EVALUATION OF FATIGUE STRENGTH OF ARBITRARILY NOTCHED SPECIMENS WITH SMALL DEFECTS BASED ON LINEAR NOTCH MECHANICS

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Fatigue tests have been carried out on the notched specimens of two forged steels with small defects under rotating bending.

When the notch radius is larger than a definite size, the fatigue limit is affected and decreases by the existence of defects. According as the value of notch radius becomes large, the decrease in the fatigue limit becomes large. This is due to the statistical factor based on the difference in sizes of surface areas exposed to the danger of crack initiation. Because of this statistical factor, in some cases the fatigue limit of plain specimen is rather smaller than those of bluntly notched specimens.

The fatigue strength of arbitrarily notched specimens can be predicted systematically by using a master-curve derived from the concept of linear notch mechanics, including the cases where crack initiation is affected by the existence of defects.

INTRODUCTION

In most cases, the failure or fracture of machines and structures are brought on by the stress concentration due to the existence of a notch or a defect. Therefore, it is important to evaluate the fatigue strength of material with a notch or a defect. As the stress concentration factor Kt increases, the fatigue limit σ_w decreases in general, but one of authors showed that in some bluntly notched specimens of low carbon steel the fatigue limits of them increase a little according as Kt increases. This is due to the statistical factor based on the difference in the strength of each grain. This statistical phenomenon is remarkable in the material having defects.

In this paper, fatigue tests are carried out on the notched specimens of two forged steels with small defects under rotating bending and it is shown that the fatigue strength of a notched specimen having arbitrary sizes in notch radius and notch depth can be predicted systematically based on the concept of linear notch mechanics(1),(2).

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LINEAR NOTCH MECHANICS

In this section, the concept of linear notch mechanics(1) will be given in short.

Figure 1 shows the concept of linear notch mechanics and its usefulness.

Figure 1(a) indicates the relation between the limiting stress σ_{w1} or σ_{w2} and the stress concentration factor Kt, where σ_{w1} is the limiting stress for crack initiation and σ_{w2} is the limiting stress for final fracture in the range of non-propagating crack existing.

In Fig.1(a), there is no one to one correspondence between σ_{w1} or σ_{w2} and Kt. According to the concept of linear notch mechanics, there should be one to one correspondence between $Kt\,\sigma_{w1}$ or $Kt\,\sigma_{w2}$ and $1/\rho$, independent of the notch depth and the diameter. Figure 1(b) supports it clearly. By using Fig.1(b) as the master curve for the fatigue strength of this material, we can predict the limiting stresses σ_{w1} and σ_{w2} of the round bar specimen having an arbitrary circumferential notch(2).

MATERIALS, SPECIMENS AND TESTING METHOD

The materials used are two kinds of forged steels, whose distributions of defects are different as shown in Fig.2. The size and number of defects are larger in forged steel A than in forged steel B. The chemical composition of the two forged steels are shown in Table 1. Ultimate tensile strength of forged steel A and B are 829MPa and 759MPa, respectively.

Fatigue tests were carried out on the plain and notched specimens. The notch depth t is 2.0 or 0.5mm and the notch radius ρ is ∞(plain specimen), 50, 25, 10, 5, 2, 1, 0.2, 0.1 or 0.05mm. Length of the part with the same diameter in plain specimen is 10mm.

Before testing, all the specimens were polished with emery paper, and then were electro-polished to the depth of about 20 μm to eliminate the work hardened layers. The Ono-type rotating bending fatigue testing machine was used.

TABLE 1- Chemical Composition (wt%)

Forged steels	C	Si	Mn	P	S	Ni	Cr	Mo
A	0.24	0.06	0.30	0.009	0.011	3.68	1.80	0.45
B	0.23	0.02	0.06	0.003	0.002	3.55	1.69	0.42

EXPRIMENTAL RESULTS AND DISCUSSION

Figure 3 shows the results of forged steel A. In Fig.3, σ_{w0}' means the fatigue limit of plain specimen having no defects. The σ_{w0}' was determined by extrapolation. As shown in Fig.3, when the stress is higher than the fatigue limit, a microcrack appears from defects in the case where the notch radius is larger than a definite size, but a microcrack appears from slip bands in the case where the notch radius is smaller than the definite size.

Figure 3(a) shows the relation between σ_{w1} or σ_{w2} and Kt. In Fig.3(a), the σ_{w1} or σ_{w2} - Kt relations are a little dependent on the notch depth. Each curve of σ_{w1} is composed of two smooth curves connected at a point where Kt is around 1.5. In other words, the fatigue limits are influenced by the existence of defects in one curve, but are almost independent on it in another curve. This is due to the statistical factor based on the difference in sizes of surface areas exposed to crack initiation.

Figure 3(b) shows the rearranged results of the data in Fig.3(a). The rearrangement is based on the concept of the linear notch mechanics. As shown in Fig.3(b), there is one to one correspondence between $Kt\sigma_{w1}$ or $Kt\sigma_{w2}$ and $1/\rho$, independent of notch depth, including the cases affected by the existence of defects. By using Fig.3(b) as the master curve for the fatigue strength of this forged steel, we can predict the fatigue limit σ_{w1} or σ_{w2} of the round bar specimen having an arbitrary circumferential notch, including the cases affected by the existence of defects. This proves the usefulness of linear notch mechanics.

Figure 4 shows the similar results concerning forged steel B. By comparing Fig.3(a) with Fig.4(a), it is found that the notch sensitively is higher in forged steel B than in forged steel A. This is mainly due to the fact that the decrease in fatigue limit of plain specimen due to the existence of defects, $\sigma_{w0}' - \sigma_{w0}$, is larger in forged steel A than in forged steel B.

Figure 5 is the relations between $Kt\sigma_{w1}/\sigma_{w0}$ and $1/\rho$ in the range where $\rho \geqq$ 0.2mm, in forged steels A, B and a 0.45% C steel.

The decreases in fatigue limit of bluntly notched specimens can be seen more clearly in Fig.5 than in Fig.3 and 4. Further, this kind of decrease in fatigue limits is recognized even in the 0.45% C steel whose σ_{w0} is not affected by the defects. This may be due to the statistical factor based on the difference in strength of each grain.

CONCLUSIONS

Fatigue tests were carried out on notched specimens of two forged steels with small defects under rotating bending. The main results are summarized as follows:

(1) When the notch radius ρ is larger than a definite size, the fatigue limits of these forged steels are affected and decrease by the existence of defects. On the other hand, when ρ is smaller than the definite size, the fatigue limits are not affected by defects.

This is due to the statistical factor based on the difference in sizes of surface area exposed to the danger of crack initiation. Because of this statistical factor, in some cases the fatigue limit of plain specimen is rather smaller than those of bluntly notched specimens.

(2) The fatigue strength of a notched specimen having arbitrary sizes in notch radius and notch depth can be predicted systematically by using a master-curve derived from the concept of linear notch mechanics, including the cases where crack initiation is affected by the existence of defects.

SYMBOLS USED

Kt = stress concentration factor

σ_w = fatigue limit(MPa)

σ_{w0} = the fatigue limit of plain specimen(MPa)

σ_{w1} = the limiting stress for crack initiation(MPa)

σ_{w2} = the limiting stress for final fracture in the range of non-propagating crack existing(MPa)

ρ = notch radius(mm)

t = notch depth(mm)

σ_{w0}' = the fatigue limit of plain specimen having no defects(MPa)

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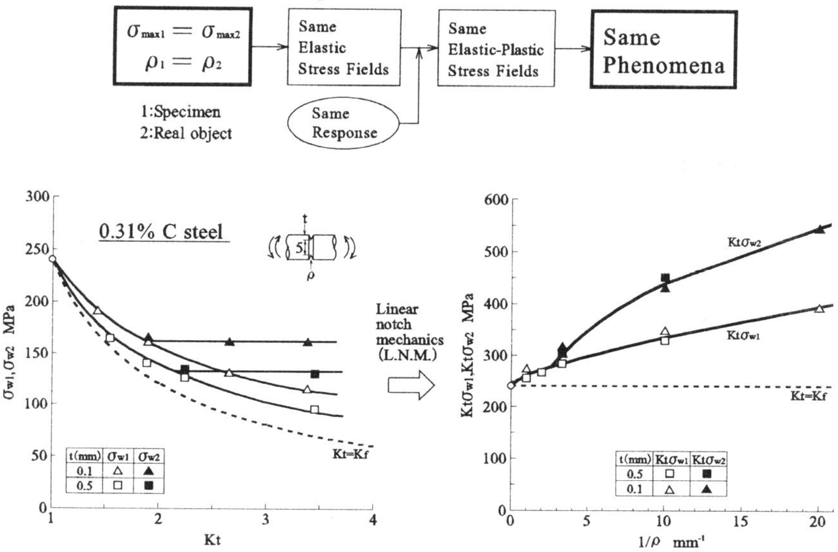
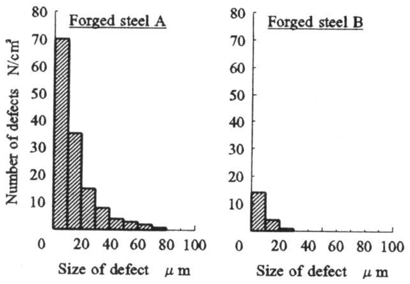


Concept of linear notch mechanics

(a) σ_{w1} or σ_{w2} — Kt relation (b) $Kt\sigma_{w1}$ or $Kt\sigma_{w2}$ — $1/\rho$ relation

Fig.1 Concept of linear notch mechanics and its application to notched fatigue strength[2]



(a) Forged steel A (b) Forged steel B

Fig.2 Distribution of defects

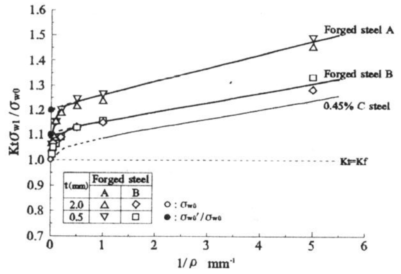
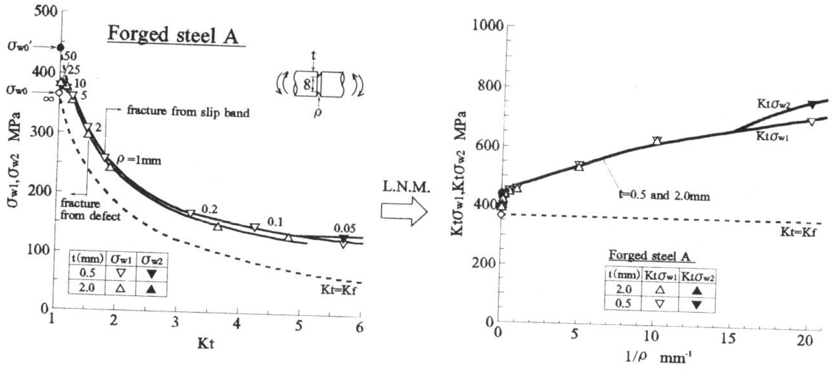
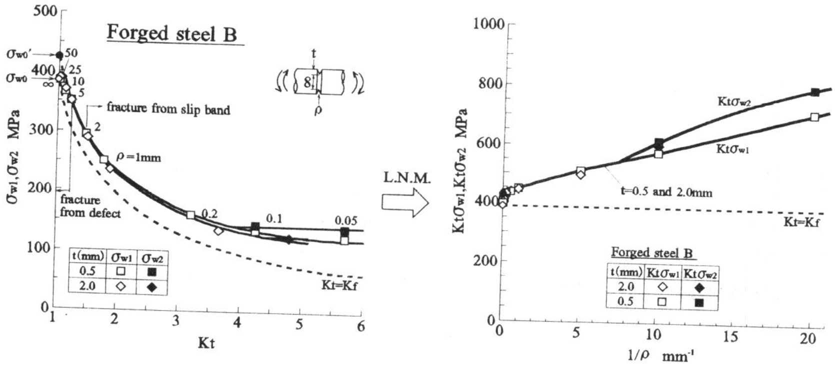


Fig.5 Relation between $Kt\sigma_{w1}/\sigma_{w0}$ and $1/\rho$



(a)Relation between σ_{w1} or σ_{w2} and Kt (b)Relation between Ktσ_{w1} or Ktσ_{w2} and $1/\rho$

Fig.3 Notched fatigue strength of forged steel A



(a)Relation between σ_{w1} or σ_{w2} and Kt (b)Relation between Ktσ_{w1} or Ktσ_{w2} and $1/\rho$

Fig.4 Notched fatigue strength of forged steel B