Finite Element Simulation of Shot Peen Forming

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1 Abstract

In this paper, both the impact model and the forming process simulation of the shot peen forming are introduced. In the impact model, effects of the shot diameter and velocity on the value and depth of the compressive stress and plastic layer are analyzed with dynamic explicit finite element method(FEM). A new equivalent thermal loading method is presented for the simulation of the shot peen forming process. The deformation of the standard Almen Strip and a wing skin with ribs are simulated with the method using static implicit FEM software. Results show that the method is very effective if the relationships between thermal loads and the shot peening strength are suitably set up

2 Introduction

For a number of years, the aircraft industry has used shot peening as a forming process to some metal parts, such as airplane wing skins [1-2]. The basic principle of the shot peen forming is a partial forging process. When the surface of a metal part is repeatedly hit at a high velocity by small steel shot, a thin plastically deformed layer is formed beneath the impacted area, and residual stresses generated in the part result in an equilibrium of forces and moments, therefore, obtains a permanent convex curvature. Figure 1 shows the typical residual stress distribution throughout the part cross-section. It can be seen from the figure that two surface layers are all compressive stress, which can improve the resistance of the metal part to fatigue and stress corrosion .

The most disadvantages of the shot peen forming is that the forming process is very difficult to be controlled. The reason is many process variables can affect the curvature generated by shot peening, such as the shot diameter D, the shot velocity V, the shot coverage ratio η, the shooting angle, the material of shots and sheets. And it is a random process for the impact of a large number of tiny shots against the surface of a metallic component. Therefore, for a long time, the shot peen forming is a try-and-error process. The experience of operators play a very important role in the process.

With the developing of the computer and finite element method, it is possible to use FEM simulation to predict the deformation of parts, to design peening process and to decrease the times of experiments.

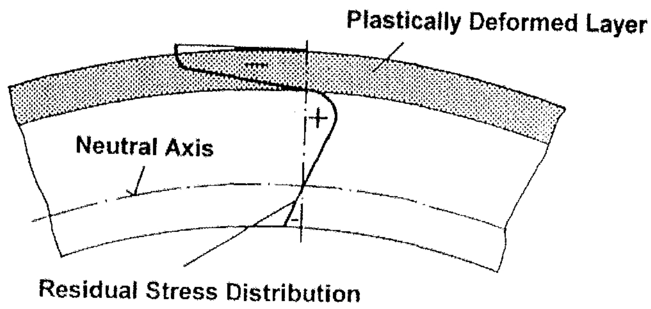

Figure 1: The residual stress distribution generated by shot peening

3 Impact Process Simulation

Because the shot peening process is comprised of the impacting of many single shot on the surface of parts, it is also very important to research the impacting process of one shot on a metal part. For the impact of one or several shots, it is easy to simulated with FEM, and it is also significative to examine the effect of varying the shot size and velocity on the local stress field.

A finite element model as shown in Figure 2 is used to simulate the impacting process of one steel shot on the surface of a part. On account of the highly dynamic impact characteristic of the shot peening, a dynamic explicit finite element program, ANSYS/LS-DYNA, was used to simulate the process. Dynamic effect, contact and elasto-plastic nonlinear parameters are taken into consideration.

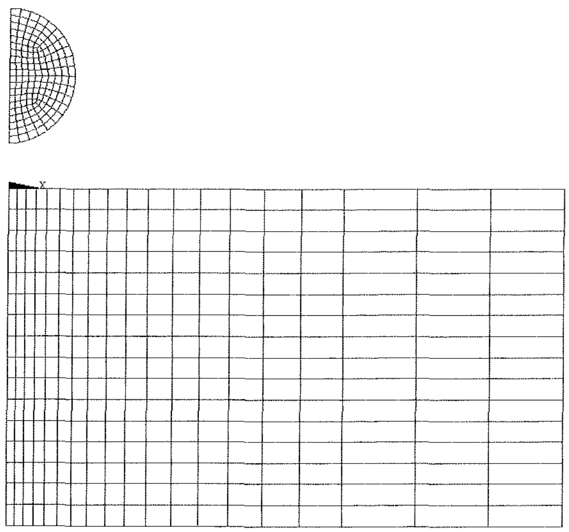

Figure 2: The impacting model of one shot

The thickness of the part is 3mm and the material is LY12CZ, which the properties are shown in Table 1. It is supposed that the effect of the strain rate hardening on the deformation is omitted.

Table 1: The properties of aluminum alloy YL12CZ

Young's modulus [MPa]	Shear modulus [MPa]	Poisson's ratio	Yield stress [MPa]	Strength [MPa]
71000	27000	0.32	300	426

From the Figure 3 it can be seen that with the increasing of *D*, the maximal compressive stress gradually move from the surface to the core zone, its value is also increased, and the stress at the surface changes from the compressive stress to the tensile stress, which express that shots with small diameter should be used for getting the compressive stress on the peened surface. The same situation take place if increasing *V*, except for the value of the maximal compressive stress is not changed as shown in Figure 4. That is to say, we can obtained the desired depth and value of the compressive stress through adjusting *D* and *V*.

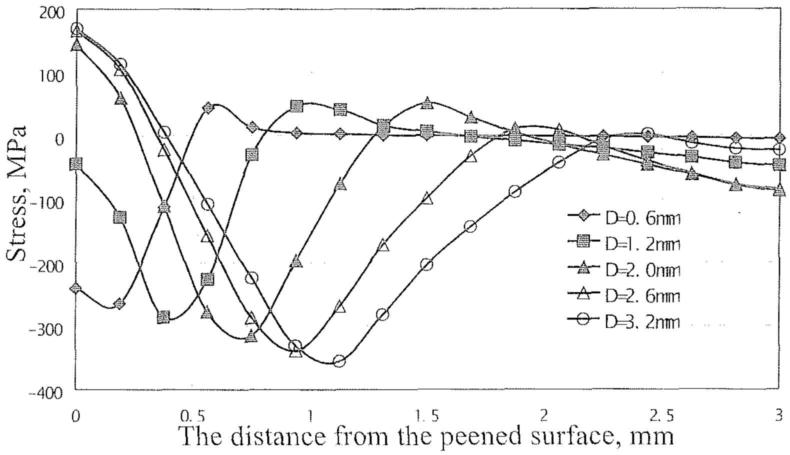

Figure 3: The effect of *D* on the stress(*V*= 60m/s)

From the distribution of the effective plastic strain shown in Figure 5 and Figure 6, the depth of plastic layer after peening can be obtained very directly. Results shown that with the increasing of *D* and *V*, the depth of plastic layer and the value of the effective plastic strain will be increased.

Although, the impact model is able to directly simulate the impact process of finite shots, and the stress distribution and plastic layer also can be obtained, it is impossible to simulate the impact process of many shots, and the final shape of the part is also not easily predicted.

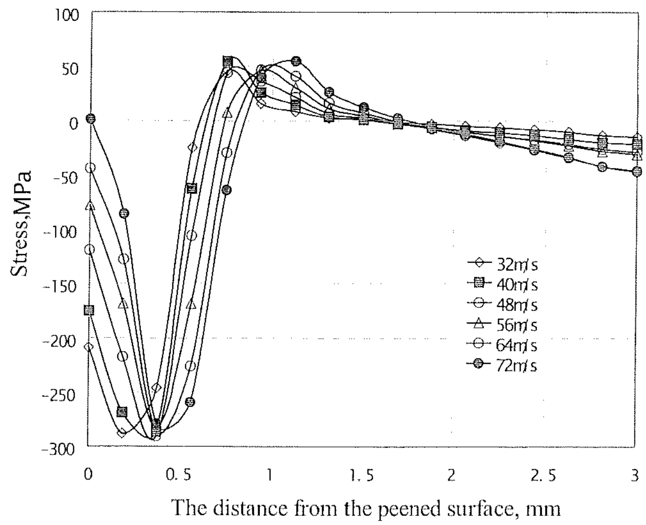

Figure 4: The effect of V on the stress (D= 0.046 inch)

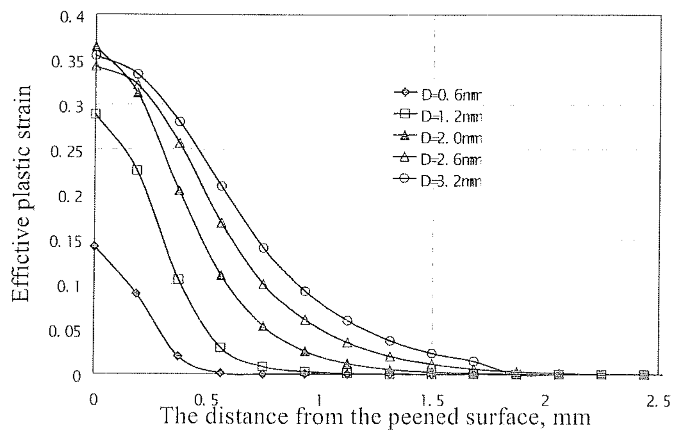

Figure 5: The effect of D on the hardening layer(V= 60m/s)

Figure 7 is a numerical model which can be used to simulate the effect of η on the stress distribution. In this model, the central shot is evenly surrounded by six shots. So, if the shot coverage ratio can be changed with the changing of the distance L, which will lead to the change of stress distribution under the center shot. From Figure 8 it can be seen that the depth of the compressive stress increased with the increasing of η.

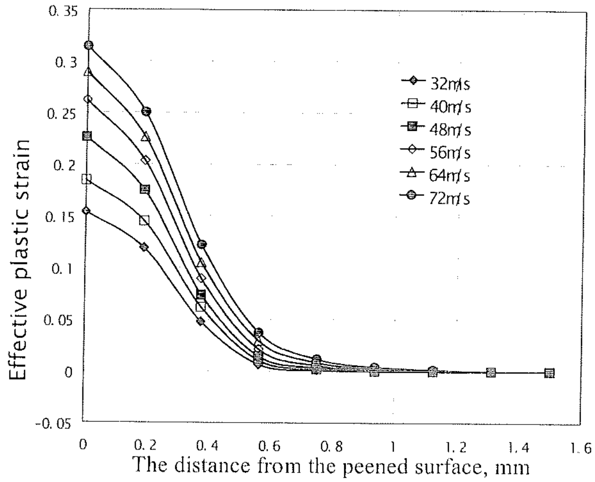

Figure 6: The effect of V on the hardening layer(D = 0.046 inch)

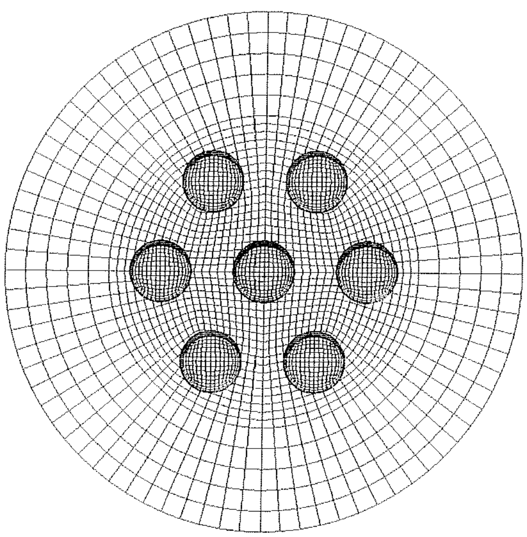

Figure 7: The numerical model of 7 shots

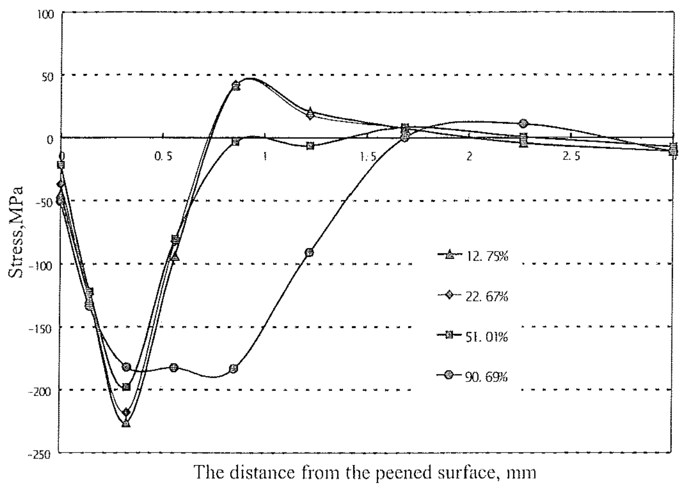

Figure 8: The effect of η on the stress(V = 60 m/s, D = 0.046 inch)

4 Forming Process Simulation

Some method to simulate the shot peen forming process have been presented [3]. One method is to input a set of initial stresses to the finite element mesh, so that when the analysis starts elements are immediately subject to a residual non-equilibrating stress field that causes deformation. However, this instantaneous application of the residual stress can be difficult to analysis successfully. Another method is to apply pressure to the faces of elements near the surface of the component. But the value and lasting time of the pressure is very difficult to determine. The third method is to use the thermal loads to set up the residual stress profile across the thickness of the sheet [3]. In this method, the load application is straightforward because the existing input methods for thermal analysis can be used only by the temperature profile and the coefficient of thermal expansion. But in practical shot peen forming process, shot coverage is often not more than 50 %, the 100 % shot coverage is very seldom used so the residual stress field is very difficult to tested precisely. Therefore, the application range of this method is very limited.

In present, a new method is presented, which also use the thermal loads to produce the equivalent deformation not the residual field. That is to say, if the deformation on a part induced by a thermal load is the same as that of a set of peening variables, the thermal load will be regarded as the equivalent load of the set of peening variables. A relationship between thermal loads and the deformation can be set up with Almen Strip, which can be expressed as follow.

$$\gamma = \mathrm{F}(T,\beta) \qquad (1)$$

Where, γ is the arc height of Almen Strip, i.e. the shot peening strength, T temperature, β the coefficient of thermal expansion in the plane of the sheet, the expansion in the thickness direction is omitted in order to agree with the practical situation. And the relationship between the arc height of Almen Strip and the main peening variables also should be set up according to experimental data:

$$\gamma = f(D, V, \eta, \ldots) \tag{2}$$

Using above two equations, it is possible to simulate all kinds of shot peening process with finite element method regardless of complex residual stress field.

It is supposed that the thermal loading process is a steady process, then the shot peen forming process can be simulated with static implicit FEM. Figure 9 is the deformation of an Almen Strip simulated by MARC software. Multi-layer shell elements in the simulation are adopted to describe the grads of temperatures from the peened surface to the other surface. It can be seen the deformation is very same as that of peening process. It should be stated that the rigid constraint of the un-peened area to the peened area should be take into account. Otherwise, the simulated shape will not same as the practical shape.

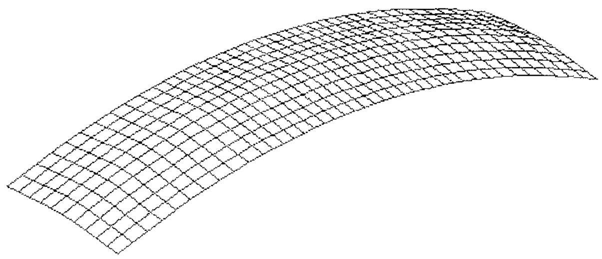

Figure 9: The deformation of an Almen strip after peening

The complex structure are also able to be simulated with the method. Figure 10 is the peening track of a wing-skin panel with strengthening ribs along the longitudinal direction, where shade areas are peening bands. The shape of the panel after peening will be nearly a single curvature outline according to the peening track. Figure 11 is the shape simulated with the thermal loading. The simulated shape of the panel is very in agreement with that of peening process. These results show that the shot peen forming process can be simulated using thermal loads according to the rule of equivalent deformation.

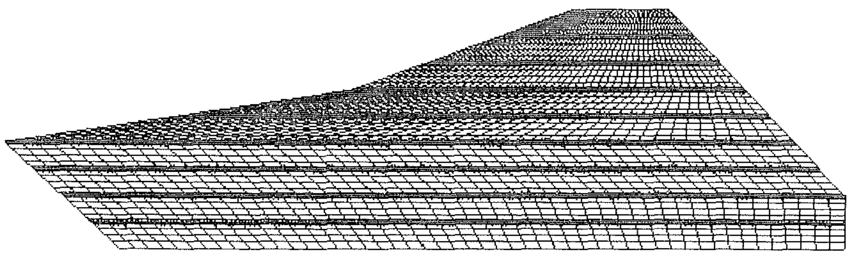

Figure 10: The peening treak of a wingskin with ribs

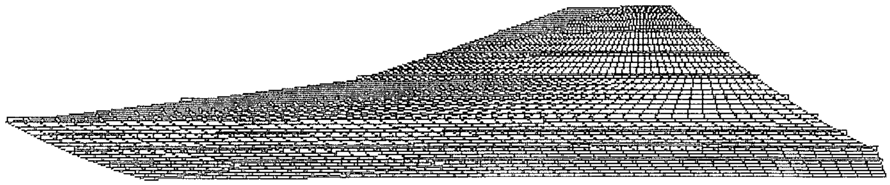

Figure 11: The deformation of a wingskin with ribs after peening

6 Conclusions

The effects of the shot diameter, the shot velocity and the shot coverage ratio on the stress distribution and plastic layer were analyzed by impacting model with the dynamic explicit finite element method. On the basis of experimental data, the shot peen forming process is able to be modeled with static implicit finite element method through the equivalent thermal loads with the help of the Almen Strip.

7 References

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