Effect of Shot Peening Intensity on Residual Stress Field of 7075 Auminium Alloy

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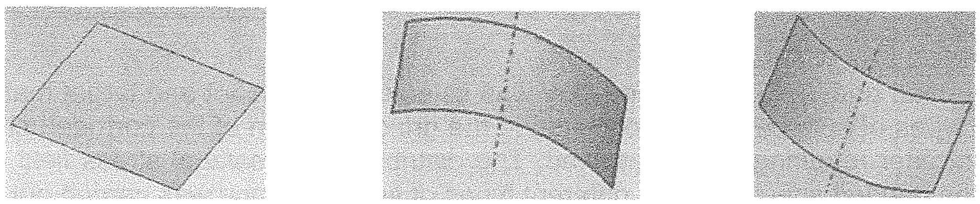
Abstract
The glass bead and 7075 aluminium alloy was selected as the shot and target material, and the basic types of surface shape consisted in the grinded region of the corroded civil aircraft component after repairing were classified. The distribution of residual stress field along the depth of the grinded specimen with different types of surface shape was carried out based on numerical simulation. It shows that the strongest residual stress field occurs in the specimen with the concave surface, and the weakest residual stress occurs in the specimen with the biconvex surface. The concave surface, in which stress concentration occurs easily, was selected to further research the distribution of residual stress field along the depth of the grinded specimen under the different shot peening intensity or constant intensity combined with different shot peening parameters. The results show that different residual stress fields exist under a constant intensity combined with different diameter and impact velocity of shots. The distribution and variation of residual stress along the surface of component with different types of surface shape was analyzed and verified by the experimental results. The results indicate that the finite element model established was reliable and accurate.

Keywords Shot peening intensity, Residual stress field, 7075 aluminium alloy, Corroded civil aircraft component, Shot peening parameters.

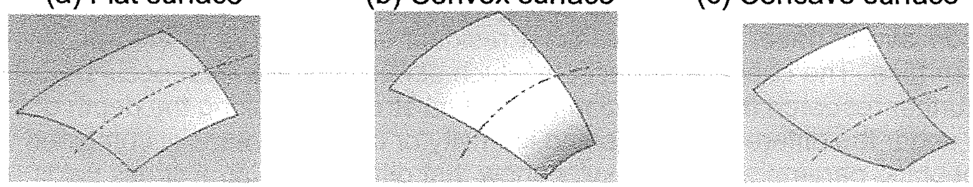
Introduction
For some slight damaged components of civil aircraft caused by the corrosion due to long flight service, the damaged components can continue to be used after removing the corroded portion by grinding and strengthening the grinded region by shot peening. Different types of surface shape will be formed in the grinded region of the repaired components, and stress concentration may occur due to the non-planar surface during shot peening and the succedent service of the component of civil aircraft[1]. Besides, in the guidance documents of shot peening for the corroded component, the data of shot peening intensity is normally concerned[2], rather than the effect of the combination of the diameter and impact velocity of shots, the main parameters determining the effect of the shot peening intensity on the residual stress.
In the research of the effect of the shot peening parameters on the distribution of residual stress field, Majzoobi et al.[3] discussed the impact velocity and surface coverage; Johnson et al.[4] analyzed the friction between shot and component; Taehyung Kim et al.[5] researched the impact consequence of shots and friction coefficient; Yan Wu-zhu et al.[6] studied the diameter and incident angle of shots, yielding strength of target material and other parameters. The results show that the residual stress caused by shot peening was mainly affected by the shot peening intensity, diameter and impact velocity of shots, and the mechanical properties of the target materials. However, the above researches just aimed at components with simple flat surface, the components with complex shape and the effect of types of surface shape on distribution of residual stress field has not been mentioned.

Establishment of the finite element model
The area of the corroded region usually takes small part of the whole component. The steps exist between the grinded and uncorroded portion after removing the corrosion, stress concentration may occur in these steps due to the thickness change in the repaired component, therefore, chamfering and rounding is necessary for the relieving of the stress concentration.

Transition regions are formed due to chamfering and rounding, and the shapes of the grinded region mainly consist of the flat, the convex, the concave, the saddle, the biconvex and the biconcave, as shown in Fig. 1. Fig.2 shows the random-shots finite element model under different surface shapes established based on software ABAQUS. The minimum size of elements was 1/10 of shot diameter[7]. The dimension of target material was 1×1×2 mm3. The random shots were realized by programming based on PYTHON language and the impact direction of shots was always perpendicular to the shot peening surface. The friction coefficient in the finite element model was 0.1[8], the sandglass stiffness was 2.0[9].

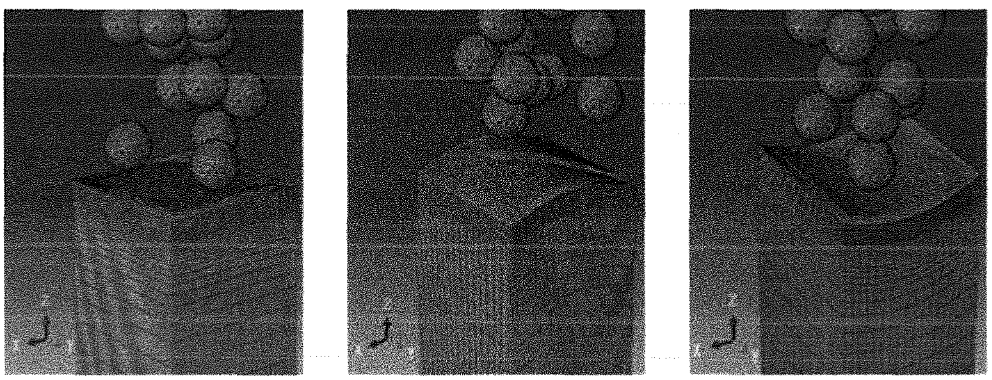


(a) Flat surface (b) Convex surface (c) Concave surface

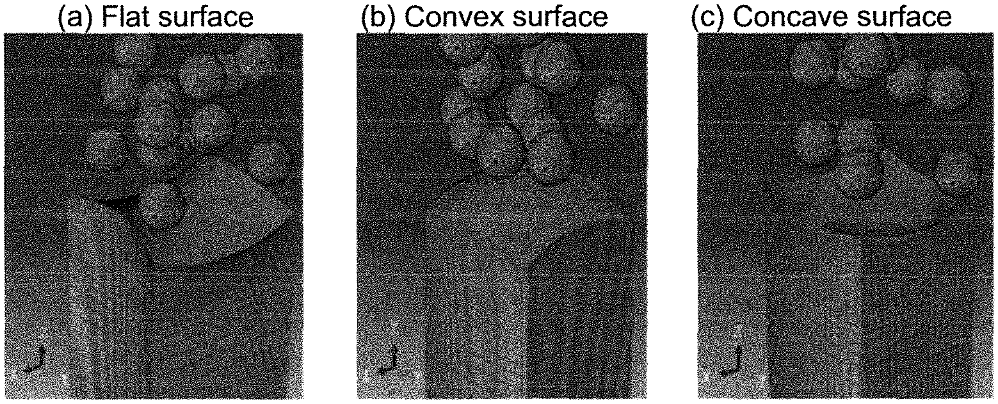


(d) Saddle-shape surface (e) Biconvex surface (f) Biconcave surface

Fig.1 Basic surface shapes of the grinded region



(a) Flat surface (b) Convex surface (c) Concave surface



(d) Saddle-shape surface (e) Biconvex surface (f) Biconcave surface

Fig. 2 Random-shots finite element model under different surface shapes

In the finite element model, glass beads were selected as the shots and 7075 aluminium alloy as the target material, Johnson-Cook constitutive model was adopted[10]:

$$\sigma=(A+B\varepsilon^{n})\left[1+C\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\right]\left[1-\left(\frac{T-T_0}{T_m-T_0}\right)^{m}\right] \quad (1)$$

where A=305MPa, B=347MPa, C=0.017, m=1.61, n=0.5, σ—Von-Mises equivalent stress, ε—equivalent strain, $\dot{\varepsilon}$—equivalent strain rate, $\dot{\varepsilon}_0$—reference equivalent strain rate, $\dot{\varepsilon}_0$=1.0 s^{-1}, T—temperature, T_m—fusion point of material, T_m=565°C, T_0—reference temperature, T_0=25°C.

The distribution of residual stress along the depth of the specimen was obtained by taking the 23 layers element from the top surface and calculating the average residual stress of 900 nodes around the centre of each element layer. Fig.3 shows the distribution of residual stress field under different types of surface shape when the arc radius of shot peening surface r=1 mm, diameter of shots d=0.2 mm, impact velocity of shots V=100 ms^{-1}, surface coverage of shot peened surface C_s=100%, where D refers to the distance from the surface of specimen and S refers to the residual stress.
Fig.3 shows that the surface residual compressive stress S_s, the maximum residual compressive stress S_m, the depth of maximum residual compressive stress D_m, and the total depth of residual compressive stress D_c varies with the types of surface shape of shot peening. It shows that the strongest residual stress field occurs in the specimen with the concave surface, and the weakest residual stress occurs in the specimen with the biconvex surface. It indicates that stress concentration may easily occur in the concave surface of the grinded region. The degree of the residual stress concentration after shot peening reflexes the actual stress concentration status born by the component during flight[1]. Therefore, the following researches mainly aim at shot peening of the grinded specimen with concave surface.

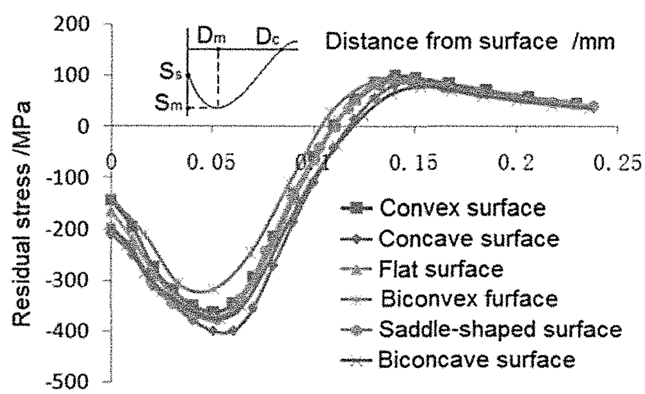


Fig.3 Distribution of residual stress field with different types of surface shape

Determination of the research scheme

The shot peening intensity AH (the arc height of Almen test strip, mm) is related only with the diameter (d) and the impact velocity (V) of shots for a determined shot material, and can be calculated by the two parameters combined with the density of shot material (ρ), AH=f (ρ, d, V) [11]. The N type Almen test strip was selected to analyze the shot peening strengthening effect of 7075 aluminium alloy. According to the standard of shot peening of aircraft parts (HB/Z 26-2011[12]), the range of the shot peening intensity AH was 0.2~0.6 N, the diameter of shots d was 0.2~0.5 mm, the surface coverage of shot peened surface C_s was 100%. The selected processing parameters for the discussed three situations are shown in Tab.1.
1) For constant shot peening intensity AH (0.35 N), 4 groups of d and V were selected to analyze the effect of different combination of parameters on residual stress, the No. 1~4 in Tab.1.
2) For constant diameter of shots d (0.2 mm), 4 different V was selected to analyze the effect of the parameter V on residual stress, the No. 5~8 in Tab.1.

3) For constant impact velocity of shots V (50 ms^{-1}), 4 different d was selected to analyze the effect of the parameter d on residual stress, the No. 5, 9~11 in Tab.1.

Tab.1 Combinations of different shot peening parameters and AH value

No.	1	2	3	4	5	6	7	8	9	10	11
D(mm)	0.2	0.3	0.4	0.5	0.2	0.2	0.2	0.2	0.3	0.4	0.5
V(ms^{-1})	93.5	53.2	34.5	24.3	50.0	75.0	100.0	125.0	50.0	50.0	50.0
AH(N)	0.35	0.35	0.35	0.35	0.23	0.30	0.36	0.41	0.34	0.44	0.53

Residual stress field under different shot peening intensity AH

Fig. 4 shows the residual stress filed along the depth of the specimen with the concave surface under the variable shot peening intensity AH combined with the constant shot diameter d (d=0.2 mm) and the variable impact velocity V. It shows that the maximum residual compressive stress S_m, the layer depth D_m of the maximum residual compressive stress and the total depth D_c of the residual compressive stress increases with the increase of the intensity AH or V. However, the surface residual compressive stress S_s varies hardly with V when it is within 50~125 ms^{-1}.

Fig. 5 shows the residual stress filed along the depth of specimen with the concave surface under the variable intensity AH combined with the constant impact velocity V (V=50 ms^{-1}) and the variable shot diameter d. It shows that S_s decreases with the increase of AH or d, and S_m, D_m and D_c increase with the increase of the intensity AH or d obviously.

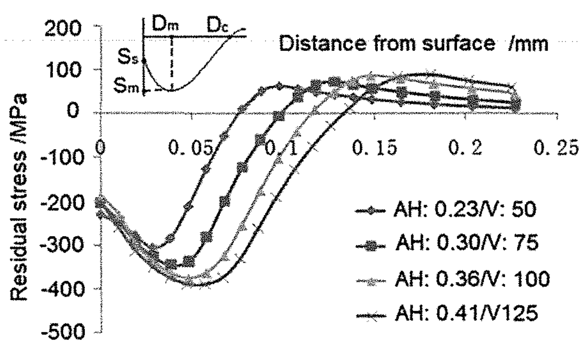


Fig.4 Residual stress field with variable V (d=0.2mm)

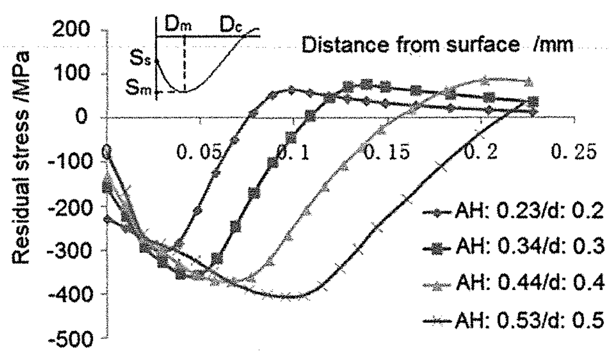


Fig.5 Residual stress field with variable d (V=50ms^{-1})

Residual stress field under constant shot peening intensity AH

Fig. 6 shows the residual stress filed along the depth of specimen with the concave surface under the constant intensity AH (AH=0.35 N) combined with the variable diameter d and the variable impact velocity V of shots. It shows that large surface residual compressive stress S_s occurs under the small shot diameter d combined with the large impact velocity V, however under this combination, the maximum residual compressive stress S_m, the layer depth D_m of the maximum residual compressive stress and the total depth D_c of the residual compressive stress may be small.

Experimental verification

Fig.3 shows that the residual stress field varies with the types of the shot peened surface shape. The experimental component with transition region, including the flat, convex, slope and concave surface, as shown in Fig. 7a), was designed to research the distribution and variation of residual compressive stress along the shot peened surface. The material of the component was 7075 aluminium alloy, and the dimension was 100×24×16 mm^3, the inclination angle of the slop was 30°, the arc radius of both the convex and concave was r=16mm. The corresponding finite element model is shown in Fig. 7b), where, the dimension of the component in the simulation model was 30×24×3 mm^3, with the same shape of transition region as experimental one, smaller total size was adopted for decreasing the elements amount and shortening the simulation time. The parameters used for both the simulation and experiment were as follows: the diameter of glass beads d=0.2 mm, the pressure of compressed air p=0.45 MPa (transformational impact velocity of shots[13] V=93.8 ms^{-1}), the impact direction of shots was perpendicular to the shot peening surface.

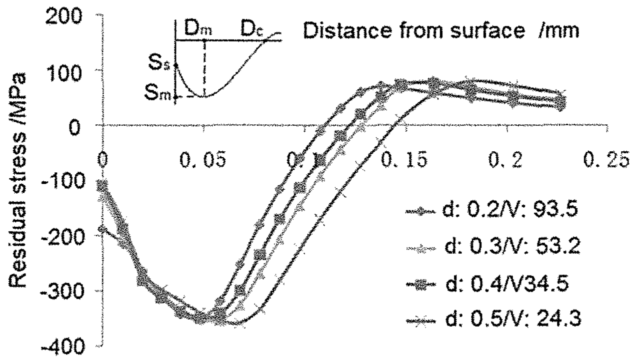
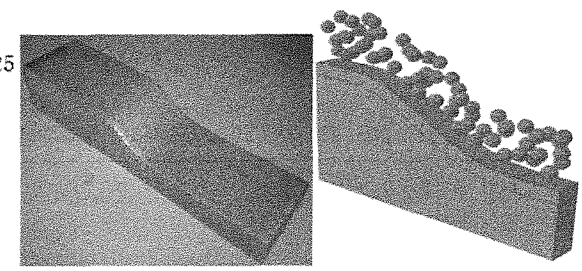


Fig.6 Residual stress field under constant AH (AH=0.35 N)



(a) Shot peened component (b) FE model

Fig. 7 Experimental component and the FE model

Fig. 8 shows the distribution and variation of surface residual stress along the shot peened surface, where, the full line refers to the simulation results, and the circular points refer to the experimental results measuring at the centre point of each surface shape. It shows that the maximum surface residual compressive stress is located on the concave surface, and the minimum is located on the convex surface, which is the same as the results shown in Fig.3 under the condition that the impact direction of shots is always perpendicular to the shot peening surface, and the residual compressive stress on the flat and slope surfaces are almost the same. The simulation results conform well to the experimental one, which indicates that the established finite element model is reliable and accurate.

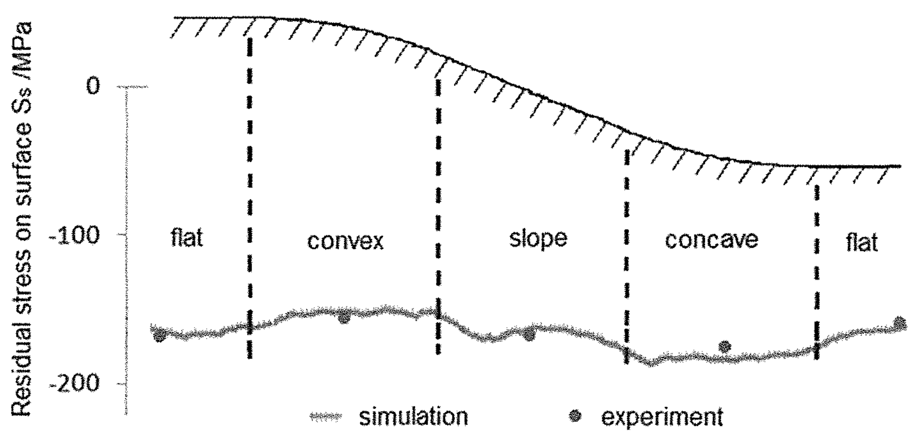


Fig.8 Comparison of surface residual stress between experimental and simulation results

Conclusions

The effect of shot peening intensity on residual stress field of 7075 aluminium alloy of the grinded specimen with different types of surface shape was analyzed. The conclusions can be drawn as follows:

1) The residual stress fields of the grinded component vary with the types of shot peening surface shape, the strongest residual stress field occurs in the specimen with the concave surface, and the weakest residual stress occurs in the specimen with the biconvex surface.
2) Under the condition of varied shot peening intensity AH and constant shot diameter d or constant shot impact velocity V, the maximum residual compressive stress S_m, the depth of maximum residual compressive stress D_m, and the total depth of residual compressive stress D_c increases with whether d or V; The surface residual compressive stress S_s increases with the increase of d and varies hardly with V when it is within 50~125 ms^{-1}.

3) Under the condition of constant shot peening intensity AH and varied combination of shot diameter d and shot impact velocity V, large surface residual compressive stress S_s occurs under the small shot diameter d combined with the large impact velocity V, however under this combination, the maximum residual compressive stress S_m, the layer depth D_m of the maximum residual compressive stress and the total depth D_c of the residual compressive stress is small.
4) The distribution of residual stress along the shot peened surface of the grinded component with different types of surface shape is uneven; the maximum residual compressive stress is located on the concave surface, where high stress concentration may occur when the shot peened component bears fatigue load during service.

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