INFLUENCE OF SHOT-PEENING ON THE INITIATION AND PROPAGATION OF FATIGUE CRACK IN SOME CONSTRUCTIONAL STEELS

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ABSTRACT

This paper presents the results of an experimental investigation on the effect of shot-peening upon the initiation and propagation of fatigue cracks and its relation with the mechanical behavior parameters of the materials. It shows that, shot-peening prodominately elongates the crack initiation period N_i and has comaaratively minor effect on the crack propagation period N_p. The correlation between N_i for shot-peened specimen with residual stress σ_r and strain hardening exponent n of the material may be expressed by the type of formula:

$$N_i(s) = A + B(-\sigma_r)^{(an+b)}.$$

KEYWORDS

Shot-peening, fatigue crack initiation and propagation, residual stresses, strain-hardening exponent.

INTRODUCTION

Shot-peening is a kind of simple, convenient, low-cost and effective technical means for imorofing the fatigue resistance of machine parts. The effects of shot-peening on raising the fatigue limit, prolonging the fatigue life under light over loading resistance against corrosion fatigue and stress corrosion and lowering the fatigue notch sensitivety have been amply investigated. But the fundamental behavior of fatigue failure is fatigue crack initiation and propagation. The study of these problems is very important in clarifying the changes brought about by shot-peening and its suitable application.

The purpose of our work is to investigate the effect upon the initiation and propagation of fatigue cracks in some low alloy constructional steels, quenched and tempered at different temperatures and its relation with the mechanical behaviour parameters of material under certain conditions.

EXPERIMENTS

The materials used in this experiment are 18CrNiW steel quenched and tempered at 250 °C (No.1) and 650 °C (No.2), 20SiMnMoV steel quenched and tempered at 250 °C (No.3), 35CrMo steel quenched and tempered at 250 °C (No.4), 400 °C (No.5) and 650 °C (No.6). The cylindrical specimen (diameter 15 mm) with a notch was used in our fatigue testing. A part of specimens were shot-peened. Fatigue tests are carried out in an Amsler Vibrophor in three point bending. The range of load is Pmin/Pmax = 320/1600 kgf. ($\sigma_{min}/\sigma_{max}$ = 14.4/72.4kgf/mm²). The initiation and propagation of fatigue crack was monitored by periodical varying the peak load to outline the crack front followed by oxidation stainning after fracture. The no. of cycles for the appearence of a crack 0.1 mm in depth was taken as the cycle of crack initiation(Ni). This actually also includes the initial stage of crack propagation. The no. of cycles for the propagation of crack deep to 4 mm was taken as the arbitrary total fatigue life (N4) (due to the resonance nature ofthe testing machine), and the cycles of crack propagation Np=N4-Ni .

The residual stresses on the surface and in depth of shot-peened specimens were determined by X-ray diffrection.

The total depth of strengthened layer is about 0.5 mm. Typical fracture surfaces are shown in Fig. 1.

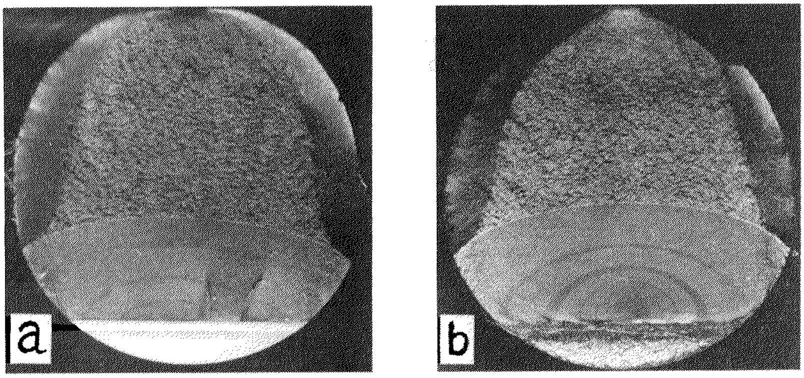

Fig.1. Fatigue fracture surface outline showing crack fronts. (a) Condition No.4,non-peened; (b) Condition No.4, shot-peened.

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental results obtained for values of N_i of the tested materials shot-peened and non-peened respectively are shown in Fig. 2. It is clear that, shot-peening predominately elongated N_i and has comparatively minor effect on Np . Under the conditions of our experiment, Ni can be increased to 12 times (No.3), while Np was increased only to 2 times (No.2). This result does not agree with that obtained by previous authors, which concludes (Kudryavtsev 1972),that the effect of shot-peening in increasing N_p is more obvious than N_i .

One evidence for the increase in N_i by shot-peening can be found in Fig.3. Dimples as a fast fracture mechanism occur in the fatigue origin ($a<0.1$ mm) of the un-peened specimen No.4 but they are not found in the fracture of the same specimen No.4 shot-peened until a reaches 3 mm. This shows that the effect of shot-peening including the increased resistance of deformation and presence of a residual compressive stress layer has effectively supressed the rapid fracture mechanism from the start.

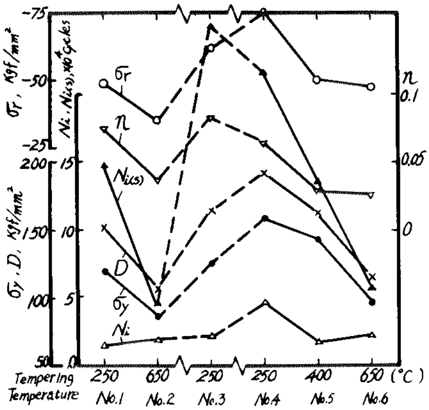

Fig.2.N for shot-peened and non-peened specimen, and tensile test parameters for various materials.

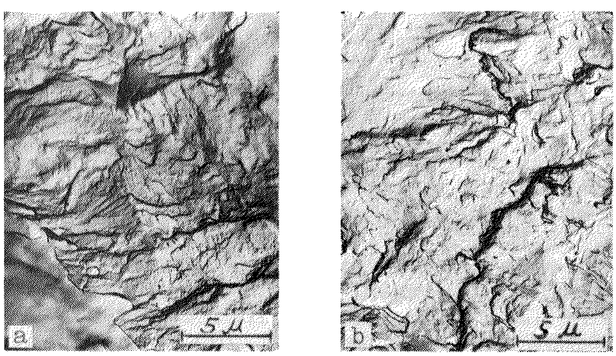

Fig.3. Fractographs of specimen No.4 showing the crack initiation area, (a) shot-peened, (b) Non-Peened.

Fig.4 shows the relation between da/dN and crack depth a of 35CrMo steel, tempered at high, medium and low temperatures, shot-peened and non-peened. When the depth of crack is shallow, e.g. $a\leq 1$ mm, the effect of shot-peening on reducing the rate of crack propagation is very obvious. This effect decreases and fades out gradually as the crack penetrates deeper, such that finally the rate of crack propagation for shot-peened and non-peened specimen approach each other. It is clear from the fatigue fracture surfaces shown in Fig.1 that when the crack is shallow, the radius of curvature the outlined crack front for shot-peened specimen is smaller than that for non-peened one and their shape are also quite different, varying gradually as the crack penetrates inward. This indicates that the restraint of residual compressive stress layer due to shot-peening against crack propagation weakens gradually following the increase of crack depth. SEM observations show already no more difference in the fracture morphology between shot-peened and non-peened specimen 2 mm from the surface.

As a result of shot peening, the increase in strength and formation of residual compressive stresses are both results of plastic deformation. The degree of work hardening should be determined by the strength factors: yield strength σ_y , ultimate strength σ_b , initial work hardening exponent n and slope of deformed s-e curve D, plastic deformation capacity factors: uniform and final reduction of area ψ_b and ψk, percentage elongation δ etc. of the materials. Expe-

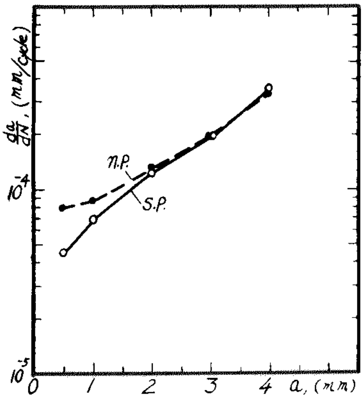

Fig.4. Relation between rate of crack propagation da/dN and crack depth for specimen No.5 shot-peened and non-peened.

rimental results has indicated that the higher the strength, the better the effect of shot-peening, while the strain hardening exponent n plays a more important role in increasing N_i. For example, σ_y, σ_b and D of 20SiMnMoV steel tempered at 250 °C are much lower than that of 35CrMo steel tempered at 250°C, but the effect of increase in N_i is the highest for 20SimnMoV the reason most probably lies in the difference in the value of strain hardening exponent n, such as shown in this work and the other Report (Xi'an Jiaotong Univ.1974). 35CrMo Steel tempered at 250°C has the highest slope of deformed section of S-e curve (strain hardening coefficient) D, but the increase of N_i is comparatively low. This shows that D is not a major factor for increase in N_i. The effect of shot-peening is not noticiable for the 2 materials tempered at high temperature in this experiment, may be attributed to the presence long yield point platform in their tensile stress strain curves. For in these cases, on the one hand, the yield point is low which is unfavorable to keep a high residual compressive stress and on the other, the strain hardening exponent n approaches zero which induces negligible strain hardening before and during the platform.

The crack propagation period Np represents the limit of crack propagation before unstable rapid fracture occurs. It is governed by suitable balance between strength and ample ductility, such as elucidated in (Zhou,1980). Thus the Np for high temperature tempered steels are superior than those tempered at low temperature.

From the point of view or residual stresses high residual compressive stress as a rule is favorable for obtaining a magnificient beneficial effect of shot-peening. However in this experiment, although 35CrMo steel tempered at 250°C has the highest residual compressive stress after shot peening it did not give the longest N_i. The max. value of N_i was obtained in 20SiMnMoV steel tempered at 250°C. Although its residual compressive stress after shot peening is lower than that of 35CrMo steel tempered at 250°C,but its value of n is the highest of the whole series. Thus it can be seen that either the state of residual stress or any single mechanical property parameter of the material alone can correlate with the effect of shot-peening only qualitatively. Although the tread of variation of N_i for shot-peened specimen follows closely with n, in all series of steel we tested, no functional relation between N_i and n can be set up. This directs us to think about may be the effects of shot-peening on N_i are the results of synthetic actions of residual stress σ_r and some mechanical behavior parameters of the material. Although the crack initiation period N_i for non-peened specimen is mainly controlled by the strength factor of the material and needs a suitable balance between the strength and its ductility (Zhou,1979; Deng and Jin,1979) , but for shot-peened material new factors are introduced through surface plastic deformation. Among the mechanical behaviors parameters of the materials tested in our experiment n has the closest relationship with N_i. In general, for ordinary tempered constructional steels strain hardening exponent n not only expresses the hardening ability of the alloy complexion, but also to a certain degree reflects its strength level of the materials. Of course, beside the material factor production of persistant compressive residual stress offers the other determining for the shot-peening effect on fatigue crack initiation. On the basis of our limited experimental data, a functional relation between N_i for shot-peened specimen with σ_r , n was established :

$$N_i(s) = -1.79\times10^4+1.06\times10^3(-\sigma_r)^{(4n + 1)} \qquad (1)$$

From Fig.5 it can be seen that formula (1) can fit all experimental data satisfactorily, except the data of 35CrMo steel tempered at 400°C, which just falls into the first temper brittleness rigion.

Formula (1) may be written as :

$$N_i(s) = A+B\ (-\sigma_r)^{(an+b)} \qquad (2)$$

where A,B and a,b are constants. They depend on experimental and material conditions. If we give consideration to the effect of surface condition on N_i, then $N_i(s)$ will be a function of σ_r, n and the surface condition (such as roughness H).

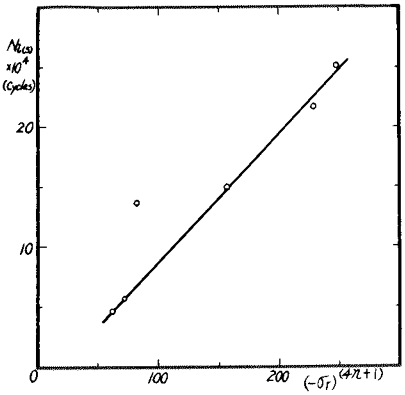

Fig.5. Normalized correlation of $N_i(s)$ for shot-peened specimen with σ_r and n for various tested materials.

CONCLUSIONS

1. For conditions of high cycle fatigue with comparatively low overloading, shot-peening predominately elongates the crack initiation period N_i and has comparatively minor effect on the crack propagation period N_p.

2. When the depth of crack is shallow the effect of shot-peening on reducing the rate of crack propagation is rather obvious. This decreases and fades out gradually as the crack penetrates deeper.

3. The crack initiation period N_i for shot-peened specimen has a closer relation with residual stress σ_r and the strain hardening exponent n of the material, their correlation may be expressed by the type of formula:

$$N_i(S) = A + B(-\sigma_r)^{(an+b)}$$

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