SIZE EFFECT IN IMPACT TENSILE FATIGUE

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INTRODUCTION

Nowadays,fracture mechanics is a powerful approach to study fracture behavior of engineering materials. It is also applied to study fatigue problems,and so many studies have been made concerning fatigue of metals. But,when an impact torsion or compression was pulsated,the size dependence of fatigue life was studied[1],[2]. These results were discussed by taking into account the superposition of stress waves produced in a specimen by a given impact load. In this paper,the effect of the length of a specimen on the impact tensile fatigue life is studied. From the results, it is pointed out that the mechanical size effect can be seen in impact fatigue and this effect should be considered for the application of fracture mechanics to impact fatigue problems.

SPECIMENS AND EXPERIMENTS

The material used was a commercial steel,S45C. This as rolled material was named series A,and series B was prepared by water quenching after heating at 850°C and successive tempering after heating at 600°C for one hour. Their mechanical properties are shown in Table 1.

Table 1 Mechanical properties

Material	σ (MPa)	δ %(G.L.=100mm)	ψ %	Hardness(Hv)
Series A	878	2.1	5.7	241
Series B	775	2.6	11.6	266

Specimens were prepared as shown in Fig.1. Their lengths are 150mm, 200mm and 250mm respectively.

The experimental apparatus was made in our laboratory and the schematic diagram is shown in Fig.2. A compression piece is driven by a cam on the periphery of a rotating disc to compress the impact spring. After the cam pass through the maximum compression(stroke=60mm),the piece runs back with the connection rod and gives an impact tension to a specimen of which another end is fixed to the apparatus base. Thus impact tension can be pulsated 50 times per minute.

EXPERIMENTAL RESULTS AND DISCUSSIONS

Impact fatigue experiments were carried out at two stress levels by using an impact spring of which spring constant was S_1=1627N/m or S_2=931N/m. Two cracks initiated at the both notch roots of each specimen after incubation periods which were different for these two cracks. These cracks propagated gradually with increase of pulsated times and connected with each other at last. These results are shown in Figs.3 and 4. In these figures,solid and broken lines show the results for series A and B ,re-

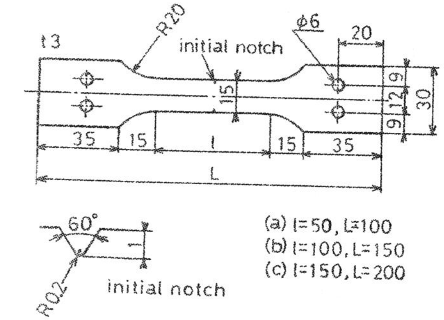

Fig. 1 Dimensions of specimens

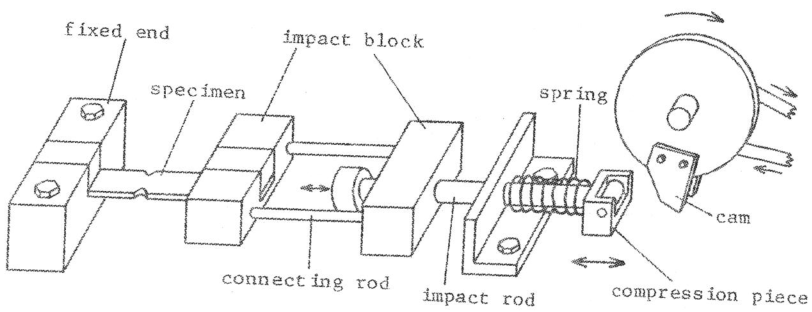

Fig.2 Experimental apparatus for impact fatigue

spectively.

According to these figures,the incubation period till crack initiation and the fatigue life of shorter specimen were shorter than that of longer one for series A and B,respectively. This size dependence of fatigue life is similar to the previous results[1],[2]. It can also be seen that fatigue lives were improved,especially for longer specimen,by heat treatments. In the case of series B, the improved ductility seems to increased the resistivity to fracture.

In these experiments,the dynamic stress state in a specimen was not in equilibrium. For such a transition phenomenon,the dynamic stress is difficult to study by energy consideration. It should be studied by taking into

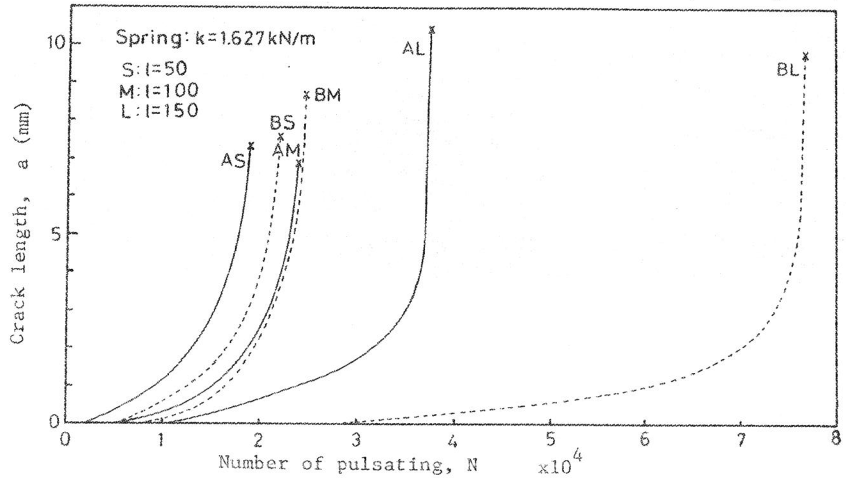

Fig. 3 Experimental results

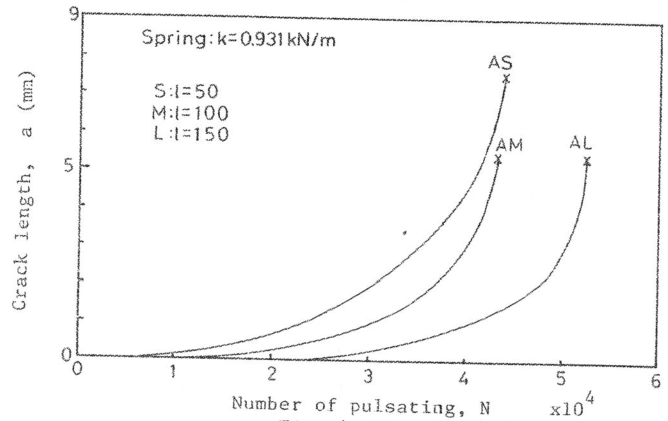

Fig. 4 Experimental results

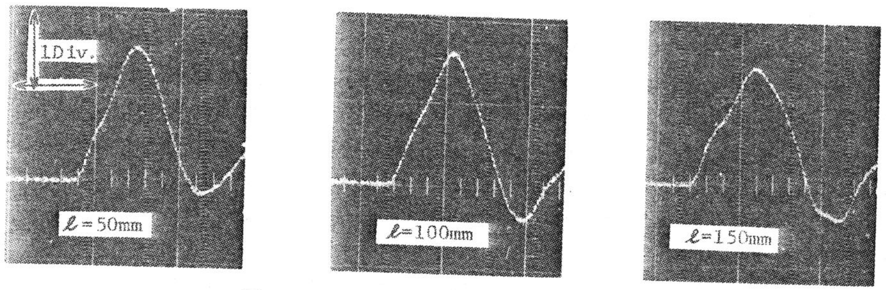

Photo.1 Strain Waves (Impact tensile fatigue, Steel)
[Ordinate; 1Div=0.25×10^{-3} strain
Abscissa; 1Div=2msec]

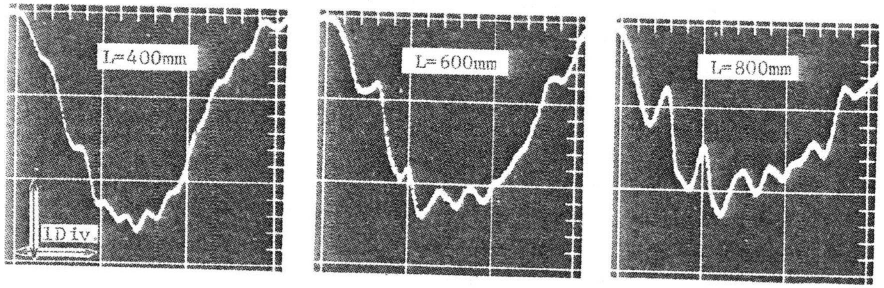

Photo.2 Strain Waves (Impact compression, PMMA)
[Ordinate; 1Div=0.2×10^{-3} strain
Abscissa; 1Div=1msec]

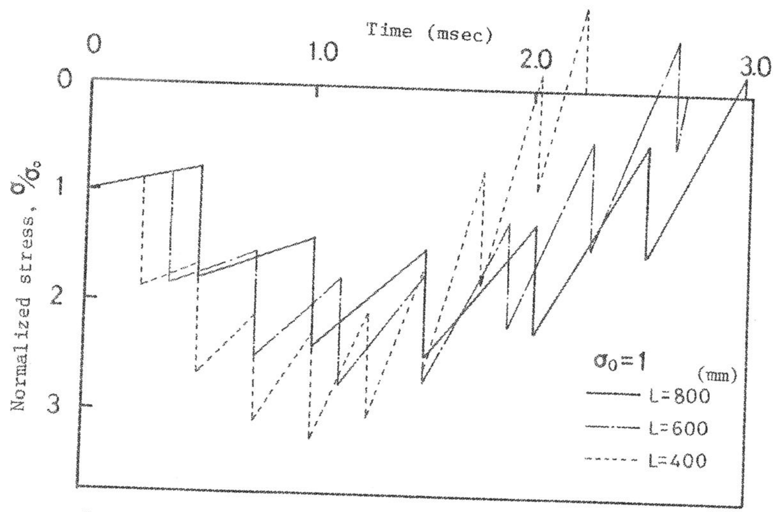

Fig.5 Stress Waves (Impact compression, theoretical, PMMA)

account the effect of wave properties. Then, strain waves were measured by a strain gauge pasted on each type of specimen and the typical examples are shown in Photo.1. In these Photos, the maximum of strain wave is a little higher for shorter specimen. Therefore, it was supposed that impact fatigue life was affected by the maximum of a stress wave and the maximum was composed of reflected waves in a specimen which has a finite dimension. In order to see this latter point more clearly, PMMA plate specimens were used. As stress wave propagates in PMMA with the velocity less than one third of steel, it was expected that a resultant wave would has more simple form than that of steel. It is convenient to observe a wave form. The width, the thickness and the lengths of specimen, L, were 300mm, 10mm and L=400, 600, 800mm, respectively. An impact load was given by a swing type weight to the free end of a specimen of which another end was attached to the fixed steel plate[3]. The length of swing arm, the swing angle and the mass were 460mm, 10° and 11Kg. The typical examples of strain wave are shown in Photo.2. The similar size dependece of the wave form can be seen for both Photos.1 and 2, and the latter shows the stepwise increase of strain wave clearly. As the stepwise increase implies the superposition of reflected stress waves, we consider a simple model as follows.

When the one end of a bar which has a unit cross section and length, L, is struck by a mass M with the velocity v, the equation of motion of impact end is written as[4]

$$\frac{M}{\sqrt{E\rho}}\frac{d\sigma}{dt} + \sigma = 0 \qquad (1)$$

by using the relation $v=\sigma/\sqrt{E\rho}$. Where σ, E and ρ are the impact stress on the impact end, Young's modulus and the density of the bar. The solution is given by $\sigma=\sigma_0\exp(-t\sqrt{E\rho}/M)$ at time t less than 2L/c, where $c(=\sqrt{E/\rho})$ is the velocity of stress wave. When another end of the bar is supported rigidly, the resultant stresses are expressed by the superposition of waves up to the nth reflection for $t>2L/c$. The nth reflection wave is not expressed in a simple form, but it can be written as

$$F_n(t)=F_{n-1}(t) + \sigma_0\sum_{r=0}^{n}\frac{{}_nC_r}{r!}\left\{4\alpha\left(n-\frac{ct}{2L}\right)\right\}^r\cdot\exp\left\{-2\alpha\left(\frac{ct}{2L}-n\right)\right\}$$

$$\text{where } {}_nC_r = n!/n!(n-r)!\ ,\ \alpha = \rho L/M \qquad (2)$$

by putting $0!=1$, ${}_nC_0=1$ from the practical point of view. This equation shows that the nth wave and then the resultant stress depends on the length of the bar. Applying this result to PMMA specimens, Fig.5 was obtained. Although, strictly speaking, some studies including various reflected and transmitted waves from the supporter of a specimen are necessary in future, above discussions seems to give a reasonable explanation qualitatively.

The size effect studied in this paper may be called mechanical size effect. On the contrary, usual wellknown size effect may be called volumetric size effect for which smaller specimen is stronger than that of longer one due to the less probability of the presence of weak points.

CONCLUSIONS

Impact fatigue experiments were carried out for steel specimens which are prepared to have three different lengths. The results are summerlized as follows.

1) The incubation period till crack initiation and the fatigue life are shorter for shorter specimen.

2) This size dependence of fatigue life can be explained by taking into account the superposition of reflected waves produced in a specimen by an impact load.

3) This mechanical size effect is contrary to the usual volumetric size effect.

4) The effect should be considered when fracture mechanics parameter, for example a stress intensity factor, is applied to a finite body under impact loads.

5) Improvement of impact fatigue life can be expected, especially for longer size specimen, by suitable heat treatment.

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