FATIGUE CRACK PROPAGATION BEHAVIOURS IN SHOT PEENED LAYERS OF METALS

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ABSTRACT

In this paper, effect of shot peening on fatigue crack propagation behaviours has been studied by means of surface crack growth method in 2Cr13 steel and ZM5 magnesium alloy. The results show that effect of compressive residual stresses on crack propagation rate is larger than that of material hardened by shot peening, it results obviourslly in the decrease of surface crack growth rate in shot peened layer, and causes a "Turn Back" phenomenon of fatigue crack growth front line on fatigue fracture surface. A model is proposed for distinguishing the effect of compressive residual stresses on crack growth rate from that of material itself of hardened layer.

KEYWORDS

Shot peening   case hardening   surface crack   crack growth   residual stress

INTRODUCTION

Shot peening can increase remarkedly fatigue strength of metals, it has been used widely in industry. It is well known that the improvement of fatigue strength results from the strengthened material and the existance of high compressive residual stresses in shot peened layer. However, the two factors play a contrary part in fatigue crack growth rate. The information about the characteristic of fatigue crack growth behaviour in shot peened layer seems also insufficient and little attention has been paid to distinguish different effect of two factors on crack growth behaviours. A "Turn Back" phenomenon of fatigue crack growth front line was observed on fatigue fracture surface of case hardened metals(1), but the essential aspect of this phenomenon was not described well.

In this paper, effect of shot peening on fatigue crack growth behaviours will be studied by means of surface crack growth method in 2Cr13 steel and ZM5 magnesium alloy. The aim is to clarify the roles of residual stresses and material itself of hardened layer in crack growth behaviours, and to reasonably assess the contribution of compressive residual stresses to crack growth rate.

EXPERIMENTAL PROCEDURES

Materials and heat treatment: Plate samples (L140 × w40 × t8, mm) were cut from 2Cr13 steel (C0. 18, Cr12. 73, Si0. 35, Mn0. 56, S0. 013, P0. 021, % wt). and ZM5 casting magnesium alloy (Al 7. 5—9. 0, Mn0. 15—0. 05, Zn0. 2—0. 8, % wt). 2Cr13 steel was quenched at 980℃ and tempered at 650℃. ZM5 magnesium alloy was solution treated at 415℃ for 16 hours, then air cooling (T 4).

Shot peenging process: Shot peening was brought in pneumatic machine with chilled iron shots of 1mm. The indensity was controlled in Almen samples f 0. 31 mm and f 0. 28 mm for 2Cr13 steel and ZM5 alloy, respectively. Then a small shallow notch was prefabricated with a special milling cutter on surface center of plate sample to initiate a surface crack.

Fatigue testing: Pulsating fatigue was performed in three point bending with freguency 46Hz and stress ratio R 0. 2 on Amsler test machine. The crack growth length on surface was measured with electric resistance strain gauge sticked on surface of sample. The carck length and depth below surface was measured with microscope on fatigue surface fracture according to crack growth front line trace produced by lifting — shedding load cycles.

Residual stresses measurement: Residual stresses were measured by x—ray diffraction with Fe (211) of Cr—k and Fe—k for 2Cr13 steel and ZM5 alloy, respectively. Fracture features were observed on scanning electron microscope.

EXPERIMENTAL RESULTS AND DISCUSSIONS

Efffect of shot peening on crack growth rate in shot peened layer: Some investigations showed that surface crack growth was nearly a semiellipse in a homogeneous material, and the crack growth rates on the major and minor axis of semiellipse depend upon the crack tip stress intensity factor range and properties of material(2). Under cyclic loading in three point bending, the stress intensity factor k_I was calculated using following expression: (3,4)

$$K = S_b \sqrt{\pi a/Q} \cdot F(a/c, a/t, c/w, \varphi) \quad (1)$$

$$Q = 1 + 1.464(a/c)^{1.65} \quad (2)$$

$$S_b = 3/2(ps/wt^2) \quad (3)$$

$$F(a/c, a/t, c/w, \varphi) = [M_1 + M_2(a/t)^2 + M_3(a/t)^4] \cdot f\varphi \cdot g \cdot f\omega \quad (4)$$

$$M_1 = 1.13 - 0.09(a/c) \quad (5)$$

$$M_2 = -0.54 + [0.89/(0.2 + a/c)] \quad (6)$$

$$M_3 = 0.5 - [1/(0.65 + a/c)] + 14(1 - a/c)^{24} \quad (7)$$

$$f_\varphi = [(a/c)^2 \cdot \cos^2\varphi + \sin^2\varphi]^{1/4} \quad (8)$$

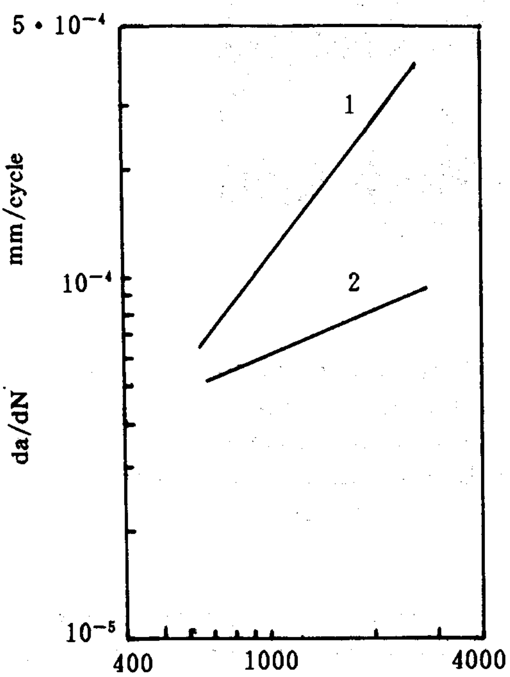
$$f_w = \{\sec [(\pi c/2w) \cdot \sqrt{a/t}]\}^{1/2} \quad (9)$$

$$g = 1 + [0.1 + 0.35(a/t)^2](1 - \sin\varphi)^2 \quad (10)$$

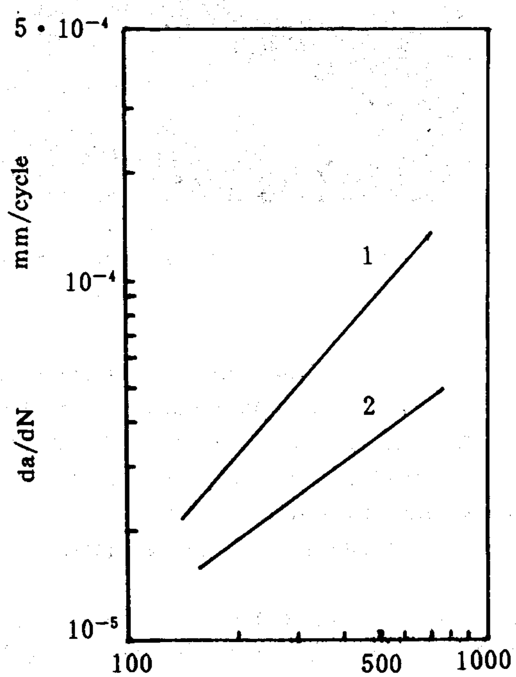
Figs. 1—2 are experiment results of surface crack growth rates of samples in 2Cr13 steel and ZM5 alloy, respectively. The results show that after shot peening the surface crack growth rates of two metals are obvioursly decreased.

"Turn Back" phenomenon of fatigue crack growth front line on fatigue frarcture surface: In generally, there is following relationship between the major and minor axis of a semi—ellipse crack: (4)

$$a/c + a/t = 1 \quad (11)$$



ΔK N/mm$^{3/2}$
1—without shot peening
2—shot peening
Fig. 1 da/dN as a function of Δk of surface crack growth on shot peened layer of 2Cr13 steel



ΔK N/mm$^{3/2}$
1—without shot peeming
2—shot peening
Fig. 2 da/dN a function of Δk of surface crack growth on shot peened layer of ZM5 magnesium alloy

that is, the crack growth rate is largest on surface and decreases gradually with increasing the distance from surface. However, observations of fatigue fracture surface show taht the fatigue crack growth front line is not a perfect semi—elliptic shape, and it bents toward the fatigue nucleus in shot peened layer, especially near centre on surface, as shown in Fig. 3. This phenomenon was called as fatigue crack growth front line"Turn Back" (1). This penomenon is also observed in other kind of case hardened metals, such as nitriding, carbonitriding, surface rolling etc(5). It means that the crack growth is greatly restrained in case hardened layer.

Assessment on contribution of compressive residual stress to crack growth in shot peened layer: It has been known that the fatigue crack growth rate is increased with the increase of strength and hardness of metals. For instance, the fatigue crack growth rate is increased with increasing carbon content or with decreasing tempering temperature in steel. (6,7)

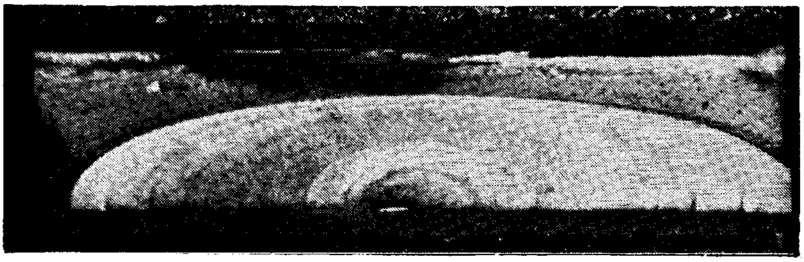


Fig. 3 Fractography of surface fatigue crack growth in shot peened 2Cr13 steel

After shot peening, both hardness and copmressive residual stresses are increased (Table 1). After shot penning, although compressive residual stress value is not very large for magnesium alloy, yet it is about one—third of tensile strength of this alloy. It means that the crack growth rate should be increased with respect of material itself of shot peened layer, regardless of compressive residual stresses. It follows that the reduction of crack growth rate has to completely attribute to the role of compressive residual stresses in shot peened layer.

It is worth indicating that while assessing the contribution of compressive residual stresses to constrain the crack growth, another contribution should be not neglect, which overcome the increment of crack growth rate caused by hardened material.

Table 1. Effect of shot peening on hardness and residual stress on surface layer of sample

Material	Hardness (HV)		Residual stress (MPa)	
	without s. p.	s. p*	without s. p.	s. p. *
2Cr13	27	310	−20	−490
ZM5	80	90		−75

* s. p. ———shot peening

A model of fatigue crack growth behaviour in case hardened layer: If a case hardened (or shot peened) sample is taken for a complex one, which is composed of two kind of homogeneous materials with different hardness and add to compressive residual stresses, the surface crack growth behaviour can be explained using a model as shown in Fig. 4. In Fig. 4 the different semi—circle (or semi—ellipse) curves represent the different crack growth front lines in different homogeneous materials, the distance from the centre of a circle represents the crack growth rate, as follow:

S curve — crack growth fornt line in a homogeneous material of case hardened layer with high hardness;

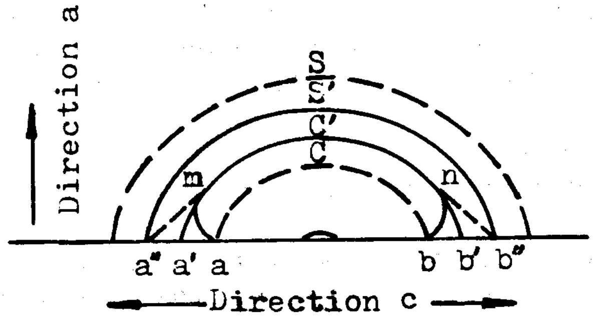


Fig. 4 Schematic of a model for explaining fatigue crack propagation front line "Turn Back" phenomenon in case hardened samples

C curve — crack growth front line in a homogeneous centre (virgin)material with low hardness;

S′ curve — crack growth front line in a hardened layer material constrained by a centre material, regardless of residual stress;

C′curve—crack growth front line in a centre material constrained by a hardened layer, regardless of residual stress;

a″m and nb″ segment — crack growth front line from surface to centre material of case hardened sample, regardless of residual stress

am and nb segment — crack growth front line from surface to centre material of case hardened sample due to the existance of compressive residual stresses. i. e. amc′nb curve represents an actual shape of crack growth front line.

This model indicates that: (1) The compressive residual stresses and the material itself of case hardened layer play a contrary role in crack growth rate, but effect of the former is often larger than that of the latter in case hardened layer. (2) The "Turn Back " phenomenon of fatigue crack growth front line results from the constraint role of compressive residual stresses to constrain crack growth should include another one to overcome the increment of crack growth rate caused by hardened material, as shown a ″a′ and b″b′in Fig. 4.

The fatigue strength is generally controlled by the crack initiation, but it can be controlled by the crack growth, when higher compressive residual stresses exist. This has been proved by the existace of non—propagating crack in case hardened layer. (8)

CONCLUSIONS

(1) The compressive residual stresses and the material of hardened layer play a contrary part in crack growth rate in shot peened layer. Effect of the former is often larger than that of the latter in shot peened sample, so that after shot peening the crack growth rate is obviously reduced.

(2)The "Turn Back" phenomenon of fatigue crack growth front line results from the constraint role of compressive residual stresses in crack growth in case hardened (shot peened)layer.

(3)A model for explaining the crack growth behavious is proposed in shot peened layer. The model can distinguish effect of compresive residual stresses on crack growth rate that of material of hardened layer. The contribution of compressive residual stresses to constrain the crack growth is assessed reasonably, which should include another contribution to comeover the increment of crack growth rate by hardened material.

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