FINITE ELEMENT SIMULATION OF SHOT PEENING AND STRESS PEEN FORMING

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ABSTRACT

Shot peening is widely used to improve fatigue life of the metal component. It can also induce the distortion of thin component, which is called peen forming and is widely used for shaping aircraft wing skin. Shot peening surface coverage, intensity and saturation are important shot peening control parameters and have greatly influence on shot peening and peen forming results. Due to the insufficient investigation and control of these parameters, the design of peen forming for a specific shape has been based on experimental trial and error. The objective of this paper is to simulate the actual shot peening and peen forming process and relate the results with shot peening parameters. A newly developed 3D finite element model with multiple random distributed shots has been developed to simulate the shot peening process. An Implicit-Explicit sequence solution is applied to compare the results of conventional peen forming and stress peen forming.

KEY WORDS

Finite element method, Shot peening coverage, Shot peening intensity, Conventional peen forming, Stress peen forming

INTRODUCTION

Shot peening is a cold-working process and is widely used to improve the fatigue life of metallic component. It is accomplished by bombarding the surface of the component with spherical shots at high velocities. Explicit finite element models have been widely used to simulate the shot peening process. Different types of finite element models have been established. (K.I. Mori, 1994) used a 2D axi-symmetric model to simulate the plastic deformation of the work piece. (J. Edberg, 1995) simulated the impact between a shot and a surface by a quarter of a 3D model with two symmetric surfaces. (S.A. Meguid, 2002) developed a representative symmetry cell with a square contact surface and 4 symmetric surfaces. The advantage of this model is its ability to simulate the multiple impacts with the minimum model size. (J. schwarzer, 2002) developed a three-dimensional model without symmetric surface. This model can be used to effectively simulate the fact that the shots impact one after the other instead of impacting simultaneously. Its results showed that the impact sequence has a great influence on the development of residual stresses.

Shot type and size, shot velocity, surface coverage, saturation and intensity are the importance shot peening control parameters that greatly influence the effectiveness of the shot peening treatment. Of these parameters, the influences of shot type, shot size and velocity on shot peening results have been widely studied by theoretical analysis and Finite Element Method. While the investigations of surface coverage, saturation and intensity are mainly performed by experiments.

Shot peen forming is a dieless process, which has been widely used to form various aircraft components since the 1960's. After shot peening on thin component, the plastic deformations induce a residual stress distribution in the component and a convex curvature of the component towards the peening direction. Conventional peen forming causes the sheet to deform to a spherical shape, because it causes same curvatures of deformation throughout the directions of the component. For a complicated aircraft component, which has different curvatures of the deformation in the chordwise and spanwise direction, a technique called stress peen forming is preferred. In stress peen forming, the component is elastically pre-bent along spanwise direction during peen forming, so that after peen forming, the chordwise contour curvature will be further increased (K. Li, 1981).

For conventional peen forming, several theoretical and numerical works have been performed to study the residual stress distribution and the deformation of the component after peen forming (Y.F. AL-Obaid, 1990). While most of the investigations of stress peen forming are based on experiments and empirical relationships. In this paper, a new 3D finite element model with random distributed multiple shots was firstly developed. With this model, shot peeing surface coverage, shot peening saturation and intensity can be studied to acquire their relationship with the number of shots impacting at a representative surface. In case of stress peen forming, Implicit and explicit sequence solution was applied to simulate the induced stress under pre-bending conditions. With these induced stresses, the stretching forces and bending moments were calculated, then the deformations of an aluminum strip after conventional peen forming and stress peen forming were investigated and compared.

DESCRIPTION OF FINITE ELEMENT MODEL

Explicit software LS-DYNA has been used to simulate the shot peening process. Figure 1 presents the finite element model with multiple randomly distributed shots and aluminum component.

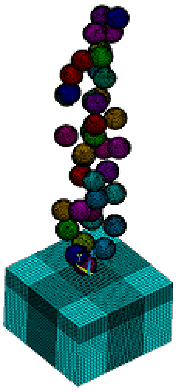

Fig.1 3D random Finite element model of shot peening

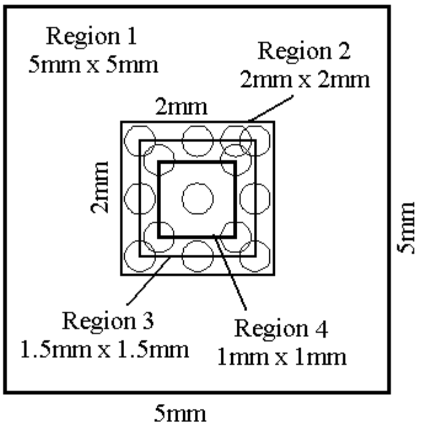

Fig.2 Representative surface

The dimensions of the aluminum plate are 5mmX5mmX3mm. 5 group different number of randomly distributed shots N={6, 12, 24, 48 and 96} with radius 0.5mm are impacted to the component vertically. In order to consider the influence of random impact sequence and location, for each number of shots, 5 random impacts were simulated. The mesh in the region being impacted by the shots is much finer that in the other region. The fine meshing dimensions are 2mmX2mmX1mm, as region 2 in Figure 2. After convergence study, the element sizes in the impact region were chosen to 0.05mm. The center of shots impacting indentation located inside region 3 with the dimensions 1.5mmX1.5mm. Matlab program was combined with ANSYS APDL language to develop randomly distributed shots. A surface of region 4 with dimensions 1mmX1mm is selected as a representative surface to study the surface coverage and roughness. A volume of 1mmX1mmX3mm is selected as a representative volume to study intensity, saturation and average residual stress profiles. Four side surfaces and bottom surface of the component are constrained.

A bilinear isotropic elastoplastic model with elastic modulus 71.7GPa, Poisson's ratio 0.33, density 2810Kg/m^3, yield stress 503 MPa and tangent modulus 3.3GPa was selected to simulate high strain aluminum component. The shot is assumed to be rigid due to its relatively high rigidity and hardness values compared with the target aluminum, and the density of the steel shot is 7800Kg/m, shots velocity is 50m/s,.

SURFACE COVERAGE

Coverage is defined as the ratio of the area covered by plastic indentation to the complete surface area treated by shot peening expressed in percentage. For practical purposes, 98% coverage is considered as full coverage, A 200% coverage is attained by peening for twice the peening time required to attain 98% coverage.

Figure 3 presents the Von Mises equivalent plastic strain contour after one vertical impact. It can be found that the maximum plastic strain is beneath the impact point. Figure 4 shows the plastic strain and the Uz displacement profiles at the component surface. A circular indentation is obtained for a single vertical impact. Therefore, the results are presented for a plane passing through the circular indent center. It can be seen that an indentation of radius r = 0.2mm was obtained for this shot peening case. It can also be seen that the Von Mises equivalent plastic strain is equal to 0.027 at this location. Therefore, we considered all points where the Von Mises equivalent plastic strain greater than 0.027 as impacted indentation. This definition enables us to compute the coverage as the ration of the number of nodes which have plastic strain larger than 0.027 to the total number of nodes on the representative surface, which equal to 441 in this specific model.

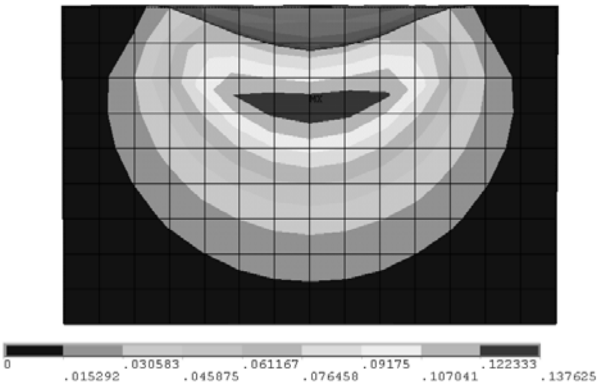

Fig.3 Von Mises equivalent plastic strain contour beneath one vertical shot impact

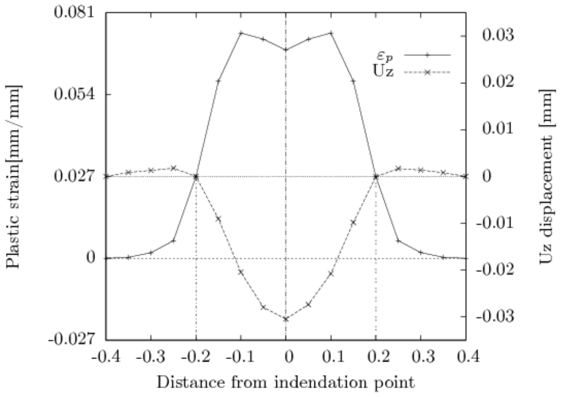

Fig.4. Von Mises plastic strain profile and indentation profile(xz plane).

Figure 5 presents relationship between coverage and number of shots (25 simulated coverage have been presented). An Avrami Equation

$$C(N) = 100(1 - e^{-mN}) \qquad (1)$$

where N is the number of shots was fitted through these data with the fitting parameter m=0.082 and led to a regression coefficient R^2=0.969.

From this Avrami Equation, it can be calculated that coverage reach 98% with N=48. In addition, a 200% coverage with N=96 under these specific peening conditions can be obtained according to the definition of 200% coverage.

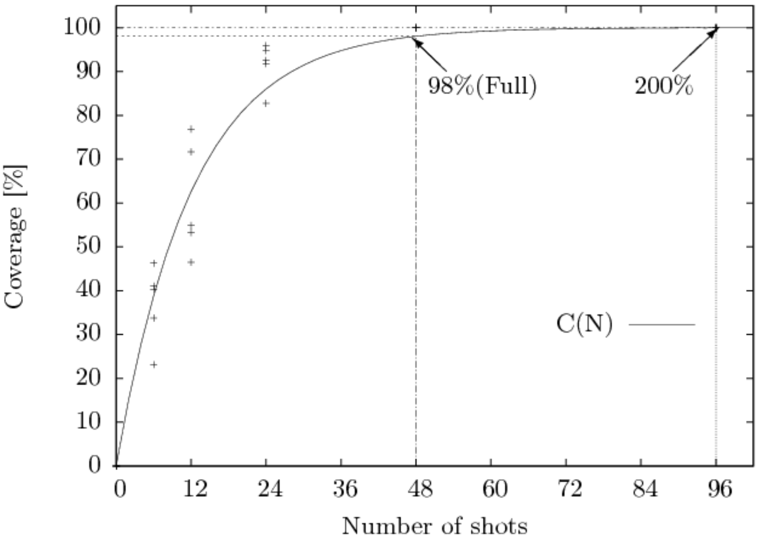

Fig.5 Relation between coverage and number of shots

SHOT PEENING INTENSITY AND SATURATION

Almen intensity was introduced by John Almen and involves peening a Almen strip of given dimensions and material, fixed to a mounting fixture by means of four roundhead bolts with nuts as in Figure 6(a). Once the bolts are removed, the strip will curve towards the peening direction as in Figure 6(c). The residual arc height over a fixed length is measured by means of an Almen gauge.
With this 3D random model, the average induced stress in the representative volume is assumed to be applied on an aluminum strip with dimensions 76mmX 19mmX3mm. Here the induced stress is a stress profile caused by shot peening of a constrained component. Since the induced stress is not self-equilibrated, a bending moment and a stretching force and the arc height of the deformed component and residual stress profiles can be calculated with equations introduced in (M. Guagliano, 2001, K. Li, 1981). In this paper, the average induced stress profiles after multiple randomly impacting shots replaced the $\sigma_{res,imp}$ values of (M. Guagliano, 2001), which is the stress profile beneath the impact point.

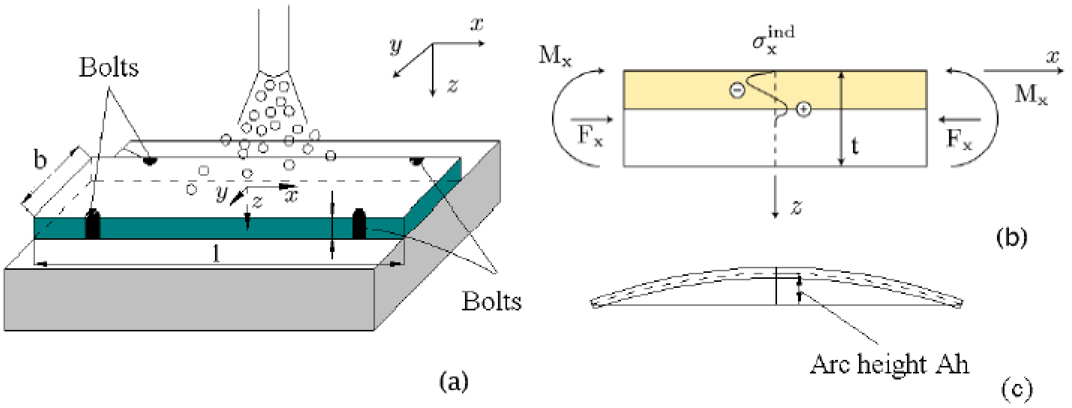

Fig. 6 Schematic view of shot peening on a trip with dimensions 76mm × 19mm × 3mm . (a) Shot peening of a strip with bolts; (b) Induced stress profile in the strip; (c) Arc height of the deformed strip.

Shot peening saturation is defined as a point, at which when shot peening time doubles, the increase of arc height is less than 10%. In this study, the average induced stress after 6, 12, 24, 48 and 96 random shot peening were obtained and the arc heights of the deformed component after different number of impact can be calculated.

Figure 5 presents the 25 calculated arc height data. An equation of the form

$$Ah(N) = \frac{p_1 N^2 + p_2 N + p_3}{N + q_1} \qquad (2)$$

is fitted, according to a least squares criterion through these 25 simulated values. A regression coefficient $R^2 = 0.9812$ has been obtained in this case. With the help of Equation (2), it is possible to calculate a saturation point where when the number of shots doubles, the arc height increases by 10% with the Fminsearch function in Matlab. It was found that arc height reaches saturation for N = 48 and the intensity is equal to 1.1409mm. So, our model predicts that saturation, according to the Almen intensity definition, is reached after 48 shots for the shot peeing conditions we have simulated.

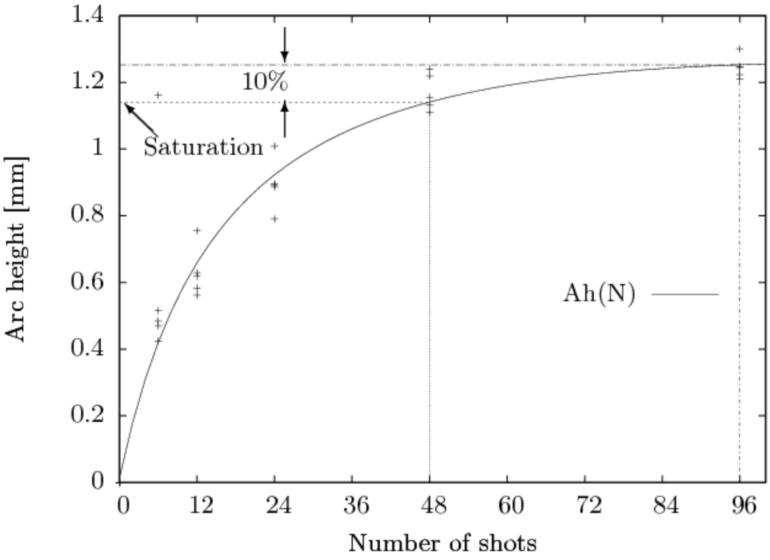

Fig.5 Relation between arc heights and number of shots

Stress peening forming

In case of conventional peen forming, the component is kept straight during shot peening, while in stress peen forming, the component is elastically pre-bent before shot peening and kept bending during shot peenig. With this 3D random model, an ANSYS Implicit and LS-DYNA Explicit sequence solution is used to study the influence of pre-bending on the peen forming results. Three steps were performed. First, an implicit finite element analysis with pre-bending moment along the width direction of the strip was performed to acquire the distributions of initial stress σ_{ini} in the length direction of the strip. Then, an explicit simulation with shots impacting at the pre-stressed component allowed determination of the average combined stress σ_{com} in the representative volume of the component. Here combined stress can be assumed as the sum of induced stress and initial stress. So the induced stress σ_{ind} in the representative component can be obtained as: $\sigma_{ind} = \sigma_{com} - \sigma_{ini}$. Finally, the equilibrated forces and moments of the induced stress profiles in length direction were calculated to obtain the residual stresses, bending moments, curvature radius and arc heights of the component.

Table 1 lists the arc heights calculated from conventional peen forming and stress peen forming with pre-bending moment 8550Nmm after 48 shots impacts (100%

coverage). it can be seen that, compared with conventional peen forming, stress peen forming causes larger arc height than conventional peen forming.

Table 1 Arc heights after conventional peen forming and stress peen forming

	Conventional peen forming	Stress peen forming
Arc height (mm)	1.14	1.84

CONCLUSIONS

In this paper, a new 3D random shot peening model was developed firstly. In this model, numerous of shots were bombarded to the component with randomly impact location and sequence. With this model, the relationship between surface coverage, surface roughness, saturation, shot peening intensity and the number of shots in a representative surface and volume can be simulated. Equations fitted from the simulated data can be used to calculate the number of shots at full coverage and saturation.

Implicit and Explicit sequence solution was firstly used to simulate stress peen forming process. The results of conventional peen forming and stress peen forming were compared numerically.

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