Effect of Shot Peening on Surface Integrity of AerMet100 Steel

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Keywords: shot peening; AerMet100 ultra high strength steel; roughness; hardness; residual compressive stress

Abstract: This paper studies the effect of shot peening on its surface properties for AerMet100 ultra-high strength steel. Scanning electron microscopy and white light interferometer were used to analyze the effects of shot peening on the surface morphology, roughness, hardness, residual stress and element content of the samples. The results show that after shot peening, a large number of craters remain on the surface of the sample, resulting in obvious plastic deformation; The surface roughness is increased, and the arithmetic mean roughness is 1.33μm; The hardness is significantly increased, the hardness of the outermost layer is increased from 476HV before shot peening to 497HV, and the depth of hardened layer is about 150μm; The residual compressive stress value of the surface layer of the sample is increased from -375MPa to -475MPa, the maximum residual compressive stress value is about -518MPa, located at a depth of 50μm from the surface, and the residual compressive stress layer formed by shot peening has a depth of about 134μm; The mass fraction of C, Si, Cr and other elements in the sample after shot peening increased slightly. Shot peening improves the surface properties of ArerMet100 steel material to a certain extent, which is beneficial to improve its fatigue resistance and corrosion resistance.

1. Introduction

The development of the aviation industry provides a broad platform for the application of ultra-high strength steel materials. As a new type of ultra-high strength steel, AerMet100 (23Co14Ni12Cr3Mo) has good strength, toughness and fatigue properties, and is increasingly used in the manufacture of key structural components such as aircraft engines and landing gear[1].

Under the actual service conditions, the aircraft structure is susceptible to corrosion damage and fatigue failure due to the influence of the service environment and the alternating fatigue load. Therefore, in order to improve the durability, reliability and safety of aircraft components, surface strengthening techniques are often used to increase the service life of components. The shot peening process has the characteristics of good practicability, wide application range and low price. It can significantly improve the surface properties of the material, improve its corrosion resistance and fatigue performance, and is often applied to the surface strengthening of components. Domestic and foreign scholars have also carried out many researches on the impact of shot peening on material

Published by CSP © 2018 the Authors
DOI: 10.23977/icmit.2018.009

properties. Xiao Zhiyu et al[2]studied the bending fatigue performance of Fe-2Cu-2Ni-1Mo-1C material by shot peening. The results show that the surface of the sample before shot peening has more pores and the pore size is larger. After the shot peening, the pores of the surface layer of the sample were significantly reduced, nearly full density, and the thickness of the surface dense layer was about 70 μm. Sun Hanxi et al[3]studied the effects of fatigue loading on the residual stress and microstructure of 17CrNiMo6 shot peening layer. The results show that the residual compressive stress field depth of the sample before shot peening is about 50μm, and the maximum residual compressive stress is -220MPa, which is located on the surface of the sample; the residual compressive stress field depth of the sample after shot peening is 400 μm, and the maximum residual compressive stress is -650 MPa, which is located at a depth of about 100 μm from the surface layer. Xu Xingchen et al[4]studied the effect of shot peening on the surface integrity and fatigue properties of 2060 aluminum-lithium alloy. The results show that: shot peening increases the surface roughness of the sample, and there are pits of different depths. There is obvious plastic damage rheology and cracking and delamination at the edge of the stack; the surface hardness of the sample after shot peening increases by about 9%~12%. Guo Changgang et al[5]studied the effect of shot peening on the corrosion behavior of magnesium alloy in simulated body fluids. The results showed that the mass fraction of Mg in the sample decreased from 82.88% to 70.13% after shot peening, and the mass fraction of Al From 16.28% to 28.08%, the reduction of Mg and the enrichment of Al increase the corrosion resistance of the magnesium alloy.

Shot blasting is a common method currently used for surface strengthening of metal materials. It can not only introduce favorable factors for improving fatigue performance and corrosion resistance on the surface of materials, but also cause adverse effects such as increased surface roughness and cracking of materials. In this paper, AerMet100 ultra-high strength steel was used as the research object to analyze the effect of shot peening on its surface properties, which laid a foundation for further study on the effect of shot peening on the fatigue properties and corrosion resistance of materials.

2. Test

2.1 Test materials and samples

The test material used in this paper is the new ultra-high strength steel AerMet100 (23Co14Ni12Cr3Mo), and its chemical composition is shown in Table 1. The test material was processed into a block sample having a size of 10×10 mm and a thickness of 5 mm by wire cutting for shot peening.

Table 1 Chemical composition of Aermet100 (mass fraction/%)

C	Ni	Co	Cr	Mo	Si	Mn	Fe
0.23	11.73	13.85	3.13	1.25	0.10	0.10	Bal

The material heat treatment system was solution treatment at 879°C for 1.5h, air cooling to 95°C for 3 hours, -72°C deep cooling for 1.5h, and after rising to room temperature, it was deactivated at 483°C for 4.5h and cooled to room temperature. Its mechanical properties are shown in Table 2.

Table 2 Mechanical properties of Aermet100

$\sigma_{0.2}$/MPa	σ_b/MPa	δ_s/%	Ψ/%	K_{IC}/(MPa·$m^{1/2}$)
1755	1970	13	65	120

The metallographic structure of the material is shown in Fig.1. It can be seen that the metallographic structure of AerMet100 steel is mainly composed of lath martensite and polygonal austenite.

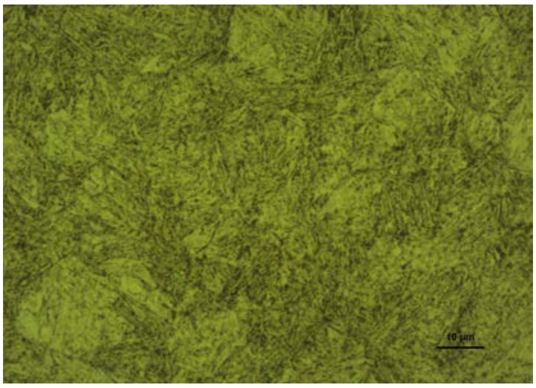


Figure.1 Metallographic organization

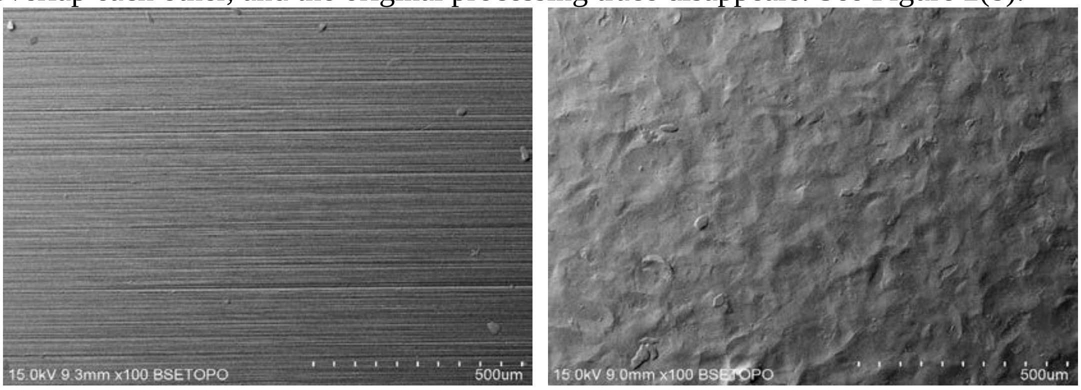
2.2 Shot peening

The test piece was subjected to shot peening according to the standard (SAE) AMS-S-13165-1997[6] using the RT3-G81-4 automatic shot blasting apparatus. The projectile is a cast steel projectile with a diameter of 0.3 mm, a hardness of 56-60 HRC, and a shot peening rate of 200%. The shot peening strength is determined to be 0.246 mmA according to the Almen test strip saturation strength test.

3. Test results

3.1 Surface topography

The surface morphology of the sample before and after shot peening is shown in Figure 2. It can be seen that the surface of the sample before shot peening is flat and smooth, and there are obvious processing trace lines, as shown in Fig. 2(a). After the shot peening, the surface of the sample has obvious plastic deformation, leaving different craters of different sizes and different depths. The craters overlap each other, and the original processing trace disappears. See Figure 2(b).



(a) (b)

Figure.2 Surface morphology before and after shot peening

3.2 Roughness

The surface roughness of the sample before and after shot peening was detected by NeXView type three-dimensional white light interferometer, as shown in Fig. 3. It can be seen that the roughness test results reflect the surface topography of the samples before and after shot peening. It can be seen from Table 3 that the surface roughness value of the sample after shot peening is increased, and a slight increase in roughness may increase the stress concentration level on the surface of the sample [7]. Where: R_a: arithmetic mean roughness; R_q: root mean square roughness; R_t: maximum roughness height.

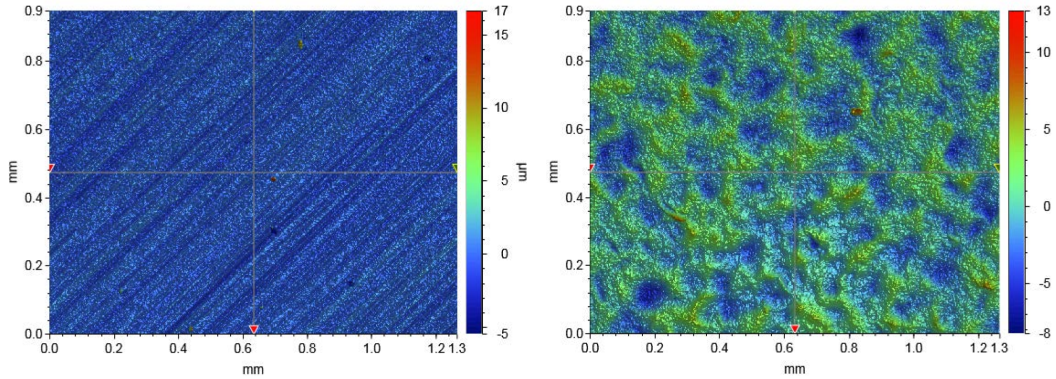


Figure.3 Roughness before and after shot peening

Table 3 Surface roughness before and after shot peening

Specimen	Ra/μm	Rq/μm	Rt/μm
Unpeened	0.47	0.59	6.62
Shot peened	1.33	1.68	15.34

3.3 Hardness

The hardness test was carried out along the depth direction of the cross section of the sample, and 3 points were tested at the same depth, and the average value was taken as the hardness value of the depth. As can be seen from Fig. 4, the hardness of the sample after shot peening is significantly increased, and the hardness of the outermost layer is increased from 476 HV before shot peening to 497 HV, and the depth of the hardened layer is about 150 μm. This is because during the shot peening process, the impact of the projectile causes plastic deformation on the surface of the sample, and grain microstructure and dislocations and other microstructure changes occur in the deformed layer [8-10], thereby improving the hardness of the sample. Changes in grain refinement and dislocations inside the sample are beneficial to improve corrosion resistance and fatigue properties [11-13].

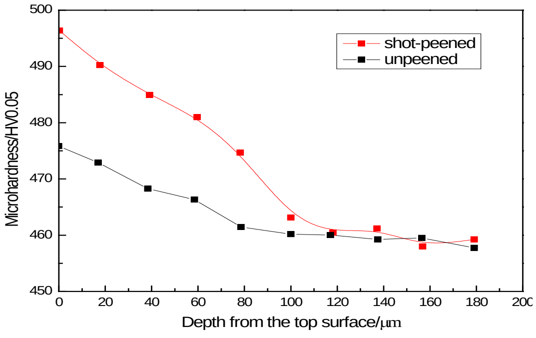


Figure.4 Hardness distribution before and after shot peening

3.4 Residual Stress

The residual stress test was carried out along the depth direction of the cross section of the sample, and 4 points were tested at the same depth, and the average value was taken as the residual stress value of the depth. Figure 5 is a test result of residual stress at different depths before and after shot peening of the sample. It can be seen that the residual compressive stress value of the surface layer of the sample after shot peening is increased from -375 MPa to -475 MPa, and the maximum residual compressive stress value is about -518 MPa. It is located at a depth of about 50 μm from the surface, and the depth of the residual compressive stress layer formed by shot peening is about 134 μm. The existence of residual compressive stress can offset part of the tensile stress under cyclic loading, reduce local payload, and delay the initiation and propagation of fatigue cracks [14,15].

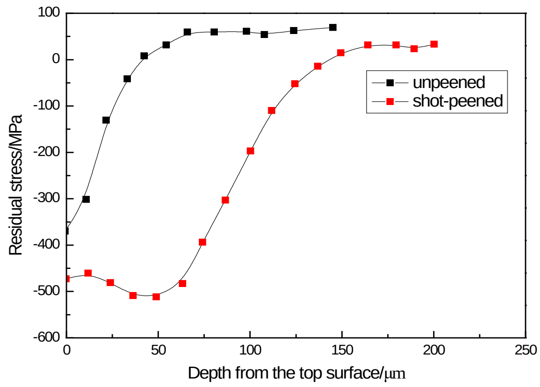
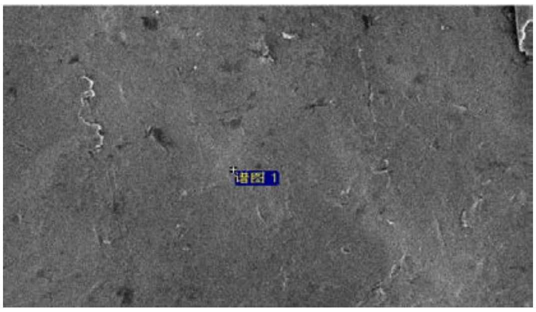
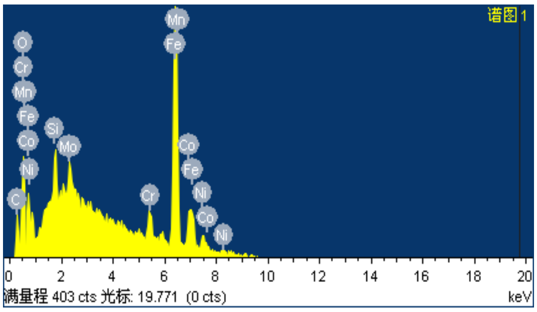


Figure.5 Distribution of residual stress before and after shot peening

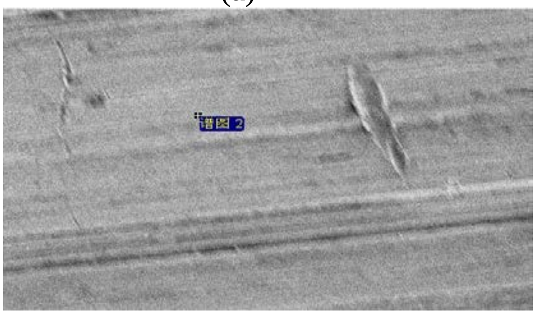
3.5 Element content



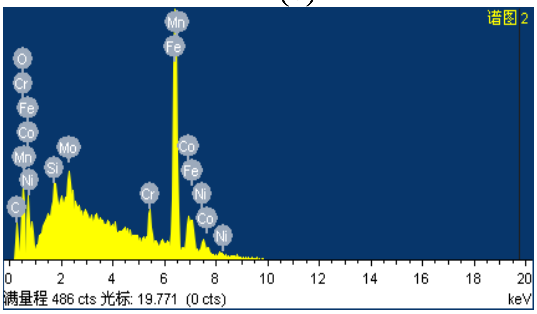
(a)



(b)



(c)



(d)

Figure.6 EDS before and after shot peening

Figs. 6(a), 6(b) and Figs. 6(c) and 6(d) are the results of EDS test after shot peening and before shot peening, respectively, and Table 4 is the content of elements in the sample before and after shot peening. It can be seen that the mass fraction of C, Si, Cr and other elements increased slightly after shot peening, mainly due to the phenomenon of material transfer during shot peening, At high collision rates and frequencies, contact fatigue wear occurs. During the impact process, the steel ball debris is decomposed and the alloying elements (such as Cr, C, etc.) are transferred into the surface of the sample. Due to the concentration gradient, the alloy atoms diffuse rapidly into the depth [16]. On the other hand, the material generates a large number of defects (vacancies, dislocations, etc.) under the action of high energy collision. The formation of vacancies reduces the diffusion activation energy, and the diffusion coefficient increases, making the diffusion easy [17].

Table 4 Element content

Elements	Weight percentage/%		Atomic percentage/%	
	Unpeened	Shot peened	Unpeened	Shot peened
C	8.36	8.42	26.76	26.89
O	5.14	5.46	12.34	13.10
Si	1.11	1.31	1.52	1.79
Cr	2.62	2.81	1.94	2.07
Mn	1.31	1.34	3.01	0.07
Fe	61.53	59.98	42.35	41.23
Co	10.07	10.21	6.57	6.65
Ni	6.14	6.54	4.02	4.27
Mo	3.72	3.93	1.49	3.93
Total amount	100.00	100.00	100.00	100.00

4. Conclusion

(1) After the shot peening, the surface of the sample showed obvious plastic deformation, the surface roughness increased, and the arithmetic mean roughness R_a increased from 0.47 μm before shot peening to 1.33 μm.

(2) Shot peening significantly increased the hardness of the sample, and the hardness of the outermost layer increased from 476 HV before shot peening to 497 HV, and the depth of the hardened layer formed by shot peening was about 150 μm.

(3) The residual compressive stress on the surface of the sample after shot peening is increased from -375 MPa to -475 MPa, and the maximum residual compressive stress value is about -518 MPa. It is located at a depth of 50 μm from the surface, and the residual compressive stress layer formed by shot peening is about 134 μm deep.

(4) The mass fractions of C, Si, Cr and other elements in the sample after shot peening are slightly increased, which is mainly caused by the phenomenon of material transfer during shot peening.

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