Investigating Effect of Shot Speed in Shot Peening Process on Residual Stress Level of Piston Material

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***Abstract* - Shot peening is a complex and random process which is controlled by many input parameters. Numerical methods, which are normally used for impact problems will prohibitively put strain on the computing resources since a large number of impacts are involved in the computations. 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 aluminium (LM 13) component and then actual fatigue testing is carried out followed by shot peening process. A study is conducted to investigate the effect of shot impact on component surface and the resulting residual stress profile and its impact on fatigue life of piston component. 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. So modelling used in this paper is help full to predict residual stress after shot peening. This will becomes guide for selection of shot peening parameter which will reduce iterations in actual shot peening process and saves lot of effort in finalizing shot peening parameter.**

Keywords: Shot Peening, Residual Stress, Finite Element Modelling, Fatigue Testing, LM13.

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, it involves dynamic analysis of fast moving shot impacting on a metallic component which can often has complex geometry. There are some significant numbers 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. A parametric study is then performed with the aim of gaining a better understanding of the effect of shot impact on the resultant residual stress pattern.

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 [5–6] 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, 7–8]. 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 this paper measurement of residual stress is carried out as the function of time.

The FE modeling 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. A dynamic elastic–plastic FE method to predict the residual stress distribution in shot peening was developed by Al-Obaid [10] Hardy et al. [9] was the first to solve the contact problem of a rigid sphere indenting an elastic–perfect plastic half-space using the FE method. 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 goodAl-Hassani et al. [11] 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 [12], Baragetti [13] 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 [14, 15] 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 [16, 17]. 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 study, 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.

3. FINITE ELEMENT MODEL

The model used for shot peening simulation is generated in LS Dyna, consist of three dimensional circular body of Aluminium (LM 13) material having following boundary condition and geometrical properties and act as target in impact analysis. Target have radius R = 8dshot, height H = 3dshot where d shot is the shot diameter.

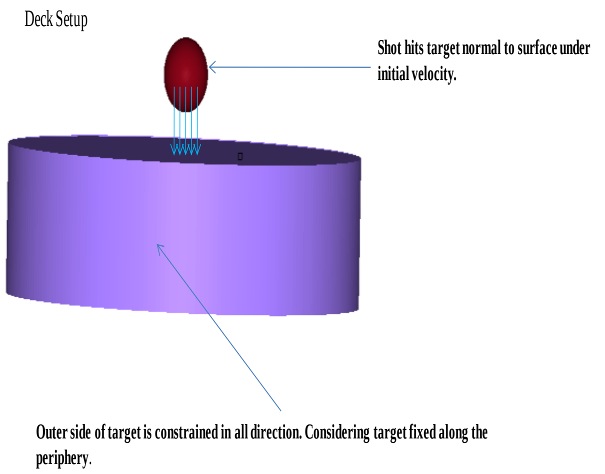

Fig.1 Boundary conditions

Material	Tensile strength	Young's modulus	Poisson's ratio	Density
Aluminium LM 13	180 Mpa	73.1 Gpa	0.35	2070Gm/ Cm 3

Table 1 Target properties

Young's modulus	Poisson's ratio	Density	Hardness HRC	Shot size
2.1*10E5 Mpa	0.265	7200 Kg / M 3	45	1mm S 320 steel

Table 2. Shot Properties

The three-dimensional FE model was developed using the commercial finite element code Ls Dyna. Fig. 2a and b shows the FE mesh that was used to investigate single shot impact on a component in the present paper.

Mesh Model

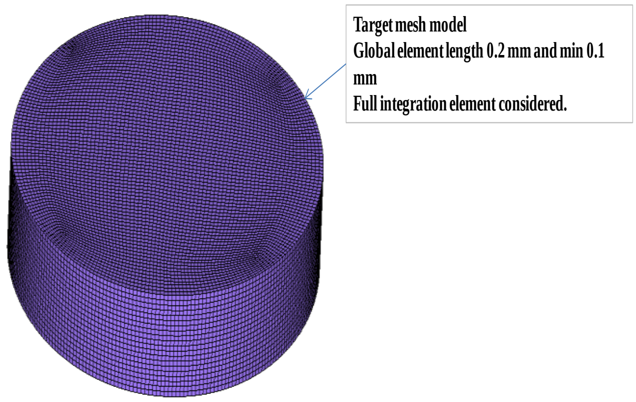

Fig.2 a Mesh model

In LS Dyna, 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. 1 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.

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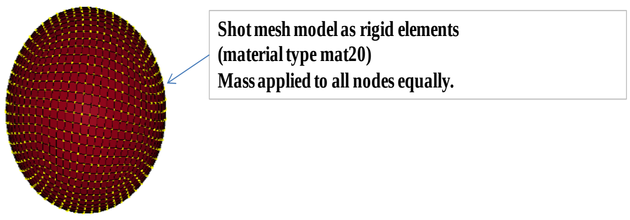

Fig.2 b mesh model

4. PARAMETRIC STUDY OF SINGLE SHOT IMPACT MODEL:

Experimental measurement of single shot impact was very rare. No experimental data is found in the literature for comparison with this study. Fig 2 shows impact zone of metallic shot on aluminium LM13 target with a velocity and at perfectly at normal to the surface of circular target.

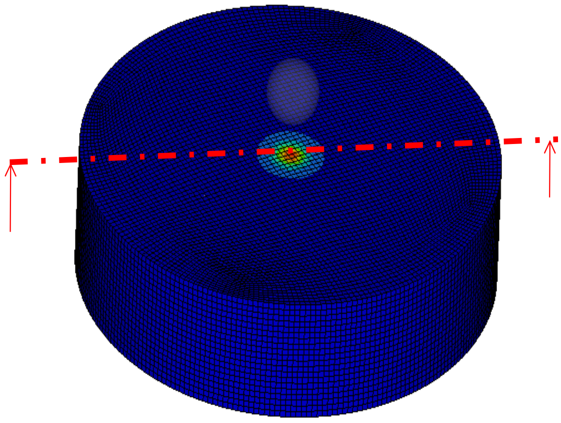

Fig.3 Shot impact zone.

Following are the results of shot peening simulation with different speeds of metallic shot. In this parametric study only one parameter is varied & rest all parameters are maintained constant. In this study other process parameter like shot size maintained as 1mm, distance between nozzle & target is 150mm & angle of impact taken as 90^0.First iteration is carried at a speed of 15 meters per second whose result of stress & displacement variation are shown below.

5. FINITE ELEMENT MODELLING AT DIFFERENT SHOT SPEED-:

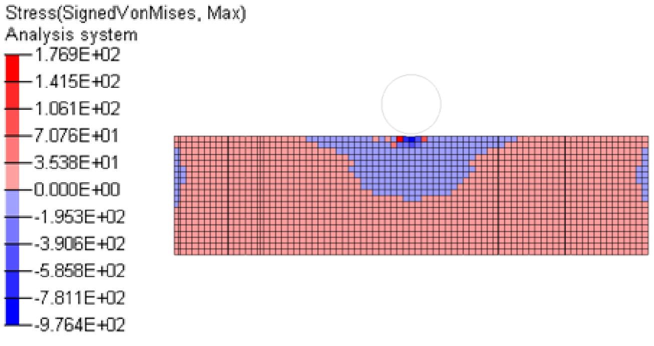

Fig.4 Stress contour at shot speed 15 m/s

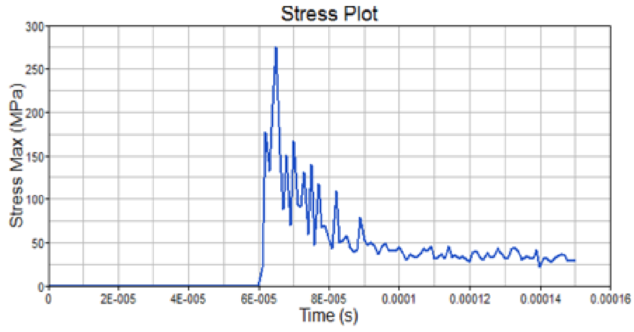

Fig.5 Stress plot at shot speed 15m/s

Figure 4 & 5 shows stress contour and stress plot at a shot speed of 15 m/s. Stress plot shows stresses developed in circular plate. Stress plot should be drawn for time interval from point of contact of shot up to rebounding of shot. Stress plot shows maximum stress developed at the time of contact is 275 Mpa. After rebounding of shot due to stress relaxation some part of stress is released. After 0.00014 second 27 Mpa residual compressive stress retained in material. This residual stress forms compressive stress layer on material surface.

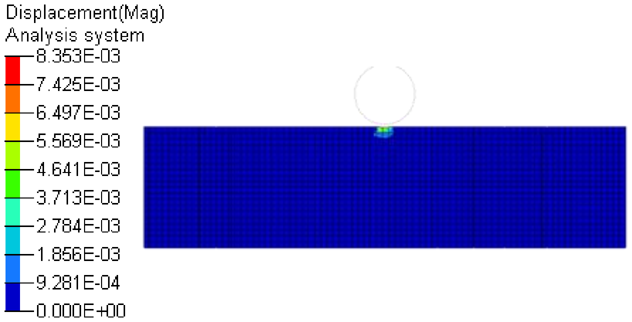

Fig.6 Displacement contour at shot speed 15m/s

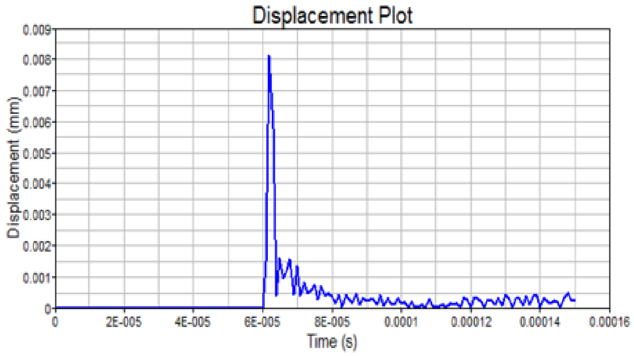

Fig.7 Displacement plot at shot speed 15m/s

From figure 6 & 7 it is clear that at the time of contact material deform 0.008 mm & due to elastic recovery, material contracts and final displacement is 0.0005 mm.

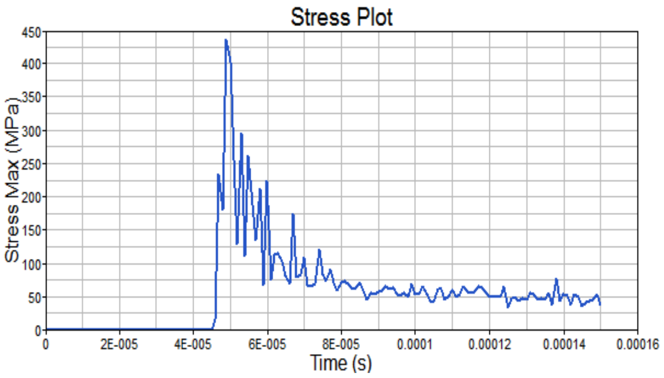

Fig. 8 Stress plot at shot speed 20m/s

Fig. 8 shows stress contour and stress plot at a shot speed of 20 m/s. Stress plot shows stresses developed in circular plate. Stress plot shows maximum stress developed at the time of contact is 427 Mpa. After rebounding of shot due to stress relaxation some part of stress is released. After 0.00015 second 50Mpa residual compressive stress is retained in material. This residual stress forms compressive stress layer on material surface.

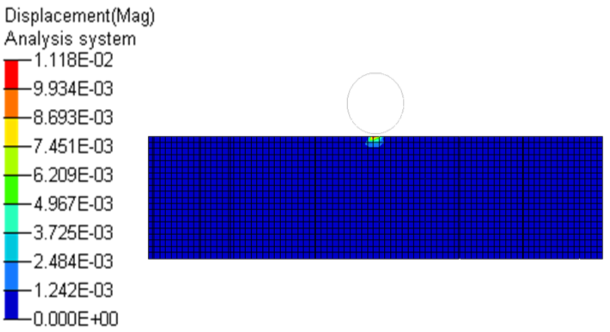

Fig.9 Displacement contour at shot speed 20 m/s

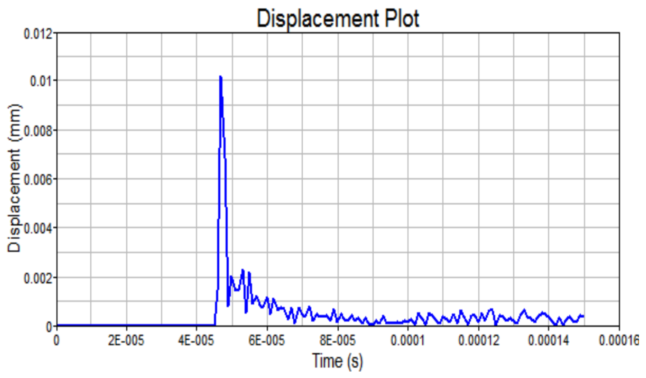

Fig. 10 Displacement plot at shot speed 20 m/s

Fig. no.9 and 10 shows displacement plot of impact analysis at shot speed of 20 m/s. From the displacement plot it is clear that plate deformation is about 0.005mm which is negligible. In this way we can find out stress retained in material after relaxation of stress.

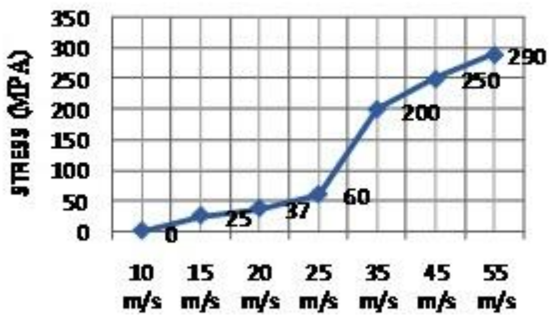

Fig. 11Residual stress intensity at variable shot speed

Stress plot and displacement plot obtained by above method shows result of analysis at different speed of shot. Consolidate graph of residual stress at different speed is shown below. Fig. 11 shows residual stress obtained in material at different speed. From graph it is clear that at speed 35 m/s residual stress is 200 MPa which exceed yield limit of material. Graph clearly shows as speed increases residual stress value also increases.

Deflection plots obtained for all these speeds maximum deflection in material is 0.022 mm which is negligible. From above study it is clear that there may be chances of getting good fatigue life after shot peening for speed of shot in between 15 m/s to 35 m/s.

11. CONCLUSION-:

This study presents a 3D finite element dynamic analysis of single shot impacting on a component. This parametric study has been conducted to investigate the effect of the single shot impact on the residual stress distribution in surface layer. The parameters which are investigated include shot velocity.

This study is particularly carried out for piston material (LM 13). In this study standard specimen of LM 13 material is prepared and shot peening is carry out on the same instead of actual piston. From finite element analysis and experimental work following conclusions are drawn.

1. In the shot peening process shot speed is one of the important parameter that influences the residual stress level. It observed that beyond shot speed 35 m/s residual stress level crosses yield stress level of material hence chances to destruct material so from the FE Analysis it is clear that 35 m/s is optimum speed for shot peening for LM 13 piston material.

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