INVESTIGATION ON SHOT PEENING STRENGTHENING OF RENE′95 POWDER ALLOY

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ABSTRACT

Residual stresses, microstructure and density of HIP Rene′95 powder superalloy due to shot peening have been investigated. The amount and size of microporosities can be reduced by shot peening, resulting in increasing the density of the alloy. The amount of γ'-phase in the surface plastic layer is decreased from virgin 45% to 25%, which is then increased with following heating. The subgrain size can be broken from original $D_0=0.179(\mu m)$ to $D=0.015(\mu m)$ due to shot peening, which does not grow remarkably within 650(℃). Besides, compressive residual stresses and microstresses are introduced by shot peening. All changes mentioned above result in enhancing elevated temperature fatigue strength of Rene′95 powder superalloy.

KEYWORDS: residual stresses, subgrain size, fatigue strength, density

1 INTRODUCTION

The hot isostatically pressed (HIP) Rene′95 powder superalloy exhibits the small grain, homogenious microstructure and without macrosegregation, resulting in a good mechanical and physical properties comparing with the same forging alloy. The elevated temperature fatigue properties, however, must be decreased because of the existence of original boundaries, inclusions and hot induced microporosities. Therefore, shot peening is the effective technology employed to improve the fatigue properties of HIP Rene′95.

The residual stress field, microstructure, density and the fatigue properties before and after shot peening have been systematically investigated and the shot peening strengthening mechanisms have been discussed.

2 MATERIAL AND EXPERIMENTAL PROCEDURE

The main chemical compositions of HIP Rene′95 and its mechanical properties are listed in Table 1 and Table 2 respectively.

Table 1 Chemical compositions of Rene′95 (wt%)

Cr	Co	Al	Ti	Nb	W	Ni
12	7	3.3	2.3	3.3	3.3	remain

Table 2 Mechanical properties of Rene′95

Testing Temperature (℃)	σ_b(MPa)	$\sigma_{0.2}$(MPa)	δ(%)	ψ(%)
20	1730	1344	16.7	15.8
650	1524	1224	10.4	14.8

The size range of powder particles is 30～106(μm) and the average size is 60(μm). The size range of powder grains is 2～10(μm)and the average size is 4.5(μm)

The heat treatment specification of Rene′95 is: 1120～1150(℃)→salt bath quenching AC→870(℃) AC→650(℃) AC.

The macrostresses, σ_{mac} (or residual stress, σ_r), were determined on 2903 type X-ray strain diffractometer. The microstresses, σ_{mic} (i. e. lattice distortion $\Delta a/a$), and the subgrain size (D) were measured on D9-C type X-ray diffractometer. The density was measured on balance with 10^{-4} g sensitivity. The foil specimens were examined by H-800 electron transmission microscopy to observe the morphology of subgrains and dislocations.

Rotating bending fatigue test was carried out at 550(℃) and 83.3(Hz) with notched specimens (stress concentration factor Kt = 1.7). Strain-controlled, fully-reversed low-cycle-fatigue test were conducted on MTS machine at 550(℃) and 0.66(Hz) using hour-glass specimens.

The secondary shot peening procedure were applied for all specimens with glass beads after cast steel shots.

3 RESULTS AND DISCUSSION

3.1 Fatigue property

The S—N curves of rotating bending fatigue for specimens with Kt = 1.7 were shown in Fig. 1. According to up-and-down method, the fatigue limits before and after shot peening

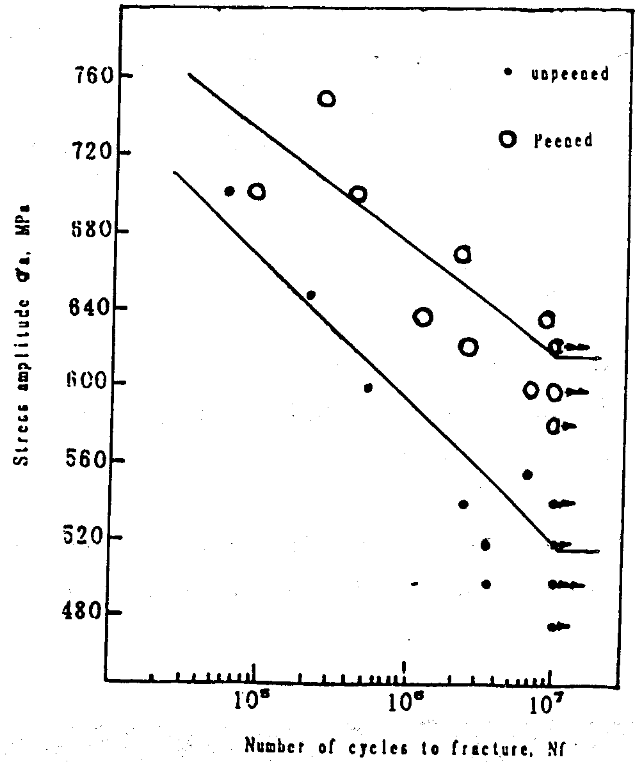


Fig. 1 Rotating bending fatigue S—N curves at 550(℃) for specimens with Kt=1.7 before and after shot peening

are σ_{-1}=518(MPa) and σ_{-1}=614(MPa) respectively. The fatigue limit is increased 18.5% by shot peening. In addition, the fatigue strength even at higher alternating stress level on the S—N curve can also be improved by shot peening (Fig. 1).

Elevated temperature low cycle fatigue results are presented in Table 3. It shows that the elevated temperature low-cycle fatigue properties can be obviously increased by shot peening.

Table 3 Testing results of low-cycle fatigue

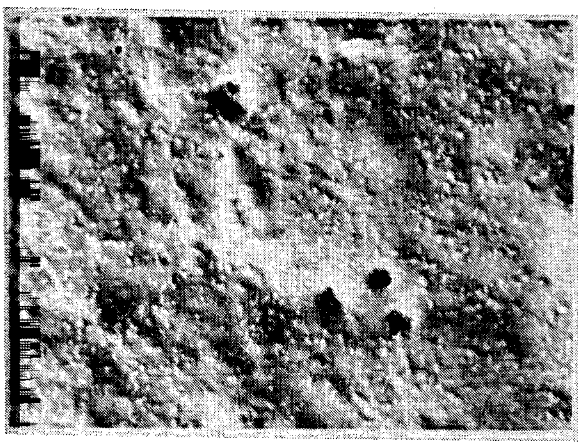
Surface Conditions	Total Strain Range $\Delta\varepsilon_t$ (%)	Half Stress Range $\Delta\sigma/2$ (MPa)	Cycle to Failure N_f (cycle)
Unpeened	1.157	1037	2992
	1.154	1030	1286
Peened	1.157	1037	>5997
	1.157	1037	>16932

3.2 Factors affecting fatigue properties

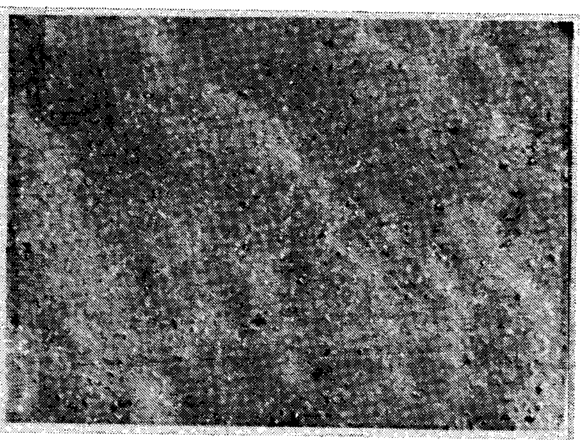
3.2.1 Density ρ

It is decided that the microporosity amount of HIP Rene'95 alloy is less then 0.3% total volume, which can be effectively reduced or eliminated in the surface deformed layer due to shot peening (Fig. 2). The density of the alloy can be changed with the fluctuation of microporosity amount.

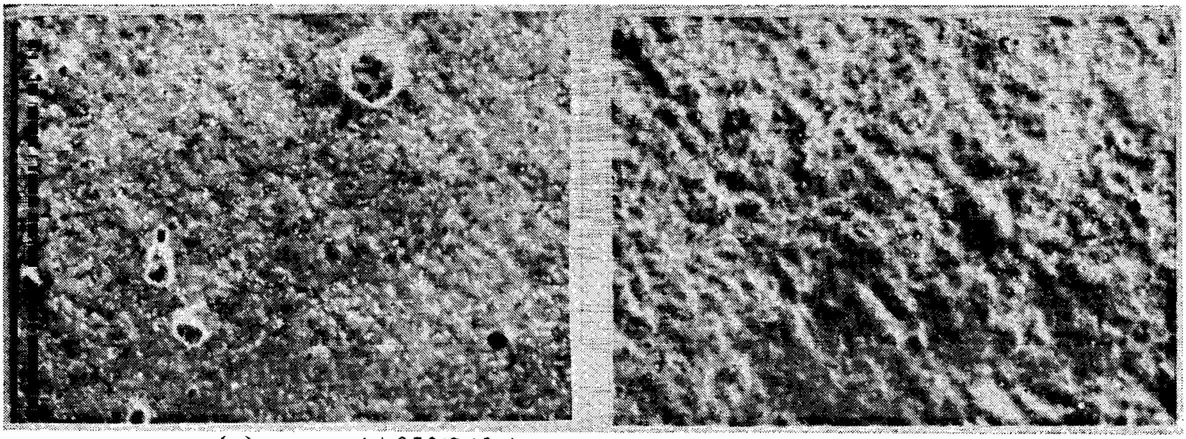
Plastic deformation due to shot peening not only influences the amount of microporosities but also induces the γ'-phase transformation. The alloy density depends on the content of both microporosity and γ'-phase.



(a) — unpeened



(b) — peened



(c) — unpeened + 950 ℃ (3h) (d) — peened + 950 ℃ (3h)

Fig. 2 SEM fractographies of microporosities before and after shot peening

In order to understand the effect of microporosity on the density, first, the γ' content in the surface deformed layer must be measured. The theoretical densities of γ and γ' phase and the relative change of $\Delta\rho/\rho$ must be calculated. All data mentioned above have been obtained in work[1]. The thin specimen (~0.3mm) was adopted to measure the density before and after shot peening. The tested ρ, $\Delta\rho/\rho$ values and the calculated $\Delta\rho/\rho$ values before and after shot peening and peened + aging at 950 ℃ (3h) are listed in Table 4. According to the calculated results[1], It is known that the calculated density of γ'-phase (7956.0kg/m^3) is higher than that of γ-phase (7369.8kg/m^3). When the γ' content reduces from 45% to 25% due to plastic deformation, it leads to the decrease of density. The content

Table 4 ρ and $\Delta\rho/\rho$ values

Surface Conditions	Amount of γ' (vol %)	ρ (kg/m^3)	$\Delta\rho/\rho$ (%)	
			Measured Values	Calculated Values
Unpeened	45	8264.3	—	—
Peened	25	8211.4	−0.64	−1.20
Peened + Aging (950℃, 3h)	45	8336.3	+1.52	+1.50

of microporosity and γ'-phase can be simutanously reduced by plastic deformation, resulting in the increase of density due to the former and in the decrease of density due to the latter. The comprehensive effect of the both leads to the reduction of density ($\Delta\rho/\rho = -0.64\%$), which is consistent basically with the calculated value.

When peened specimen was aged at 950℃, the γ'-phase amount increases. In this case the amount of microporosities is no longer change, resulting in the increase of density ($\Delta\rho/\rho = +1.52\%$), which is almost the same of calculated value ($+1.50\%$). The fatigue strength can be raised because of the reduction of the microporosity amount due to peened plastic deformation[2], which has been found to be a strengthening mechanism of the powder superalloy.

3.2.2 Macrostress, microstress and their relaxation

The distribution of macrostress σ_{mac} (or σ_r) induced by shot peening with the depth from the surface ($\sigma_r - \delta$ curve) and its relaxation at elevated temperature are shown in Fig. 3. The surface residual stresses relax about 50% during long holding period (10h) at 538(℃), but its relaxation is getting smaller with the depth. Besides, the stress relaxation can be caused by alternating stress during the fatigue process. The surface stress ($\sigma_{r,s}$) is about -421MPa after relaxation under the acting of alternating stress near the fatigue limit ($N = 10^7$ cycle). Comparing with the $\sigma_r - \delta$ curves in Fig. 3, the relaxation of residual stresses is mainly controlled by the effect of temperature field.

Shot peening introduces the lattice distortion of alloy ($\Delta a/a$, a—constant of lattice), resulting in the raise of microstresses (σ_{mic}). Both macrostresses and microstresses will be relaxed due to the effect of the temperature. The measuring results after stress relaxation are shown in Fig. 4. It is found that: ①The relaxation of σ_{mic} is more difficult than that of σ_{mac}, ②After stress relaxation during the service temperature (600~650℃) of Rene′95, the macro—and microstress are $\sigma_{mac} = -400$(MPa) and $\sigma_{mic} = \pm 900$(MPa) respectively.

The raise of σ_{mic} means the increment of dislocation density within crystal, which increases the difficulty of dislocation movement and the fatigue crack initiation[3]. The role of the high compressive residual stresses is: ①to decrease tensive stress level of applied alternating stress, ②to force the fatigue sources from the surface into the inner, obtaining the higher internal fatigue limit[4]. All these effects mentioned above can be led to the increase of elevated temperature fatigue limit.

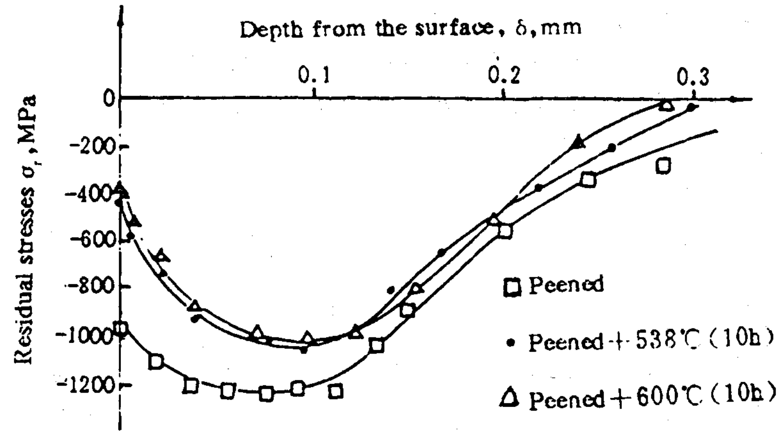


Fig. 3 $\sigma_r - \delta$ curves of peened and peened+heat treated specimens

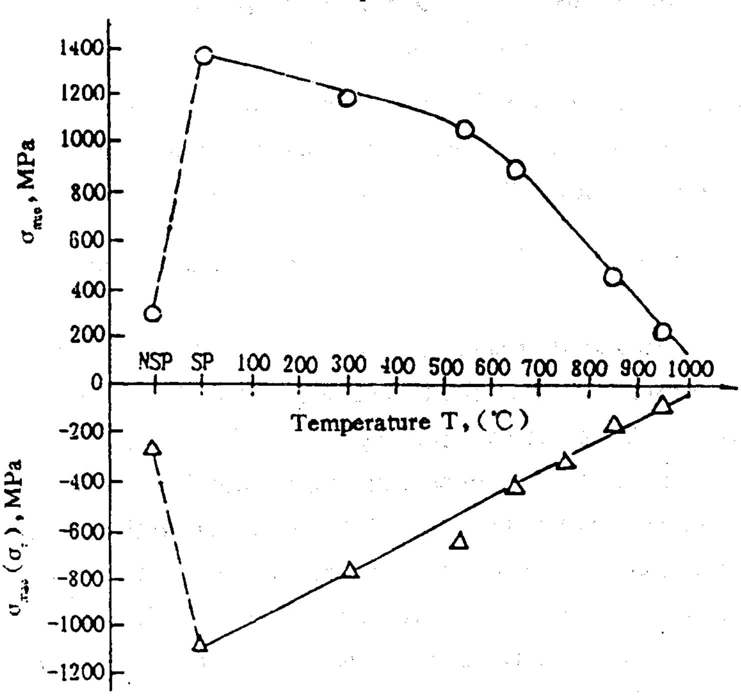


Fig. 4 σ_{mic} and σ_{mac} versus heating temperature (3h) (σ_{mic}—T and σ_{mac}—T curves)

3. 2. 3 Microstructure in the deformed layer

The transformation of γ' to γ phase is caused by the cyclic plastic deformation due to shot peening. After shot peening, the amount of γ'-phase was decreased from the virgin state 45% to 25% and its amount can be raised again with the heating temperature (Fig. 5).

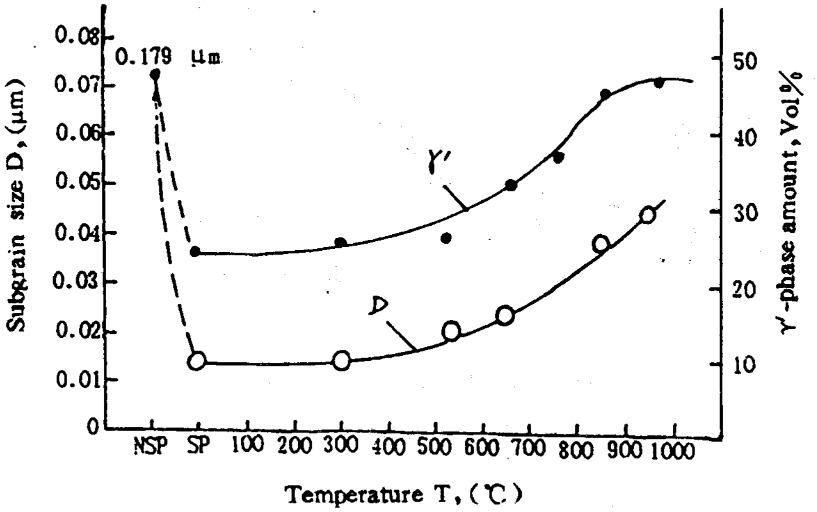
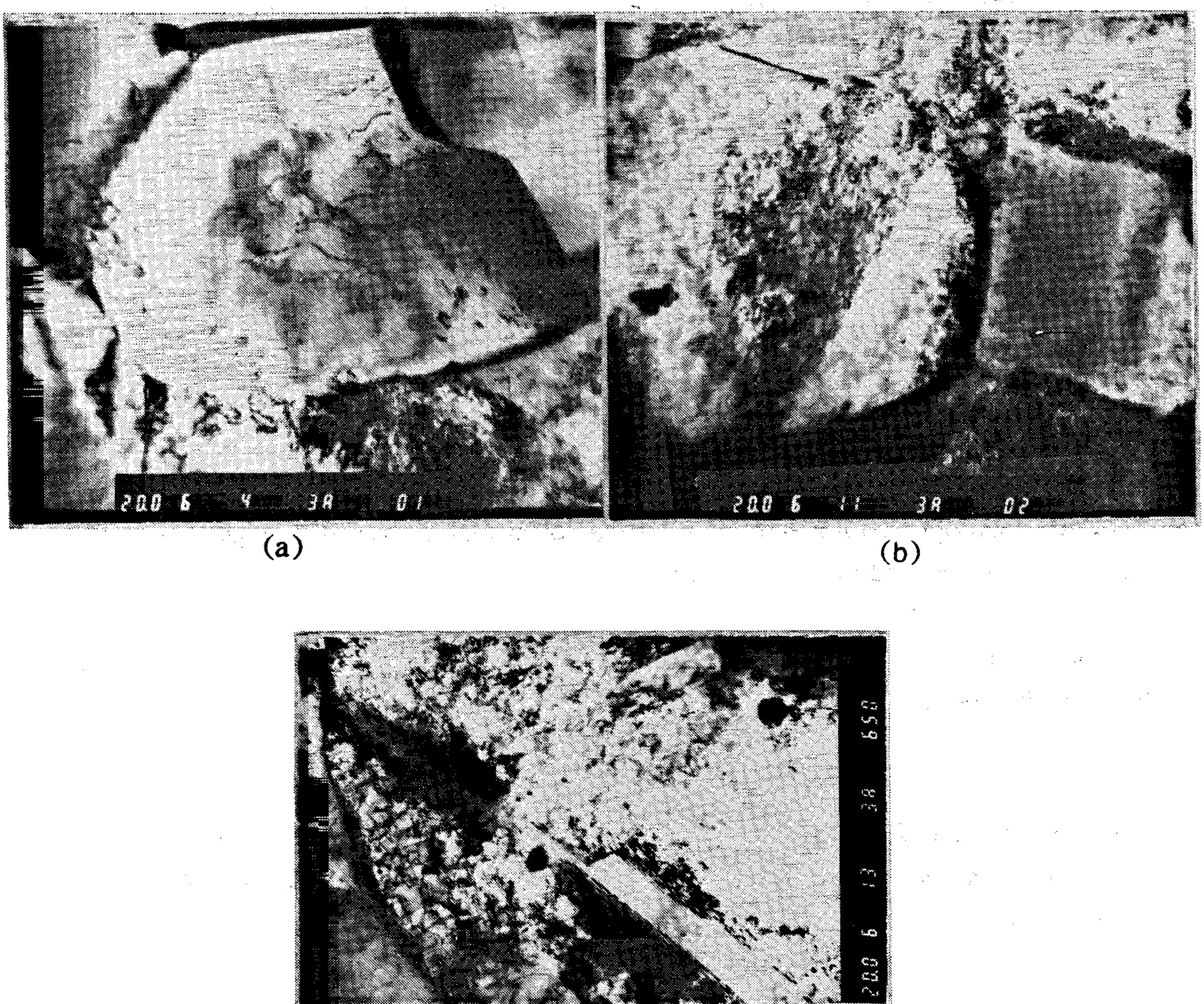


Fig. 5 Subgrain size(D) and γ'-phase content of original microstructure and peened microstructure versus heating temperature(3h)(D—T and γ'—T curves)

When the temperature raises up to 850℃, the amount of γ'-phase reaches the same level of virgin state (45%).

The subgrain size(D) before and after shot peening are D=0. 179(μm) and D=0. 015(μm) respectively. The subgrain size is fragmentized due to a large number of dislocations introduced by the cyclic deformation during the shot peening process. The fragmentized subgrains then grow slowly with temperature. At the temperature 600～650(℃), the subgrains are D= 0. 025(μm), which is much smaller than that of the virgin subgrains. It can be seen from Fig. 6 that the dislocation morphology of virgin microstructure appears to be a single feature, whereas the dislocation morphology of deformed microstructure is changed into the cell structure. The cell diameter is approximately equal to the size of the new fragmentized subgrain, which is no longer changed obviously even if at the higher temperatures (～650℃). These results obtained are consistant with that of Fig. 5.

All changes of γ'-phase transformation, the high dislocation density and the fine subgrains cause the cyclic hardening of Rene′95. The maximum hardness in the deformed layer is Hv=6400(MPa), whereas Hv=5300(MPa)[5] for the virgin microstructure. The vast amount of experimental results[6,7] have been pointed that the changes in the microstructure mentioned above must be led to the increase of resistance to the repeated motion of dislocations, Therefore the slip band at the deformed surface can not be formed easily, from which the fatigue crack initiation may be rest or prolonged resulting in the improving the fatigue strength.



(a) (b) (c)

Fig. 6 TEM photographies of unpeened (a) peened (b) and peened+aging at 650℃(3h)(c) specimens

4 CONCLUSIONS

(1)The amount of microporosities in the powder alloy can be decreased or eliminated by the cyclic plastic deformation during shot peening process, resulting in the increasement of density of the alloy, which is benefit for the improving elevated temperature high-cycle and low-cycle fatigue strength.

(2)The main factors to increase elevated temperature fatigue strength of the powder Rene′95 alloy have been found to be the residual compressive stress、fragmentized subgrain and the higher density in the surface deformed layer.

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