A numerical study of the residual stress pattern from single shot impacting on a metallic component

T. Hong a,*, J.Y. Ooi a, B.A. Shaw b

a School of Engineering and Electronics, University of Edinburgh, King’s Buildings, Edinburgh EH9 3JN, UK
b Department of Mechanical, Materials and Manufacturing Engineering, University of Newcastle, Newcastle upon Tyne NE1 7RU, UK

Received 6 September 2006; received in revised form 21 September 2007; accepted 12 October 2007
Available online 3 December 2007

Abstract

Shot peening is a process in which a stream of shot is blasted against an engineering component to generate a high compressive residual stress regime at the surface of the component. This paper describes a 3D finite element dynamic analysis of single shot impacting on a metallic component. The model is first validated against a published numerical study. A parametric study is conducted to investigate the effect of shot diameter, impact velocity, incident angle and component material properties on the resulting residual stress profile. Several meaningful conclusions can be drawn regarding the effect of shot diameter, impact velocity, incident angle and initial yield stress. The effect of strain-hardening parameter is more complex as it depends on the relative magnitude of the strain–hardening yield stress to the initial yield stress and the impact energy.

Keywords: Shot peening; Dynamic finite element analysis; Residual stress

1. Introduction

Shot peening is used in numerous engineering applications. It is a cold-work process in which a stream of spherical shot is blasted against an engineering component. Each shot impacts on the target surface, causing plastic deformation. After contact between the shot and the component ceased, a high compressive residual stress is generated at the surface of the component. Compressive residual stress in the surface layers of the component greatly improves the fatigue strength. It is therefore very useful to be able to predict the pattern and magnitude of the residual stress distribution near the surface after shot peening.

Shot peening is a very complex process to model numerically, involving dynamic analysis of fast moving shot impacting on a metallic component which can often has complex geometry. There are a significant number of parameters involved in shot peening which need to be controlled and regulated in order to produce a more beneficial compressive residual stress distribution within the component. These parameters can be categorized into three groups relating to the shot, the component and the process. The shot parameters include size, density, shape, impact velocity, rotary inertia, incident angle and hardness. The component parameters include geometry, initial yield stress, work-hardening characteristics and hardness. The process parameters include mass flow rate, air pressure, angle of attack, distance between nozzle and component and percentage coverage. In order to control the resulting residual stress pattern in peened components, it would be highly beneficial to establish quantitative relationships between these parameters and residual stress characteristics.
Modelling the entire shot peening process is both extremely difficult and very expensive and would not allow a careful examination of the effect of key parameters on the residual stress pattern within the component. This paper describes a three-dimensional dynamic finite element (FE) study of single shot impacting on a metallic component. The prediction is first validated by comparison with results from the published literature. A parametric study is then performed with the aim of gaining a better understanding of the effect of several key parameters on the resultant residual stress pattern including shot size, impact velocity, incident angle and component material properties. The relationships of these parameters and the resultant residual stress characteristics can then be extended to multiple shot impacts.

2. Literature review

Several analytical and numerical studies of single shot impacts on components have been reported. Some progress has been made in recent years but the understanding of single shot impact is still far from complete. The interrelationships of the parameters and the residual stress characteristics are not clearly determined yet.

Study of the contact problem between elastic and elastic–plastic materials resulting from the loading of two bodies was pioneered by Hertz [1]. A comprehensive source of reference material can be found in the classic works of Timoshenko and Goodier [2]. Further sources of references on indentation and allied subjects are given by Goldsmith [3] and Johnson [4]. More recent analytical models [5–7] have been developed that predict the residual stress distribution and the plastically deformed region in single shot impacts on components. Because of the complexity of the shot peening process, simplifying assumptions were adopted. These assumptions make these analytic approaches unsuitable for dealing with practical applications with, for instance, complex geometry and non-linear material properties.

There have been numerous experimental studies attempting to measure the residual stress distribution, fatigue life and the influence of the shot, component and process parameters. Some of these experiments have focused on single shot impacts on components [5,8–10]. Single steel ball static indentation tests and dynamic tests were done by Al-Hassani [5]. The dynamic tests were performed using a specially designed Tornedo cartridge gun and 4.8 mm diameter steel balls with impact velocities in the range 50–150 m/s. In the paper, the measurement results of the final indentation and the depth of plastic zone were given but residual stress within the component was not measured. Mori et al. [9] and Kobayashi et al. [10] carried out the dynamic tests by dropping single shots from a height onto a plate. The diameters and impact speeds of the ball used in their experiments were 40 mm and 12.2 m/s and 50 mm and 6.3 m/s, respectively. Kobayashi et al. [10] found that the indentation shape and residual stress distribution caused by static compression are different from those caused by dynamic impact. These parameters used in [9,10] do not reflect real peening parameters and the experimental results cannot be directly compared with shot peening applications.

The FE method provides a powerful method for simulating the shot peening process. The dynamic impacting of single or multiple shots with high velocity and the double non-linearity of the problem due to the contact of two bodies and the elastic–plastic behaviour of the component can all be taken into account in an appropriate FE analysis. Hardy et al. [11] was the first to solve the contact problem of a rigid sphere indenting an elastic–perfect plastic half-space using the FE method. Al-Obaid [12] developed a dynamic elastic–plastic FE method to analyse the residual stress distribution in shot peening. Mori et al. [9,13] presented a dynamic visco-plastic FE method to analyse the peening process with plastically deforming shot. These studies were developed when computer power was limited. Computer time was emphasized and simplifying assumptions were often necessary. The accuracy of the results was not always good. The first FE analysis of shot peening using the commercial FE program DYNA3D was presented by Edberg et al. [14]. They simulated a single shot impacting visco-plastic and elasto-plastic materials but the parameters used in their study do not represent realistic peening parameters. With the availability of greatly increased computing power and the widespread use of commercial FE programs in recent years, the use of FE analysis in simulating shot peening processes is becoming an increasingly attractive alternative [15–22]. Al-Hassani et al. [15] presented a numerical simulation of single shot impact on a component and examined single shot impacting with an oblique angle but very limited results were presented. Guagliano and their co-workers [17], Baragetti [18] simulated shot peening by using the well-known FE program ABAQUS Explicit but no numerical results of single shot impacts, except several results of multiple shots impacts, were described in those papers. Deslaef and Rouhaud [19,20] presented a FE simulation of single and multiple shot impacting a component and examined the effect of rigid and deformable shot. The numerical results were compared with those experimental measurements obtained for multiple shot impacts and showed significant differences. A more systematic study of shot peening process using FE was presented by Meguid and his co-workers [21,22]. They conducted a dynamic FE analysis of single and multiple shot impacts. The effect of some parameters was investigated but not comprehensively. The majority of the numerical studies have used specific values of the model parameters so it is not easy to assimilate the effect of each parameter on the resulting residual stress distribution from the simulation. In this paper, an attempt is made to conduct a careful parametric study of single shot impact on a component to gain a sound understanding of the effect of the key parameters concerning shot peening. It is useful for connecting with the numerical studies of entire shot peening process [24,25].
3. Finite element model

The three-dimensional FE model was developed using the commercial finite element code ABAQUS 6.3 Explicit [23]. Fig. 1a and b shows the FE mesh that was used to investigate single shot impact on a component in the present paper. Only one half of the circular plate was analysed by exploiting symmetry. The circular plate was restrained against all displacements and rotations on the bottom end and was given the following geometric properties: radius \( R = 8d_{\text{shot}} \), height \( H = 3d_{\text{shot}} \) where \( d_{\text{shot}} \) is the shot diameter. Eight-node linear brick elements with reduced integration (C3D8R) were used with element size \( 0.05d_{\text{shot}} \times 0.05d_{\text{shot}} \times 0.05d_{\text{shot}} \) in the impact region. Shot chosen for industrial applications is often as hard as the impacted component material so for simplicity, a rigid sphere was chosen to model the shot. In ABAQUS Explicit, rigid bodies can be defined with an analytical rigid surface. So, a fully spherical surface with a mass positioned at its centre was used to model a shot as shown in Fig. 1a. Convergence tests were conducted using different meshes and element types to ensure the numerical results presented in this paper were not affected by the choice of mesh or element types. The material models chosen will be discussed below.

![a](image1.png)

(a) The complete three-dimensional FE mesh

![b](image2.png)

(b) Close up view of the FE mesh on x-y plane

Fig. 1. Three-dimensional FE model for single shot impacting on a component.

3. Finite element model

The three-dimensional FE model was developed using the commercial finite element code ABAQUS 6.3 Explicit [23]. Fig. 1a and b shows the FE mesh that was used to investigate single shot impact on a component in the present paper. Only one half of the circular plate was analysed by exploiting symmetry. The circular plate was restrained against all displacements and rotations on the bottom end and was given the following geometric properties: radius \( R = 8d_{\text{shot}} \), height \( H = 3d_{\text{shot}} \) where \( d_{\text{shot}} \) is the shot diameter. Eight-node linear brick elements with reduced integration (C3D8R) were used with element size \( 0.05d_{\text{shot}} \times 0.05d_{\text{shot}} \times 0.05d_{\text{shot}} \) in the impact region. Shot chosen for industrial applications is often as hard as the impacted component material so for simplicity, a rigid sphere was chosen to model the shot. In ABAQUS Explicit, rigid bodies can be defined with an analytical rigid surface. So, a fully spherical surface with a mass positioned at its centre was used to model a shot as shown in Fig. 1a. Convergence tests were conducted using different meshes and element types to ensure the numerical results presented in this paper were not affected by the choice of mesh or element types. The material models chosen will be discussed below.

![c](image3.png)

Fig. 3. Stress–strain behaviour of the linear elastic–strain-hardening plastic material.

![d](image4.png)

Fig. 2. Numerical validation of single shot impacting on a component.
4. Numerical verification of single shot impact model

Since experimental measurement of single shot impact was very rare and no experimental data can be found in the literature for comparison with this study, a comparison was made with the numerical study of Meguid et al. [21] which were obtained using ANASYS computer program.

Meguid et al. [21] used the following properties for their single shot impact analysis: width $W = 3.5$ mm, height $H = 2$ mm, breadth $B = 2.5$ mm, mass density $\rho = 7800$ kg/m$^3$, elastic modulus $E = 200$ GPa, initial yield stress $\sigma_0 = 600$ MPa and a linear strain-hardening parameter $H^1 = 800$ MPa. The diameter and mass of shot was $d_{\text{shot}} = 1$ mm and $m = 4.085$ mg, respectively. Coulomb law with friction $\mu = 0.25$ was considered between the shot and component during contact. Fig. 2 shows the variation of residual stress with depth along the central axis in the component for both Meguid et al. [21] and the present study. Single shot impacts with two different impact velocities are compared. There is a close match between the two sets of numerical results, providing some limited validation for the accuracy of the present analysis.

5. Single shot impact parametric study

Following the numerical validation, a parametric study of single shot impact on a component was conducted. The aim was to investigate systematically the effects of shot

Fig. 4. Influence of shot diameter ($\sigma_0 = 760$ MPa, $v = 75$ m/s).
and component parameters on the residual stress pattern and to build a better understanding of the single shot impact. This study constituted a comprehensive set of residual stress predictions arising from the key shot peening parameters. The numerical results from this study thus gave a sound basis for investigating multiple shots impact by using combined finite element and discrete element analysis [24,25].

In the present single shot model, the component is assumed to be an elastic–plastic with isotropic hardening material. The reference case for the parametric study uses the identical elastic modulus, Poisson’s ratio, density adopted in [21] and the initial yield stress is $\sigma_0 = 760$ MPa for the component. To study the effect of strain-hardening, a linear strain-hardening parameter $H^1$ as defined graphically in Fig. 3 was used. In an attempt to separate the influence of strain-hardening on other parameters, two reference values of $H^1$ were explored in this parametric study: $H^1 = 0$ (perfectly plastic) and $H^1 = 500$ MPa. For the shot, the reference case adopted a normal impact velocity of 75 m/s with a shot diameter of $d_{\text{shot}} = 1$ mm. Using a steel density of 7800 kg/m$^3$, the mass of the shot $m_1 = 4.085$ mg. No friction was considered between the shot and component during contact.

The results are plotted in a normalised manner using the normalised depth $z/d_{\text{shot}}$, in which $z$ is the deformed depth along the centre line of the component. The residual stress $\sigma_{xx}$ is normalised with $\sigma_0$ the initial yield stress of the component. All residual stress distributions in this paper are

![Normalised residual stress distribution for $H^1 = 0$](image-a)

![Normalised residual stress distribution for $H^1 = 500$ MPa](image-b)

Fig. 5. Influence of shot velocity ($\sigma_0 = 760$ MPa).
plotted with the normalised deformed depth along the centre line of the component unless otherwise specified.

5.1. Influence of shot diameter

The influence of the shot diameter on the residual stress profile within the component was investigated here. Four different shot diameters \( d_{\text{shot}} = 0.5, 1, 2, 3 \text{ mm} \) and a shot impact velocity \( v = 75 \text{ m/s} \) were adopted. Elastic–perfect plastic \( (\sigma_0 = 760 \text{ MPa}, H' = 0 \text{ MPa}) \) and elastic–strain-hardening plastic \( (\sigma_0 = 760 \text{ MPa}, H' = 500 \text{ MPa}) \) materials were considered. Fig. 4a and b shows the normalised residual stress distributions along the centre line for these two material models. The differences between the normalised results for different shot diameters are extremely small for each of the material models. The choice of normalising the depth with shot diameter and the residual stress with initial yield stress was clearly the correct decision.

The main conclusion is therefore that the depth of compressive residual stress zone increases linearly with the shot diameter and the magnitude of surface residual stress remains almost constant with varying shot diameter. The maximum sub-surface residual stress is almost constant and occurs at a deformed depth equivalent to 7% of the shot diameter.

5.2. Influence of shot velocity

The influence of shot impact velocity on residual stress pattern was investigated next. Only normal impact was

Fig. 6. Influence of shot velocity \( (\sigma_0 = 760 \text{ MPa}) \).
considered. Fig. 5a shows the residual stress profiles for the reference perfect plastic material \((H^1 = 0)\) whereas Fig. 5b shows the corresponding profiles for the reference strain-hardening plastic material \((H^1 = 500 \text{ MPa})\). It can be seen that as the impact velocity increases, the depth of the compressive residual stress zone increased slightly for both material models in a similar fashion. For the surface and the maximum sub-surface residual stress, the impact velocity did not appear to have any noticeable effect in the perfect-plastic material, but showed a significant effect in the strain-hardening material.

Since the predictions of the surface residual stress and the maximum sub-surface residual stress are the most important outcomes for this study, the relationship between these and the shot impact velocity was extracted from the results above and explored further in Fig. 6a and b. The surface compressive residual stress remained relatively constant between 0.8 and 0.9\(\sigma_0\) for the perfect-plastic case, whereas for the strain-hardening case, it could be seen to increase from 0.65\(\sigma_0\) to 1.4\(\sigma_0\) as the impact velocity increased from 25 m/s to 150 m/s. This can be attributed to the greater work-hardening occurring with the greater force arising from the higher impact velocity. The effect of impact velocity on the maximum sub-surface residual stress was less significant (Fig. 6b). For the perfect-plastic material, the value remained almost constant at 1.1\(\sigma_0\) with varying shot velocity. For the strain-hardening material, the maximum compressive residual stress increased from 1.2\(\sigma_0\) to 1.5\(\sigma_0\) as the velocity increased from 50 m/s to 150 m/s. It is interesting to note that the results for the lowest velocity of 25 m/s appeared to not follow the trend. This is being investigated further but since velocity of 25 m/s lies outside the practical range of impact velocity in industrial shot peening (50–150 m/s), it should not affect the main conclusions of this study.

5.3. Influence of initial yield stress

The effect of initial yield stress \(\sigma_0\) on the residual stress distribution was investigated first. Again, the perfect-plastic case (Fig. 7) and the strain-hardening plastic case (Fig. 8) were studied separately in an attempt to identify the effect of strain-hardening. For the perfect-plastic case, the different initial yield stresses lead to only very slightly different normalised results. Therefore, it can be concluded that, for the perfect-plastic case, the magnitude of residual stress increases linearly with increasing initial yield stress with the maximum compressive sub-surface residual stress of the order of 1.1\(\sigma_0\) occurring at a depth equivalent to 10% of the shot diameter. The surface compressive residual stress is of the order of 0.8–0.9\(\sigma_0\).

For the case with strain-hardening parameter \(H^1 = 500 \text{ MPa} \) (Fig. 8), it can be seen that the resulting residual stress is still strongly influenced by the magnitude of the initial yield stress, but the presence of strain-hardening has an additional influence. Comparing the residual stress profiles for the strain-hardening material in Fig. 8a with the perfect-plastic material in Fig. 7 for the case of the highest initial yield stress of \(\sigma_0 = 1140 \text{ MPa}\), it can be seen that the differences are very small. This is in contrast with the case of the smallest initial yield stress of \(\sigma_0 = 380 \text{ MPa}\) where significant differences can be seen between the perfect plastic and the strain-hardening cases, in that a larger normalised residual stress and a deeper compressive stress zone are predicted when the initial yield stress is small. It appears that the hardening parameter only has a significant influence on the resulting residual stress when the initial yield stress is relatively small. In other words, when the initial yield stress is very high, then the impact may not mobilise much of the strain-hardening region of the material, and one can therefore expect little or no effect of strain-hardening on the outcome.

---

**Fig. 7.** Influence of initial yield stress \(\sigma_0\) \((H^1 = 0, v = 75 \text{ m/s})\).
For further clarity, the residual stress profiles for the strain-hardening case in Fig. 8a are replotted in Fig. 8b with the direct values of the residual stress in MPa. Whilst the normalised plot is better for drawing more general observations, this plot demonstrates most clearly the strong influence of initial yield stress on the profile and magnitude of the residual stress.

5.4. Influence of strain-hardening parameter

The effect of strain-hardening characteristics on the residual stress distribution was investigated with different hardening parameters \( H^1 = 0, 300, 500, 1000, 1500 \) MPa. The results with the reference initial yield stress of 760 MPa and the reference shot impact velocity of 75 m/s are shown in Fig. 9. The depth of compressive residual stress zone increases with increasing hardening rate. However, the effect of strain-hardening on the surface and maximum sub-surface residual stress is less clear for this reference case with the surface value varying between \( 0.75\sigma_0 \) and \( 1.1\sigma_0 \) and the maximum residual stress varying between \( 1.1\sigma_0 \) and \( 1.25\sigma_0 \).

It is clear from the results obtained so far that strain-hardening will only have an effect if the magnitude of the impact energy is such that the strain-hardening part of the material behaviour is mobilised. This depends principally on the initial yield stress and the impact velocity (for a constant shot mass). In an attempt to clarify the effect of strain-hardening, a matrix of simulations covering a range of impact velocities, initial yield stresses and strain-

![Diagram](image-url)

Fig. 8. Influence of initial yield stress \( \sigma_0 (H^1 = 500 \text{ MPa}, v = 75 \text{ m/s}).\)
hardening parameters was performed. A sample of the numerical results is shown next to demonstrate the key findings.

Fig. 10a shows the relationship between the surface residual stress as a function of the hardening parameter. The results for two different impact velocities \( v = 75 \) and 125 m/s are shown. In general, it is noted that the surface compressive residual stress increases with increasing hardening parameter \( H' \) when the hardening parameter is small and arrives at a peak value before decreasing as \( H' \) increases further. This pattern is observed for a wide range of impact velocity and initial yield stress and is being investigated further. The pattern indicates two separate phenomena, one dominating when the hardening parameter is small and the other coming into play strongly when the hardening parameter is large.

One possible explanation is that when the hardening parameter is small compared to the initial yield stress, the magnitude of the surface residual stress is mainly determined by the initial yield stress and increased moderately with the further work-hardening induced by the hardening parameter. As the hardening parameter increases, the capacity for the surface region of the component to yield plastically reduces with the depth and diameter of shot indentation becoming smaller. There comes a point when less kinetic energy of the shot is consumed in the plastic deformation of the surface region and more energy is available for plastic deformation in the deeper region. This results in a reduction in the magnitude of the surface residual stress.

The variation of the maximum sub-surface residual stress with hardening parameter is shown in Fig. 10b. The effect of hardening parameter on the magnitude of maximum sub-surface residual stress is not as pronounced as that on the magnitude of surface residual stress. In general, the maximum sub-surface residual stress increases with increasing hardening parameter \( H' \) when the hardening parameter is small. The maximum residual stress appears to reach the largest value before flattening out as \( H' \) increases further. It is noted that the largest maximum sub-surface residual stress occurs at approximately the same hardening rate that gives the largest surface residual stress (compare Fig. 10a with 10b).

### 5.5. Influence of incident angle

Then single shot oblique impacting on a component was investigated. As shown in Fig. 11, the impact velocity of shot is \( v = 75 \) m/s with an incident angle \( \theta \) (\( \theta = 60^\circ \) was used for the reference case), so the components of velocity along three coordinates are \( v_x = -v \cos \theta, \ v_y = 0 \) and \( v_z = -v \sin \theta \). The residual deformations at the component surface after single shot impacting with different incident angle \( \theta = 60^\circ \) and \( 90^\circ \) are compared in Fig. 12. It reveals that the residual deformation caused by shot impacting with \( \theta = 60^\circ \) is not symmetric about the centre line of the component, the high pile-up is about 0.016 mm similar as that of \( \theta = 90^\circ \) and the low one is about 0.0096 mm. The indentation generated by oblique impact (\( \theta = 60^\circ \)) is about 83% of that induced by normal impact.

Fig. 13 shows the contour of residual stress \( \sigma_{xx} \) within the component induced by single shot impacting with an incident angle \( \theta = 60^\circ \). In these contours, only the compressive residual stresses were plotted and normalised with \( \sigma_0 \) the initial yield stress of the component. The contour of residual stress \( \sigma_{xx} \) within the \( x-z \) plane at \( y = 0 \) is shown in Fig. 13a. It can be seen that the residual stress distribution is not symmetric about the centre line of the component yet, although the shot impacts on the centre point of the component. For further clarity, the contour of residual stress \( \sigma_{xx} \) within same plane for normal impact case is plotted in Fig. 14a. Compared to the residual stress profile
induced by shot normally impacting, the magnitude of compressive residual stress and the volume of compressive residual stress zone for oblique impact case were smaller, and the maximum sub-surface residual stress did not occur beneath the impact point (the centre point of the component). The contour of surface residual stress \( \sigma_{xx} \) induced by oblique impact and normal impact are shown in Figs. 13b and 14b, respectively. It can be seen that as the incident angle decreases, the magnitude of compressive surface residual stress and the area of the compressive surface residual stress zone decreased. The oblique impact appeared to have a more significant effect on the surface residual stress than that on the maximum sub-surface residual stress. In addition, the variation of the depth of the plastic deformation zone with the impact time is shown in Fig. 11. Single shot impacting with an incident angle \( \theta \) on a component.

Fig. 10. Influence of linear strain-hardening parameter \( H' (\sigma_0 = 760 \text{ MPa}) \).

(a) Normalised surface residual stress vs. strain hardening parameter

(b) Normalised maximum sub-surface residual stress vs. strain hardening parameter
in Fig. 15. It can be seen that the plastic deformation occurs in the surface region while shot impacting on the component and increases very quickly with shot impacting deeply. Then the depth of the plastic deformation zone

reaches at a peak value ($\approx 0.35$ mm) when the impact time is about 0.9 $\mu$s, and keeps almost constant as shot impacting further and rebounding from the component.

Fig. 16a shows the variations of the surface residual stress, maximum sub-surface residual stress and depth of
Fig. 15. Depth of the plastic deformation zone vs. impact time.

Fig. 16. Influence of incident angle. 

(a) Influence of incident angle $\theta$

(b) A-A' line in an impacted component
the compressive residual stress zone with the incident angle. For easy to clarify the magnitudes of the residual stresses plotted in Fig. 16a, A–A' line as shown in Fig. 16b is stated. A–A' line is a deformed straight line and coordinate x is the distance from A–A' line to the centre line of the component (z-axis). It should be noted that the maximum compressive residual stress within the component is on A–A' line. So the A–A' line may be at different position for different incident angle case, such as the distance x is about −0.2 mm for θ = 60°, whereas for θ = 90° it should be x = 0. The surface residual stresses in Fig. 16a are those values of the residual stresses at point A with different incident angles. As shown in Fig. 16a, shot impacting with θ = 60–90° has no significant effect on the maximum sub-surface residual stress and the depth of the compressive residual stress zone, but produces a significant decrease of the surface residual stress. While shot impacts with an incident angle less than 60°, both the maximum residual stress and the depth of compressive residual stress zone decreased with the incident angle decreasing. It means that the impact with a small incident angle produces small compressive residual stresses and shallow compressive residual stress zone as expected, for single shot, normal impact or close to normal impact with θ → 90° produces the most beneficial compressive residual stress regime within the component.

6. Conclusions

A 3D finite element dynamic analysis of single shot impacting on a component has been presented. The model was validated against another published numerical study. A parametric study has been conducted to investigate the effect of the shot and component parameters on the residual stress distribution. The parameters investigated include shot diameter, impact velocity, incident angle, initial yield stress and hardening parameter.

It has been found that the shot diameter has a negligible effect on the magnitude of surface and maximum sub-surface residual stresses but the depth of the residual stress zone increases linearly with increasing shot diameter. With increasing shot impact velocity, the surface and maximum sub-surface residual stresses remain unchanged for a perfect-plastic material, but increase significantly for the plastic strain-hardening case. While single shot impacting with an incident angle on a component, normal impact or close to normal impact produces the most beneficial compressive residual stress regime within the component.

For the perfect-plastic case, the magnitude of residual stress increases linearly with increasing initial yield stress with the maximum compressive sub-surface residual stress of about 110% of the initial yield stress value occurring at a deformed depth of 10% of the shot diameter. The effect of strain-hardening on residual stress is much more complex as it depends on the relative magnitude of the strain-hardening yield stress to the initial yield stress and the impact energy available (the impact velocity for a constant mass shot). However the depth of the compressive residual stress zone always increases as the strain-hardening parameter increases.

The present numerical study demonstrates the complex interaction between the material non-linearity with the non-linear contact problem in shot peening. The results represent a comprehensive set of residual stress predictions arising from the key shot peen parameters and should be useful for connecting with other numerical studies of shot peening.

Acknowledgements

The authors gratefully acknowledge the funding for this work from the UK Engineering and Physical Sciences Research Council (EPSRC Grant, GR/R28188), with contributions from ISPC Impact Finishers.

References


[25] Hong T, Ooi JY, Shaw BA. A numerical simulation to relate the shot peening parameters to the induced residual stress. Internal Report, School of Engineering and Electronics, University of Edinburgh, 2005.