual stress. (iv) The effects of any change in the angle of impact must be compensated by the increase of the shot velocity.



(a) (b)

Fig. 7: Residual stress profiles for (a) flat and oblique surfaces at the impact velocity of 50m/s and (b) various impact velocities.

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