

Study on Plastic Deformation Characteristics of Shot Peening of Ni-Based Superalloy GH4079

L Q Zhong^{1,2}, Y L Liang^{3,*} and H Hu¹

¹School of Mechanical Engineering, Guizhou University, Guiyang, Guizhou, People's Republic of China
¹ College of Mechanical Engineering, Guizhou University, Guiyang, China

²School of Mechanical Engineering, Guiyang University, Guiyang, Guizhou, People's Republic of China

³School of Material and Metallurgy, Guizhou University, Guiyang, Guizhou, People's Republic of China

E-mail address: liang_yilong@126.com (Y L Liang).

Abstract. In this paper, the X-ray stress diffractometer, surface roughness tester, field emission scanning electron microscope(SEM), dynamic ultra-small microhardness tester were used to measure the surface residual stress and roughness, topography and surface hardness changes of GH4079 superalloy, which was processed by metallographic grinding, turning, metallographic grinding +shot peening and turning + shot peening. Analysized the effects of shot peening parameters on shot peening plastic deformation features; and the effects of the surface state before shot peening on shot peening plastic deformation characteristics. Results show that: the surface residual compressive stress, surface roughness and surface hardness of GH4079 superalloy were increased by shot peening, in addition, the increment of the surface residual compressive stress, surface roughness and surface hardness induced by shot peening increased with increasing shot peening intensity, shot peening time, shot peening pressure and shot hardness, but harden layer depth was not affected considerably. The more plastic deformation degree of before shot peening surface state, the less increment of the surface residual compressive stress, surface roughness and surface hardness induced by shot peening.

1. Introduction

Shot peening has been widely used to improve fatigue property and stress corrosion cracking resistance of materials due to the advantages of simple equipment, convenient operation, energy conservation, time saving, low cost and obvious effect[1]; and the nickel-base superalloy has been widely used in the manufacture of turbine disc, turbine shaft, journal, vane and other high temperature parts in the rocket and the aero-engine, due to well high-temperature strength, heat stability, corrosion resistance, thermal fatigue resistance and creep resistance[2]; so, there is a large amount of literatures[3-8] about the shot peening of nickel-base superalloy, among which, the literatures^[3, 6] have studied the residual stresses fields of GH909 alloy and inconel718 alloy shot peening, which show that beneficial residual compressive stress field was obtained by proper shot peening both in GH909 alloy and inconel718 alloy, and partly loosed during high temperature maintenance process. The literatures[4, 5, 8] have studied DZ4 directionally solidification superalloy, GH4169 superalloy and GH907 superalloy shot peening, which show that under high temperature, strengthening effect of shot peening is basically equal to weakening effect, and even the effect on notch specimen is more obvious than on smooth specimen, there is certain function of shot peening on the smooth specimen.



The organization structure in shot peening strengthened layer of GH4169 superalloy has studied in the literature[7], it shows that the thickness of elastic-plastic deformation layer formed by shot peening is about 1.2mm, and the surface roughness Ra is 1.4274 μ m. Although the scholars have obtained some achievements on studies of the shot peening in nickel-base superalloy, it is pointed out by studies of GAO Yu-Kui[9] that there is one best shot peening specification for one given material. As for the GH4079 which is a nickel-base superalloy just like GH4742, the content of Al, Ti and Nb was further improved in order to form more Ni₃ (AlTiNb) precipitation strengthening. The characteristics of shot peening plastic deformation layer are different when the marks and compositions of materials are different, and the research of shot peening of GH4079 superalloy is few. This paper plans to study the characteristics (surface residual stress, surface roughness, surface appearance and surface hardness gradient) of GH4079 superalloy shot peening plastic deformation layer, in order to provide reliable experimental data and certain theoretical foundation for choosing technological parameters of GH4079 superalloy shot peening and confirming surface conditions before shot peening.

2. Experimental

2.1 Material

For the tests the superalloy GH4079 was selected, the chemical composition of it is(wt%): C 0.059, Cr 11.02, Co 14.35, Mo 4.62, Al 3.11, Ti 2.77, Nb 2.68, V 0.62, Fe 0.3, La 0.046, Mn 0.03 and Ni margin. Experimental sample shown as figure 1, 50mmx20mmx10mm, which was provided by a company.

2.2 Methods

Before GH4079 superalloy shot peening, the surface is processed separately by metallographic abrasive, which grinding the surface of sample by abrasive paper for metallograph without any machining, and by turning with cutting parameters shown in Table 1; shot peening parameters shown in Table 2 were adopted to process lapped surface, and No.2 shot peening parameter shown in Table 2 was adopted to turning surface. Surface roughness Ra was tested randomly seven times by CALISUM surface roughometer CR-4032, adopting the mean value as the value of tested surface roughness; using field emission scanning electron microscope(SEM) SUPPA40 to further observe the surface appearance; the state of residual stress in the surface was measured using X-ray stress diffraction (XRD). XRD analysis was conducted using Mn k_{α} source on a DRON-3M diffractometer with a diffraction angle of 151° in plane {311}, which stress constant is -349 MPa. A $\sin^2 \psi$ method with $\psi = 0, 45^\circ$ was used for stress estimation, among which, scanned area 2θ is $158^\circ \sim 143^\circ$, scanned step pitch is 0.05° , counting time is 1s, voltage is 18 kV, current is 4 mA, light pipe diameter is $\Phi 2$ mm; and using DUH-211(S) dynamic ultra-small microhardness tester to test the changes of hardness on surface of the samples before and after shot peening, the test load is 196 mN, and retention time is 10s.

Table 1. Cutting parameters of turning

number	Cutting speed v(m/min)	Cutting depth a_p (mm)	Feed f(m/r)
1	560	1.0	0.035
2	280	0.5	0.053
3	280	0.5	0.088

Table 2. Shot peening parameters

parameter	Shot peening 1	Shot peening 2	parameter	Shot peening 1	Shot peening 2
Intensity	0.11	0.15	Coverage	>100%	>100%
Time	90s	120s	Type of pill	A S70	B S70
Pressure	0.22b	0.25b	Diameter of pill	0.125~0.355	0.125~0.355

Hardness of pill	HRC42.5~ 48.5	HRC48.5~ 52.5	Nozzle diameter	Φ 8 mm	Φ 8 mm
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3. Result and analysis

3.1 Characteristics of GH4079 superalloy metallographic abrasive + shot peening plastic deformation layer

3.1.1 Surface residual stress and surface roughness

The test results of surface residual stress in X and Y directions and surface roughness of metallographic abrasive and metallographic abrasive + shot peening of GH4079 superalloy are as shown in Table 3. It shows that the surface residual stress both in X and Y directions are compressive stress for the metallographic abrasive surface of GH4079 superalloy, due to the function of grinding force, and the $\sigma_{r(x)}$ is 100MPa slightly larger than $\sigma_{r(y)}$. The surface residual stress of metallographic abrasive + shot peening which parameters shown in table 2 are about -800 MPa in X direction, and -650MPa in Y direction, about 350MPa residual compressive stress was induced by shot peening, which explains that higher surface residual compressive stress of GH4079 alloy can be achieved through shot peening with the parameters adopted in this paper. Comparing residual compressive stresses induced by two kinds of shot peening parameters, it can be find that shot peening parameter 2 is slightly superior to shot peening parameter 1, because shot peening parameter 2 has larger shot peening strength, shot peening time, shot peening pressure and shot hardness, which enlarges deformation degree of surface plasticity, that the induced residual compressive stress is larger than it of shot peening parameter 1. On the other hand, the surface residual compressive stress of shot peening mainly depends on crystal structure, yield strength and work hardening index of material [10], instead of shot peening parameter that is why the superiority is not obvious. After shot peening, the difference of $\sigma_{r(x)}$ and $\sigma_{r(y)}$ was about 100 MPa as well as before shot peening, which illustrates that the residual compressive stress induced by shot peening was isotropy when the surface residual stress status of GH4079 alloy before shot peening has few difference in different direction.

As the surface roughness shown in Table 3, the surface roughness of GH4079 alloy with metallographic abrasive + shot peening is 5 times before shot peening, which is resulted from different sizes shot marks lefted on material surface by high-speed shot flow when shot peening, and before the shot peening, the surface of material with metallographic abrasive look likes very smooth, which is as shown in figure 2(a), we can find from the surface appearance pictures before and after shot peening that the surface with metallographic abrasive + shot peening2 (figure 2(c)) is rougher than metallographic abrasive + shot peening1 (figure 2(b)), which is consistent with measurement result of roughness.

Table 3. Metallographic abrasive surface residual stress and roughness of before and after shot peening

State of surface	Surface residual stress $\sigma_{r(x)}$ (MPa)	Surface residual stress $\sigma_{r(y)}$ (MPa)	Surface roughness $R_a(\mu m)$
Before/shot peening1/shot peening2	-473.7/-793.3/-827.7	-369/-624.3/-718.3	0.155/0.833/0.882

3.1.2 Surface hardness gradient

Seen from the surface hardness gradient curve of metallographic abrasive GH4079 superalloy before and after shot peening shown in figure 3, it can be find that the surface hardness of before shot peening was 560DHV, and beyond about 30 μm away from the surface, the value maintains to be about 500DHV. However, the surface hardness of shot peening may reach 700~800DHV, due to the shock of high-speed shot flow generates work hardening to metal on surface layer, and the hardness value gradually decreases along with the increase of layer depth, the value maintains to be 500DHV. However, the surface hardness of shot peening may reach 700~800DHV, due to the shock of

high-speed shot flow generates work hardening to metal on surface layer, and the hardness value gradually decreases along with the increase of layer depth, the value maintains to be about 500DHV until the distance from the surface beyond 400 μm . The surface hardness and hardness gradient of shot peening 2 are larger than them of shot peening 1 as shown in figure 3, but the depths of hardened layer for both are equivalent. It can be conclude that higher shot peening strength, longer shot peening time and bigger shot peening pressure correspondingly with more surface plastic deformation degree, should cause further the work-hardening capacity.

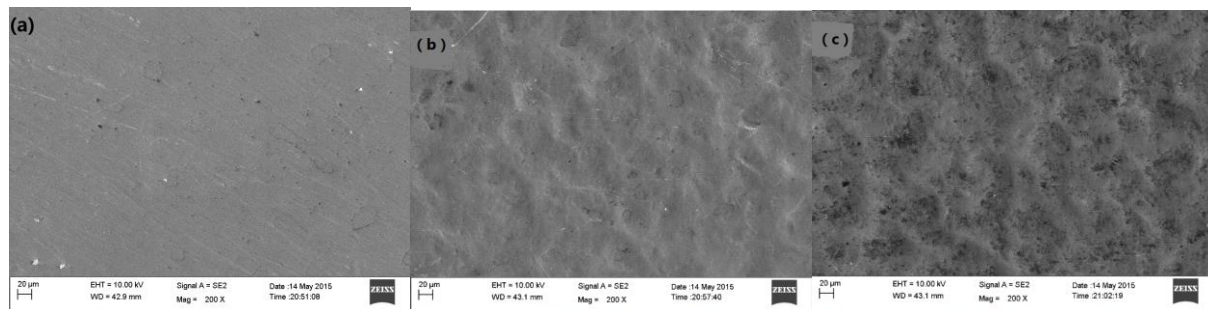


Figure 2. Surface topography(a) Metallographic abrasive,
(b) Metallographic abrasive + Shot peening1,
(c) Metallographic abrasive + Shot peening2

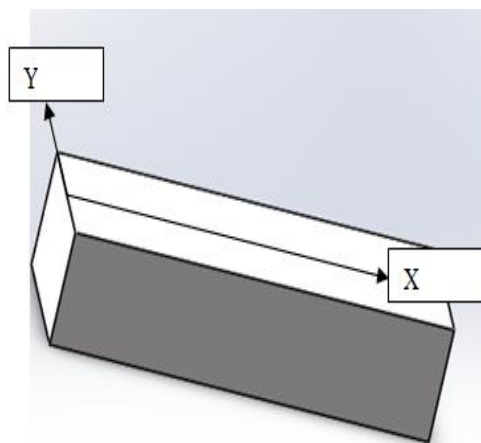


Figure 1. 3-D parts of test sample

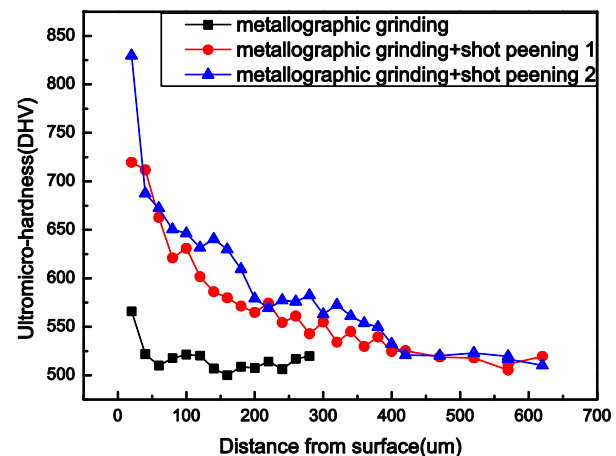


Figure 3. Curves of ultramicro-hardness before and after shot peening of metallographic grinding surface

3.2 Characteristics of GH4079 superalloy turning + shot peening

3.2.1 Surface residual stress and surface roughness

The test results of surface residual stress and surface roughness of GH4079 superalloy before and after shot peening were shown in Table 4, and 0#, 1#, 2# and 3# separately represented the surface state of metallographic abrasive+ shot peening 2, turning 1+ shot peening 2, turning 2+ shot peening 2 and turning 3+ shot peening 2. It easy to see that residual compressive stress was induced by shot peening no matter what the surface status of before shot peening. And the residual stress after shot peening of GH4079 superalloy in X direction $\sigma_{r(x)}$ can reach up to above -800 MPa and in Y direction $\sigma_{r(y)}$ can also be more than -450 MPa, due to the surface residual stress of shot peening mainly depends on crystal structure, yield strength and work hardening of material[10]. And it illustrates that residual compressive stresses induced by shot peening was changing with surface statuses of before shot peening, the more residual compressive stress before shot peening, the less residual compressive stress induced by shot peening, due to there is no obvious change at final surface residual compressive stress.

As shown in Table.4, the surface roughness of before shot peening changes within the 0.155-0.748 μm , and within the 0.787-0.957 μm after shot peening, which was obviously increased, the reason for this is that when the surface roughness of before shot peening is far smaller than diameter of the shot, passing by the shot with more than 100% coverage rate, the shot mark size left by shock of shot will be larger than the size of machining mark before shot peening and cover the whole surface. The surface roughness of shot peening are almost equivalent under different surface statuses, which illustrates that the surface roughness of after shot peening mainly depends on size of shot diameter. Figure 4 shows us the appearance pictures of turning surface before and after shot peening, the cutting mark and built-up edge on turning surface (figure 4(a),(c),(e)) are obvious, through shot peening, the shot marks on shot peening surface (figure 4(b),(d),(f)) can be seen clearly, and plastic deformation were observed, the cutting marks can just be seen indistinctly due to shock of high-speed shot.

Table 4. Surface residual stress and roughness of before and after shot peening

Number of sample	Residual stress in X direction σ_{rx} (MPa) before/after	Residual stress in Y direction σ_{ry} (MPa) before/after	Surface roughness Ra (μm) before/after
0	-473.7/-827.7	-369/-718.3	0.155/0.882
1	-998.2/-1102.3	504/-448.3	0.748/0.834
2	-546.5/-828	482/-495.5	0.675/0.787
3	-578.5/-829.7	478/-618.5	0.667/0.957

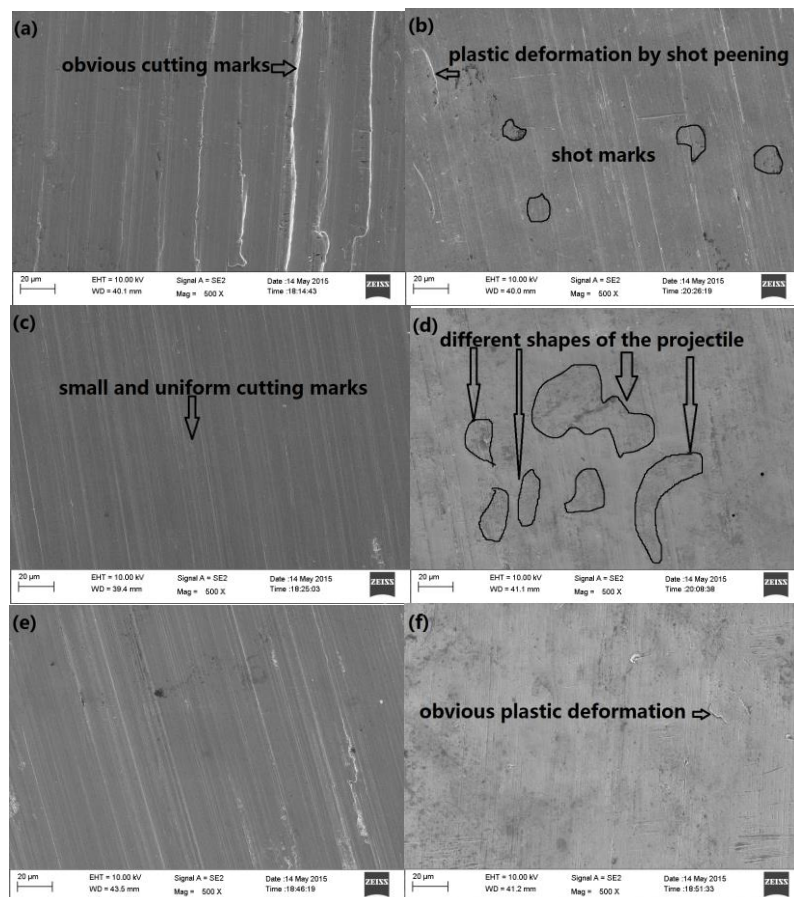


Figure 4. Surface topography (a) turning1, (b) turning1+ shot peening2 (c) turning 2 (d) turning2+shot peening2 (e) turning3 (f) turning3+shot peening2

3.2.2 Surface hardness gradient

The figure 5 shown the surface hardness gradient curves of GH4079 superalloy before and after shot peening, the variation trend of hardness of GH4079 superalloy decreased along with the increase of distance from the surface, to matrix hardness about 500DHV, which is resulted from work hardening generated from grinding, turning and shot peening, the depth of working harden was different from different surface processing, and in order to compare the effect of surface state on shot peening. Figure 5(a) shown the surface layer hardness gradient curves of turning1 surface before shot peening, we can find that the surface ultra-microhardness of turning1 was about 590DHV, which was harder than metallographic grinding surface, and the hardened depth of turning 1 was about 120 μm , deeper than metallographic grinding surface too; the surface ultra-microhardness of turning1 +shot peening2 was about 610DHV, and the hardened depths was about 130 μm . Figure 5(b) shown that the surface ultra-microhardness of turning2 was about 575DHV, and the hardened depth was about 50 μm , the surface ultra-microhardness of turning2 +shot peening2 was about 725DHV, and the hardened depth was about 250 μm . Figure 5(c) shown that the surface ultra-microhardness of turning3 was about 580DHV, and the hardened depth was about 60 μm , the surface ultra-microhardness of turning3 +shot peening2 was about 610DHV, and the hardened depth was about 100 μm . It is thus clear that the deeper hardened layer before shot peening, the less increment of hardened layer after shot peening, namely less obvious work-hardening phenomenon of shot peening. The reason for this is that harder surface affected by the shot, the larger resistance to be overcome, and the less work-hardening effect.

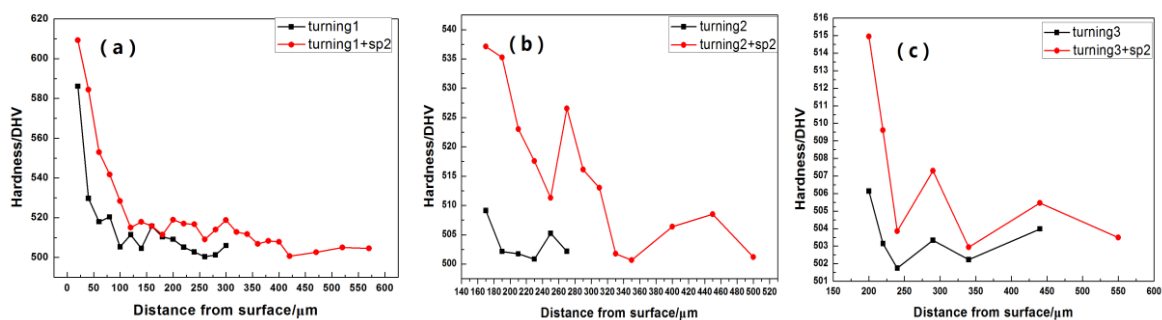


Figure 5. Curves of ultra-microhardness before and after shot peening (a) turning1 (b) turning2 (c) turning3

4 Conclusions

- (1) The surface residual compressive stress in X direction of GH4079 alloy shot peening $\sigma_{r(x)}$ can reach up to more than 800MPa, and in Y direction $\sigma_{r(y)}$ can reach up to more than 450MPa, the surface roughness waves around 0.8 μm , and the hardened depth of surface layer is more than 100 μm .
- (2) Increase shot peening intensity, shot peening time, shot peening pressure and shot hardness, the residual compressive stress induced by shot peening increases, surface roughness increases, hardness gradient of surface layer increases, and hardened depth is invariant.
- (3) The greater surface compressive stress before shot peening, the less residual compressive stress induced by shot peening; the lower surface roughness before shot peening, the larger increment of surface roughness after shot peening; the deeper hardened layer before shot peening, the less increment of hardened layer after shot peening.

5. References

- [1] Gao Y K and Ying Y F 2001 *J. Journal of Materials Engineering* 12 46-8
- [2] Xiao H M 2010 *Nanjing University of Aeronautics and Astronautics*
- [3] Gao Y K, Ying Y F and Li X B 2002 *J. Journal of Materials Engineering* 04 40-2
- [4] Gao Y K and Jing T 2010 *J. Journal of Aeronautical Materials* 06 35-8
- [5] Feng S, Zhao X J and Cheng C H 2008 *J. New technology & New Process* 06 88-90
- [6] Tang Z G, Cai D Y and Liu W C 2006 *J. Journal of Yanshan university* 06 503-6
- [7] Song Y G, Gao Y K and Lu F 2010 *J. Heat Treatment of Metals* 09 94-7
- [8] Ru J L, Wang R Z and Li X B 1997 *J. China Surface Engineering* 04 32-4

[9] Gao Y K, Li X B and Ying Y F 2003 *J. Journal of Aeronautical Materials* S1 132-5

[10] Gao Y K 2004 *J. Rare Metal Materials and Engineering* 11 1209-12

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