Shot Peening Numerical Simulation of Aircraft Aluminum Alloy Structure

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Abstract. After shot peening, the 7050 aluminum alloy has good anti-fatigue and anti-stress corrosion properties. In the shot peening process, the pellet collides with target material randomly, and generated residual stress distribution on the target material surface, which has great significance to improve material property. In this paper, a simplified numerical simulation model of shot peening was established. The influence of pellet collision velocity, pellet collision position and pellet collision time interval on the residual stress of shot peening was studied, which is simulated by the ANSYS/LS-DYNA software. The analysis results show that different velocity, different positions and different time intervals have great influence on the residual stress after shot peening. Comparing with the numerical simulation results based on Kriging model, the accuracy of the simulation results in this paper was verified. This study provides a reference for the optimization of the shot peening process, and makes an effective exploration for the precise shot peening numerical simulation.

1. Introduction

While the aircraft is in service, corrosion and damage often occurs in the aircraft structure, which promotes the formation and expansion of structure cracks, and even caused the structure suddenly failure. Corrosion damage caused by material-environment interactions has a significant effect on the security and the lifetime of aircraft structures. Studies have shown that the corrosion-induced damage under the loading does degraded the lifetime of aircraft structure about 40-60% [1-2].

Due to the economical and commercially viable of shot peening, it is widely applied to increase the strength of structure, and improve the anti-fatigue and corrosion resistance properties of structure in the aviation field[3-4]. Shot peening is using small projectile with high speed to strike the surface of structure at room temperature, making the material surface generated plastic deformation under the recrystallization temperature. Then, the ideal organization structure and residual stress distribution was obtained, which could improved the fatigue strength and the capacity of stress corrosion resistance of metal materials. A pre-corrosion test for the shot peening surface-treated 7050 aluminum alloy was performed, and the fatigue life was tested. The result was compared with non-shot peening aluminum alloy sample, which has shown that the shot peening can significantly improved the fatigue life of pre-corroded 7050 aluminum alloy specimens[5-6].

In previous work, through the pre-corrosive damage test, the corrosion damage mechanism of aircraft structure material 7050 aluminum alloy by shot peening was studied[7]. Based on the Finite Element Method(FEM), the shot peening process is simulated with ANSYS/LS-DYNA software in
this paper, and the residual stress distribution under different collision conditions has analyzed. The simulation process lays the foundation for further research on the shot peening numerical simulation.

2. The numerical simulation process
In this paper, the shot peening process is simplified to three kinds of conditions including single pellet collision, two pellets collision at different time and two pellets collision in different positions. Before the simulation, there are some basic assumptions: (i) it is assumed that no collisions occur between the projectiles; (ii) air is not obstructed; and (iii) there is no gas pressure when the projectile leaves the nozzle.

In the simulation, the relevant parameters are set based on 0.006A shot peening data. The nozzle diameter is 8mm, and S280 represents a projectile having a diameter of 0.8mm. The others are list in Table 1[5].

Table 1 The parameters of shot peening

| Shot size | Coverage | Shot flow [kg/min] | Nozzle distance [mm] | Nozzle angle [deg] | Actual intensity [A] | Saturated time[s] | Air compress Pressure [Ps] |
|-----------|----------|--------------------|----------------------|-------------------|----------------------|------------------|------------------------|
| S280      | 2.0      | 5.4                | 80                   | 90                | 0.006                | 9                | 41                     |

Based on the above assumptions and the data in Table 1, the collision velocity between the projectile and aluminum alloy surface is calculated. It was obtained in the ideal situation, which was inaccurated with the actual situation. Therefore, in simulation, a set of velocity gradients are defined as follows:

\[ V=(1,3,5,10,25,45,65)\text{m/s} \]

(1)

The FEM uses (g, cm, nm) unit system. The model used an 8-node down-integration explicit solid element Solid 164 element. The target material is 7050 aluminum alloy for aeronautics, approximately bilinear hardening constitutive model. The performance parameters for the numerical simulation lists in Table 2. Steel shots are used for the processing of the shot peening, defined as a rigid body model. The density value is 7850kg/m3, and the elastic modulus value is 210GPa. The Poisson ratio is 0.3.

Table 2 Target Material Properties

| Density [kg/m3] | Elastic Modulus [GPa] | Poisson's ratio | Yield stress [MPa] | Hardening modulus [MPa] |
|-----------------|-----------------------|-----------------|--------------------|------------------------|
| 2800            | 71                    | 0.3             | 450                | 250                    |

2.1. Numerical simulation of single pellet
In the simulation of single pellet, the target model size was set as \(1\times1\times1.5\text{mm}\), and the projectile diameter is 0.8mm, and the distance between the two is 0.1mm. The model grid as shown in Figure1.
Running the ANSYS solver, the unit equivalent stress at different speeds was calculated, such as the unit equivalent stress at the velocities of 65m/s is shown in Figure 2. It is displayed that the maximum equivalent stress value increased with the increase of projectile velocity, and the distribution range of it also increased. When the projectile speed reaches 5m/s, the maximum equivalent stress exceeds 100MPa. At 65m/s, the simulation results of three principal stress changed with the depth shown in Figure 3.

![Figure 3. Principal Stress-Depth Curve](image)

In Figure 3, the fluctuation range of first principal stress is smaller than second and third principal stress. When testing the residual stress, it is considered that the stress state of the shot peening test specimen is in the plane stress state. From the experimental measurement results, the two main stress trends are similar, which is similar to the simulation results.

With the velocity increases, the maximum equivalent stress increases gradually, and it’s position also gradually moves toward the inner layer. When the velocity is 65m/s, the trend of equivalent stress change is shown in Figure 4.

![Figure 4. Stress-Depth Curve (65m/s)](image)  
![Figure 5. Scatter Depth-Velocity Curve](image)

As can be seen from Figure 5, with the increasing of the collision velocity (V=1, 3, 5, 10, 25, 45, 65m/s), the equivalent stress distribution depth gradually increased.

2.2. Numerical simulation of two pellets

2.2.1 Two pellets collision at different time. Based on the simulation results of single pellet at different speeds, the simulation of two pellets was carried out by choosing the collision velocity of the projectile at 25m/s. To create two pellets models, assuming two pellets collision with the target material in the same spot. The distance between two pellets is 0.8mm, and the first pellet from the
target 0.1mm. The stress cloud of the solution is shown in Figure 6. When the shot peening velocity is 25m/s, the maximum equivalent stress produced by a single pellet collision is about 450MPa, and that in two pellets collisions is 384.2MPa. Obviously, the maximum equivalent stress decreased. This showed that the second collision caused part of the residual stress release.

![Figure 6](image.png)

**Figure 6.** Two pellets collide(25m/s, 800μs, 0.8mm) **Figure 7.** Two pellets collide(25m/s, 1200μs, 1.6mm)

The distance between two projectiles changed to 1.6mm, and the result is shown in Figure 7. The equivalent stress values of different depth map onto the path along the Z axis. The equivalent stress distribution along the depth of target as shown in Figure 8, which generated in the conditions of single pellet, two pellets(0.8 mm) and two pellets(1.6 mm). Increasing the distance between the projectiles would mean increasing the collision interval.

![Figure 8](image.png)

**Figure 8.** The equivalent stress-Depth Curve

As can be seen from Figure 8, the maximum stress value that produced by the collision of two pellets is reduced compared with the single pellet, but the stress layer depth has increased. Increasing the time between two collisions, the maximum equivalent stress value decreased, and the stress value appears in a deeper position. At the same time, the equivalent stress distribution does not changed obviously.

### 2.2.2 Two pellets collision in different positions

Then, we has created the model of two pellets collision in different positions, and simulated the distance between the two impact positions of 0.1mm and 0.2mm respectively. The equivalent stress cloud when the distance between two pellets is 0.1mm and 0.2mm respectively is shown in Figure 9 and Figure 10.
Figure 9. 25m/s, 800μs, 0.1mm

Figure 10. 25m/s, 800μs, 0.2mm

The equivalent stress values of different depth map onto the path. The results are shown in Figure 11.

Figure 11. The equivalent stress-Depth Curve

It can be seen from Figure 11 that the maximum equivalent stress decreases slightly with increasing distance of the collision point and the distribution of maximum equivalent stress does not change significantly in the depth of two projectiles. There is no significant change in the depth distribution.

3. Results and discussion

In Ref.[8], they have simulated the shot peening process by Kriging approximate model. The parameters setting in the literature is basically the same as the one in this paper, which can be used as the basis for the accuracy judgment of the numerical simulation model in this paper.

Figure 12. Residual compressive stress-Depth Curve
In Figure 12(a), the variation of third principal stress as a single pellet collides with the target material at 45m/s and 65m/s is shown. Compared with Figure 12(b), the results is little difference, such as the initial position of curve, the maximum stress value, the maximum stress distribution depth and the distribution range of residual stress. It is indicated that the simulation model of single pellet is correct. Because the two pellets collision model is obtained on the basis of the single pellet, it demonstrated that the two pellet model in this paper is also correct.

4. Conclusion

In this paper, the regularity of residual stress distribution is studied when the pellets collides with target material in the shot peening process. A simplified numerical simulation model of shot peening was established on the basis of shot peening 0.006A. According to this model, the impact of single pellet collision was simulated, and a group of speed was set as the pellet initial velocity in simulation. The results showed that the maximum equivalent stress gradually becomes larger with the increase of collision velocity. The depth of equivalent stress distribution and the position of maximum equivalent stress gradually move toward the target material.

Then, the research has considered the impact of two pellets collision. In the simulation, when two pellets striking the same point, the maximum equivalent stress produced by two pellets is smaller than that of the single pellet, but the stress layer depth increased in a certain extent. Increasing the collision time interval, the maximum equivalent stress decreased. When the collision relative position of two pellets has changed, the maximum equivalent stress also decreased in a certain extent, but the position and the depth of stress layer have not changed significantly.

The collision of pellets on the target material surface is a continuous process. Therefore, compared with the impact of single pellet collision, the simulation results of two pellets collision in different positions are more accurate. This study makes an effective exploration for the precise shot peening numerical simulation.

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References

[1] M. Worsfold, NATO Applied Vehicle Technology Panel on Fatigue in the Presence of Corrosion, Corfu, Greece, 1999.
[2] Lv S L, Mu Q, Gao X, et al. Influence of morphology of corrosion on fracture initiation in an aluminum alloy[J]. Materials & Design, 2013, 45(6):96-102.
[3] A.L.M. Carvalho and H.J.C. Voorwald, Influence of Shot Peening and Hard Chromium Electro-plating on Fatigue Strength of 7050-T7451 Aluminum Alloy, Int. J. Fatigue, 2007, 29(7), p 1282–1291
[4] H. Luong and M.R. Hill, The Effects of Laser Opening and Shot Peening on High Cycle Fatigue of 7050-T7451 Aluminum Alloy, Materials Science and Engineering, 2010, 527(3), p 699 – 707
[5] Sheng-Li Lv, You Cui, Xiaosheng Gao, et al. Influence of exposure to aggressive environment on fatigue behavior of a shot peened high strength aluminum alloy[J]. Materials Science & Engineering A, 2013, 574(7):243-252.
[6] Sheng-Li Lv, You Cui, Wei Zhang, et al. Influence of Shot Peening on Failure of an Aluminum Alloy Exposed to Aggressive Aqueous Environments[J]. Journal of Materials Engineering & Performance, 2013, 22(6):1735-1743.
[7] Song Lin, Sheng-Li Lv, Wei Zhang, et al. Corrosion Damage Research of Shot Peening Aluminum Alloy[J]. Applied Mechanics & Materials, 2011, 80-81(4):113-118.
[8] Hong-wei Zhang, Yi-du Zhang, Xiao-ci Zhao. Numerical Analysis of Residual Stress Field for Shot-peening Process Based on Kriging Model [J]. Journal of System Simulation, 2011, 23(4):826-831.