Cyclic Deformation of Tubular Specimens under Repeated Torsion

Tatsuo Endo and Kakuichi Kobayashi
The Kyushu Institute of Technology
Tobata, Kitakyushu - si, Japan

INTRODUCTION

The object of this paper is to reveal several fundamental factors in determining the plastic shear strain which is induced by the mean shear stress τ_m and the amplitude τ_a. The angular plastic deformation of tubular specimen of mild steel was measured under alternating torsion with static torsion. The phenomenological analysis of the results suggests the logarithmic creep law, where the static tensile stress and time in usual creep correspond to the amplitude of cyclic stress and the number of cycles in cyclic creep respectively.

SPECIMENS AND TESTING MACHINE

Carbon steel specimens are machined after the annealing at 900 °C. The mechanical properties are as follows: Tensile strength σ_B is 42.3kg/mm^2, Upper and lower yield point under tension are $\sigma_{u.y.p}$=27.1kg/mm^2 and $\sigma_{l.y.p.}$=25.8kg/mm^2, Upper and lower yield point under torsion are $\tau_{u.y.p.}$=18.9 kg/mm^2 and $\tau_{l.y.p.}$=15.6kg/mm^2. Fatigue specimen is shown in Fig.1. The polished specimens are annealed in vacuum at 600 °C prior to static or fatigue test. Shear stress of tubular specimen is expressed by the average over the section. Cyclic yield point $\tau_{c.y.p.}$=14.2kg/mm^2 is defined by the stress amplitude of hysteresis loop of which range of plastic strain is 0.3%. Testing machine, of which speed is 1800 rpm., is a constant moment type, i.e. the mean moment and the amplitude are automatically kept constant during test. Torsional fatigue limit τ_w was 11.4kg/mm^2.

EXPERIMENTAL RESULTS AND DISCUSSION

Sets of alternating stress and the mean stress, under which the relationship between shear deformation and the number of cycles was measured, are shown in Fig.2. Additionally $\tau_{u.y.p.}$ $\tau_{l.y.p.}$, $\tau_{c.y.p.}$ and τ_w are plotted by the marks ▽ ▼ ● & ■. The experimental points shown by ⊙ & △ can be divided into two groups for convenience. Each specimen which belongs to the first group is subjected to the same amplitude of stress which is combined with the various mean stress. The typical relationship between the strain of cyclic creep γ and the number of cycles N is shown in Fig.3. The result is replotted in Fig.4 by semi-log scale. The numbers in Fig.3∼Fig.6 indicate the mean stress. These figures show the followings:

a) The above cyclic creep curves, which are obtained under the same cyclic stress superimposed by various mean stresses coincide each other by the vertical shift except the part of curves where N is smaller than 500 cycles. This means that the cyclic creep curves are approximately expressed by a master curve which depends on the strain amplitude only until the cyclic creep strain cease increasing.

b) The forms of curves is expressed by the following

equation: $\gamma = K\log N + C$ ...(1) or $\gamma = K\log(\nu N)$...(1')
Namely the rate of shear strain $d\gamma/dN$ is inversely proportional to the number of cycles N : $\frac{d\gamma}{dN} = \frac{K}{N}$...(2)
Where the value K is independent of the mean stress τ_m. The constant C or ν is independent of N ,but is dependent of mean stress for constant stress amplitude. The equation (2) expresses the form of master curve. These equations obtained under constant stress amplitude τ_a are similar to the equation of usual 'logarithmic creep law' found at low homologous temperature under steady stress and the equation is the special case of the following law: $d\gamma/dN = A(N)^{-m}$, where A and m (m=1 in this case) are empirical constants.

c) The relation between K and τ_a is shown in Fig.8,which shows the relationship: $K = B(\tau_a)^n$ ...(3),where B and n are empirical material constants.

d) The incubation period for the occurrence of cyclic creep is observed when the mean stress is small.

Test results which belong to the second group are shown by triangular marks in Fig.2. The cyclic deformation curves are shown in Fig.7. Cyclic deformation does not appear when the stress is within the hatched area of Fig.2. The mathematical expression of the condition is $\frac{\tau_a}{\tau_w} + \frac{\tau_m}{\tau_{e.y.p}} < 1$..(4)
On the cross marks of Fig.2,hollow specimens which showed cyclic creep,started buckling after the repetitions of many cycles as shown by the abrupt change of curve in Fig.6.

Further investigation on the cyclic shear creep with more materials and for finding the effect of temperature, grain size and cyclic hardening properties is desirable.

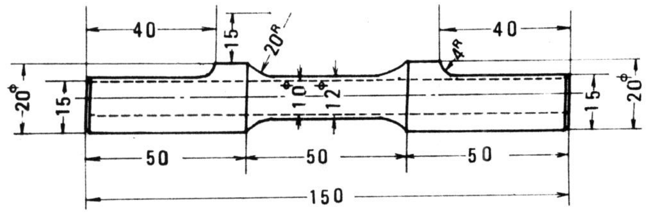

Fig.1 Fatigue Specimen

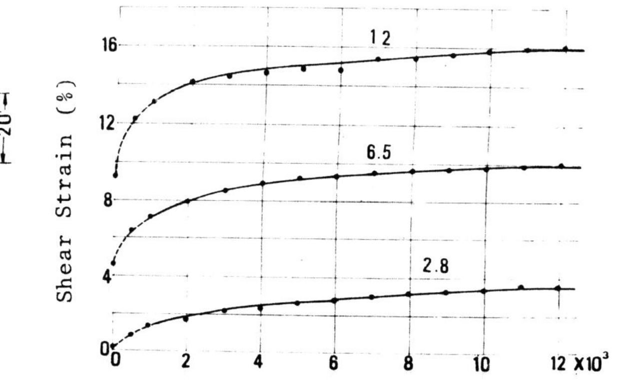

Fig.3 Cyclic Creep Curve (τ_a=11.9kg/mm^2)

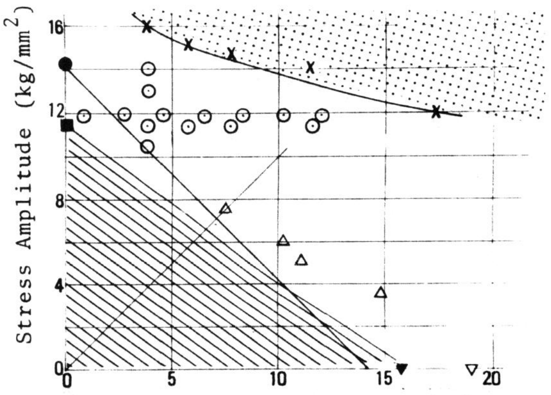

Fig.2 Experimental Condition and the Range of Cyclic Deformation

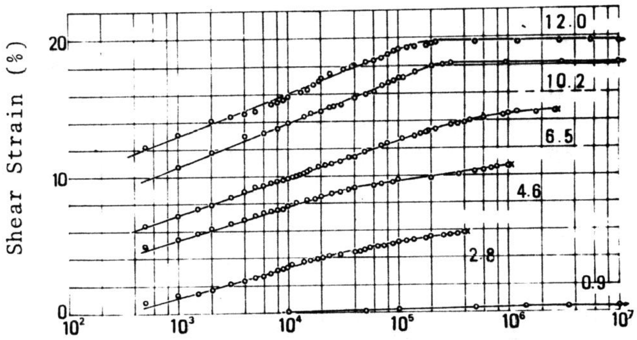

Fig.4 Cyclic Creep Curves (τ_a=11.9kg/mm^2)

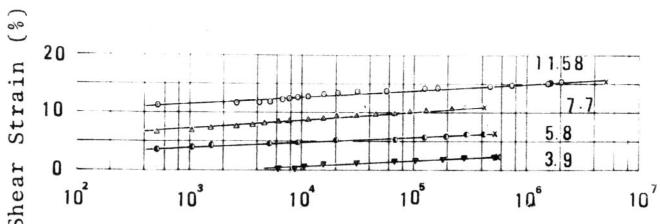

Fig.5 Cyclic Creep Curves (τ_a=11.4kg/mm^2)

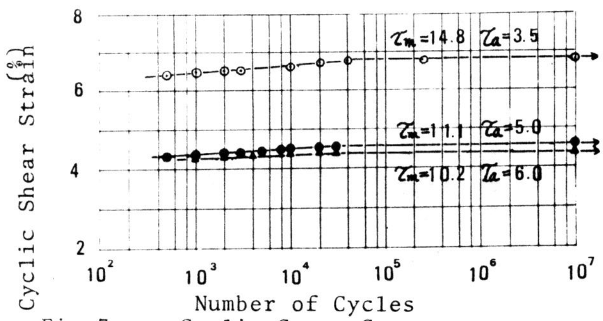

Fig.7 Cyclic Creep Curves

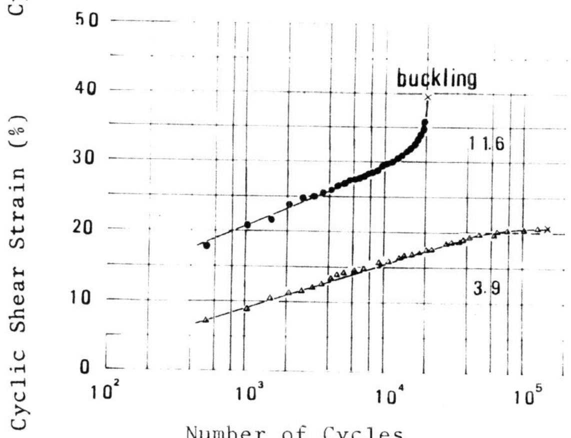

Fig.6 Cyclic Creep Curves (τ_a=14.8kg/mm^2)

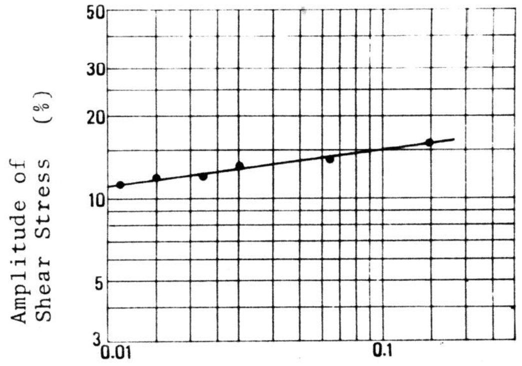

Fig.8 Constant K vs. Stress Amplitude