Effect of surface strengthening on surface integrity of high strength materials

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Abstract. The fatigue property of high strength materials is very sensitive to surface integrity. In order to study the effect of surface strengthening on surface integrity of the high strength materials, the influence and the mechanism of the surface integrity of high strength materials with different surface hardening parameters were investigated by surface roughness tester, micro-hardness tester, X ray diffraction stress tester (XRD-stress) and high resolution transmission electron microscope (HRTEM). The results show that surface strengthening will cause the surface roughness of high strength materials to increase and the notch effect is remarkable. The surface hardness of the material increases with the shot peening, and the surface hardness value decreases gradually with the depth of the layer. The residual compressive stress is induced by the surface strengthening treatment. The maximum value of effective tensile stress is not existed on the surface but in the residual tensile stress area. The plastic deformation mechanism of the surface strengthening materials is mainly dislocation slip and twin deformation.

Introduction

Surface strengthening such as shot peening (SP) treatment can improve the surface integrity of metal materials, so it is an important technical method to improve the fatigue resistance of metal materials effectively [1-3]. How to make full use of the favorable factors and avoid or reduce the influence of adverse factors of SP treatment is the key to improve the fatigue resistance of metal materials [4]. In the industrial production, the shot peening technology on the new titanium alloy is not mature, and it often blindly copy the shot peening specification of TC4 (Ti6Al4V) and other that of commonly medium and low strength titanium alloy to the new high strength titanium alloy, which will bury the hidden danger in the safety and reliability of the aviation structure [5]. Therefore, the effect and the mechanism of shot peening strengthening treatment on the surface integrity of high strength titanium alloy were studied in this paper, which would provide a basis for the application of shot peening technology in the structure engineering for the new high strength titanium alloy.

Experimental methods

According to the production demand of the aviation industry [6], the effect of surface hardening technology on the surface integrity of a novel high strength titanium alloy was studied. The parameters of the shot peening strength were mainly controlled and the optimum parameters were determined. The base material surface was prepared by grinding. The process parameters test conditions were designed as shown in Table 1.

Table 1 Parameters of surface strengthening

Strength [mmA]	Coverage	Number
Based material	– –	BM
0.10-0.15	100%	SP1
0.20-0.25	100%	SP2
0.35-0.40	100%	SP3
0.45	100%	SP4
0.50	100%	SP5

The test and analysis methods of surface integrity are as follows. The surface roughness was measured by SJ-301 roughness tester. The surface hardness was measured by HV-1000 micro-hardness tester. D/MAX2200PC type X-ray diffraction stress analyzer was used for residual stress test. Surface dislocation morphology was analyzed by Transmission Electron Microscope (TEM) produced by FEI company Tecnai F30 G^2.

Results and discussion

Surface roughness.

Figure 1 shows the comparison of the roughness value of high strength titanium alloy with untreated and SP treatments. It can be seen that, with the increasing of the shot peening strength, the surface roughness value of Ra and the Rz increased, and the Rz value of the sample surface increased more significantly. The increased Rz value indicates that the gap depth increased on the surface of the specimen. And then the degree of stress concentration on the surface increased, thus it promoted the initiation of fatigue cracks.

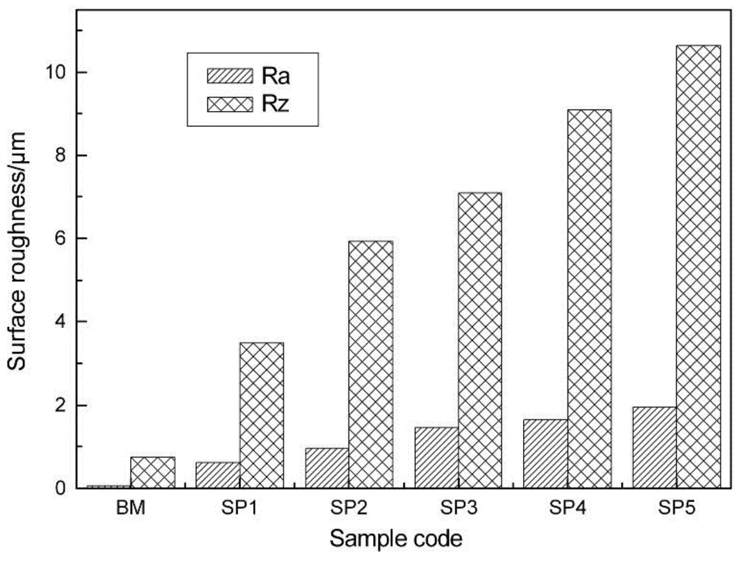


Fig. 1 Surface roughness of samples with untreated and SP treatments

Surface microhardness.
The cross-hardness distribution of high strength titanium alloy samples with different treatments is shown in Fig. 2. It can be seen that the top surface hardness value is increased with the increased shot peening strength. The hardness value of the surface layer decreases gradually with the increased surface layer depth, and finally it tends to equal the hardness value of the substrate. The depth of the hardened layer is 150~350 μm, and the microhardness value near the surface of the specimen decreases obviously. After shot peening treatment, the hardness of the surface is higher than that of the based material. However, the surface hardness value and the hardened layer depth of the high shot peening strength (SP3~SP5) treatment are not as good as those of the low shot peening strength (SP2) treatment. It shows that the high shot peening strength cannot obtain the high processing hardening. This attribute to the phenomenon of over shot peening, which leads to the process of hardening and then softening, and it is accompanied by micro cracking or delamination.

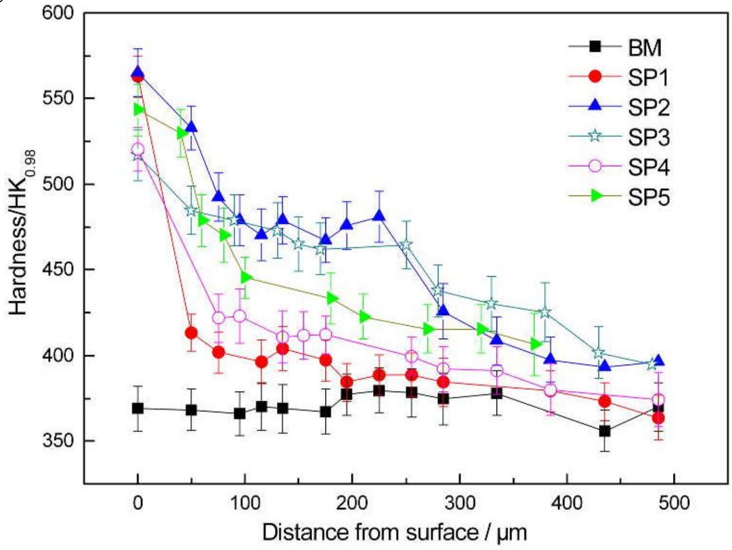


Fig. 2 Cross-hardness distribution of samples with untreated and SP treatments

Surface residual stress.
Fig. 3 shows the distribution of residual stress along the depth of the high strength titanium alloy under different shot peening conditions. It can be seen that shot peening introduces a residual compressive stress field at a certain depth to the surface, and the distribution of residual compressive stress presents gradient change characteristics. As for the conditions of SP3~SP5, the value of the residual compressive stress of the surface gradually decreases with the increased shot peening strength. The surface residual stress induced by the lowest strength SP1 is largest, but the distribution depth is the smallest (the depth is about 180 μm). Although the SP3~SP4 treated samples can obtain a deeper residual compressive stress distribution, the value of the residual compressive stress and the depth of the distribution layer are smaller than those of the SP2 treated samples. The residual compressive stress of SP5 specimen with over high shot peening strength is the lowest, and the distribution layer depth is also smallest. The moderate shot peening strength (SP2) treated sample can not only obtain the maximum value of maximum residual compressive stress σ_{mrs}, but also the depth of distribution is largest than other shot peening samples (layer depth is more than 300 μm).

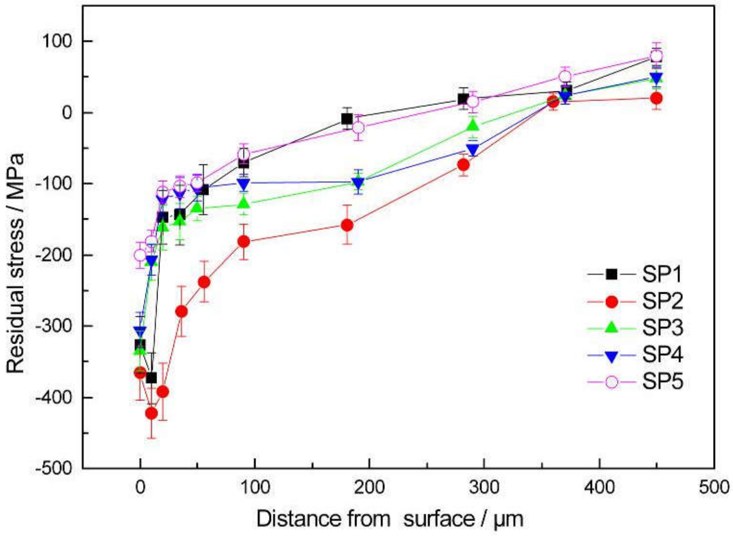
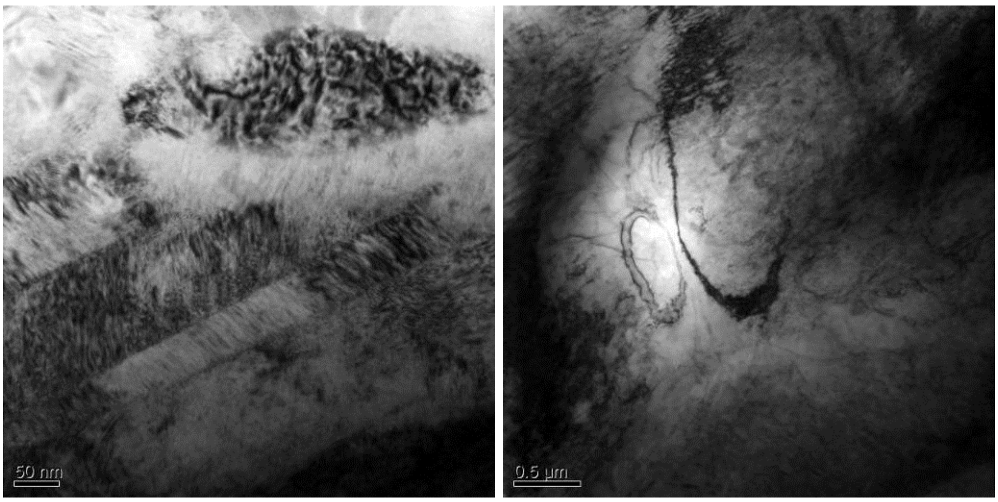


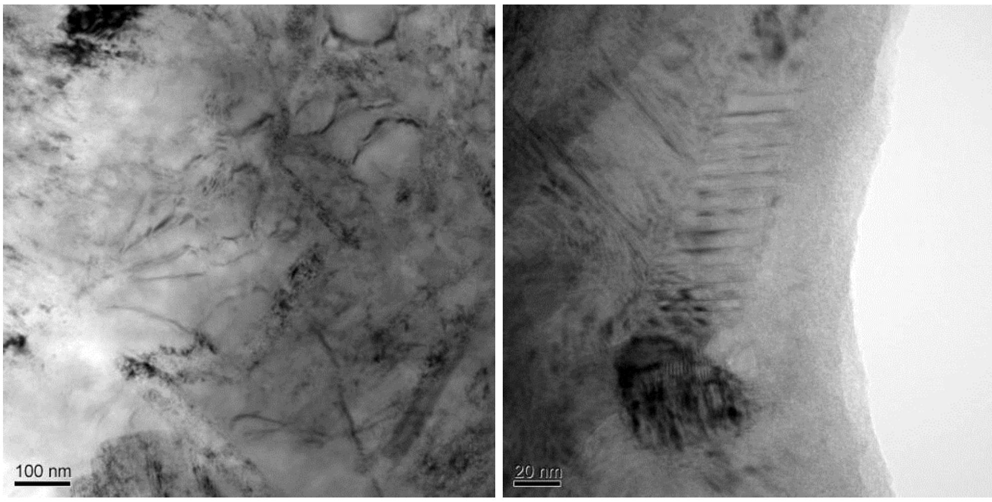
Fig. 3 Effect of SP treatments on surface residual stress of samples

Surface dislocation morphology.

TEM topography of high strength titanium alloy with SP2 treatment at 10 μm depth from surface is shown in Fig. 4. From Fig. 4, we can see that a large number of dislocation rings, dislocation walls, dislocation cells, and deformed twinning structures appear in the α phase layer after shot peening. With the increased the shot peening strength, the twin density increasing, and the repeated intersection of the twinning lines makes the grain fragmentation and it presents a random orientation distribution of small substructure.



(a) deformed twinning (b) dislocation rings



(c) dislocation rings (d) deformed twinning

Fig. 4 TEM topography of high strength alloy with SP2 treatment at 10 μm depth from surface

According to the analysis results of dislocation morphology, a schematic diagram of the formation mechanism of shot peening enhancement layer dislocation can be drawn, as shown in Figure 5. In the shot peening process, especially under the optimal shot peening strength parameters, the plastic deformation of high strength titanium alloy is mainly dislocation slip and twin deformation.

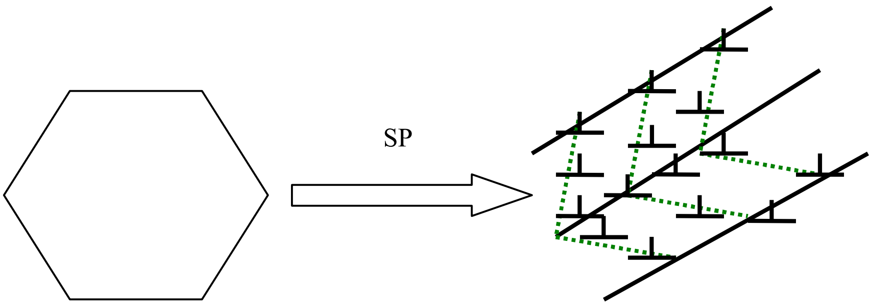


Fig.5 Sketch diagram of dislocation mechanism of SP treatment

Conclusion

(1) The increased surface roughness of the high strength material caused by the shot peening treatment, which leads to the remarkable notch effect. The surface stress concentration could The initiation of fatigue cracks easily.
(2) The over high shot peening strength cannot obtain the high processing hardening. This attribute to the phenomenon of over shot peening, which leads to the process of hardening and then softening, and it is accompanied by micro cracking or delamination.
(3) The maximum effective stress is not on the surface but in the subsurface of the residual tensile stress area. That is attributed to the residual compressive stress introduced by the surface strengthening treatment.
(4) The plastic deformation of high strength material is mainly dislocation slip and twin deformation. With the increased the shot peening strength, the twin density increasing, and the

repeated intersection of the twinning lines makes the grain fragmentation and it presents a random orientation distribution of small substructure.

Acknowledgements

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