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LOW CYCLE FATIGUE BEHAVIOR OF LOW-YIELD POINT STEEL (LYPS) ENERGY DISSIPATION DEVICES

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1. INTRODUCTION

Low-yield point steel (LYPS), which has low yield strength (around 100Mpa) and large ductility, is suitable for energy dissipation device. Because energy dissipation device is repeatedly exposed to high cyclic plastic strain during earthquake, it is important to study the fatigue characteristics of LYPS However, experimental fatigue test data for very large strain range do not seem to exist.[1)]

The paper reports the results of a series of low cycle fatigue tests on LYPS devices using flexural yielding of steel bars. The experimental data were evaluated with existing fatigue models , which relate stress-strain quantities to the failure life. Energy-based fatigue model is proposed to relate various stress and strain quantities to the dissipated energy.

2. EXPERIMENTAL PROGRAM AND RESULTS

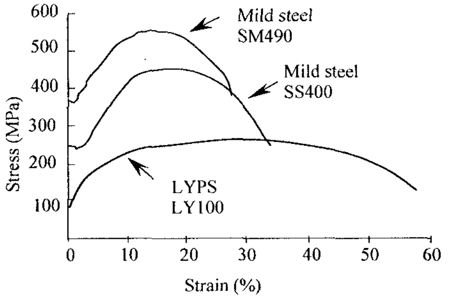

Fig. 1. Stress-strain relationship

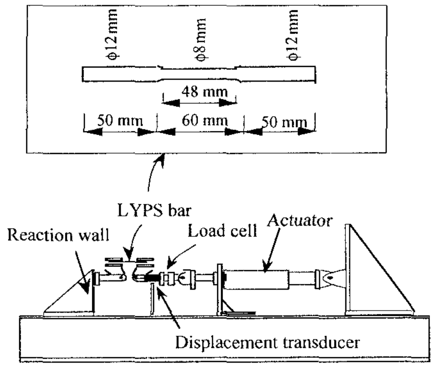

Fig. 2. Loading setup and specimen

1)Mechanical Properties of LYPS

LYPS used in this test, designated as LY100, has a nominal yield stress and maximum strength of 82.5 MPa and 258.5 MPa, respectively, and a nominal rupture strain of 57%. Fig. 1 illustrates stress-strain relationship of LY100, along with SS400 and SM490[1)].

2)Test Configuration

The specimen and loading setup are shown in Fig. 2. The experimental device was designed so that constant bending moment is induced over the central portion of the length of the specimen and plasticization occurs uniformly[2)]. Three test series including 22 specimens were carried out to investigate the low-cycle fatigue behavior at fixed displacement amplitude, path-dependency and mean strain effect.

3)Test Results

All the specimens failed by progressive degradation of strength as cracking continued to extend upon cycling. The results indicate that the displacement path order and mean strain have negligible effect on the number of cycles to failure[2)].

3. APPLICATION OF EXISTING FATIGUE-LIFE MODEL TO RESULTS

The fatigue life of a material subjected to a given strain range could be estimated by superposition of the elastic- and plastic-strain components, given by Coffin Manson relationship[3)] as:

$$\varepsilon_t = \frac{\sigma'_f}{E}(2N_f)^b + \varepsilon'_f(2N_f)^c, \quad (1)$$

where, ε_t: total strain amplitude, N_f: number of cycles. σ'_f: fatigue ductility coefficient, *E:* Young's modulus, *b*: fatigue strength exponent, ε'_f: fatigue ductility coefficient, *c*: fatigue ductility exponent. Regression of the low-cycle fatigue test results by the above equations yield the following equations, here strain is represented by the largest surface strain of the specimen:

$$\varepsilon_t = 0.000643(2N_f)^{-0.234} + 0.699(2N_f)^{-0.506}. \quad (2)$$

Comparison between this model and the experimental results is shown in Fig. 3. For the purpose of comparison, the fatigue-life curve for mild steel (BS4360/43A, yield stress 350 Mpa) bending dampers is also shown in Fig . 4. Although the sizes of the specimens are different[2)], it appears that at the same strain amplitude LYPS dampers can sustain more cycles than that of mild steel, especially at large strain range.

Keywords: low-yield point steel, low-cycle fatigue, energy dissipation device, fatigue-life model..
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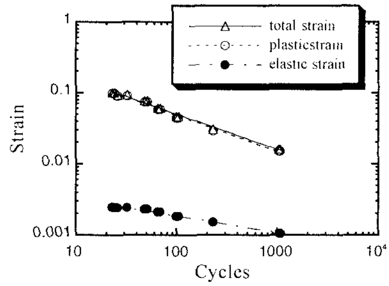

Fig.3 Regression of experiment data

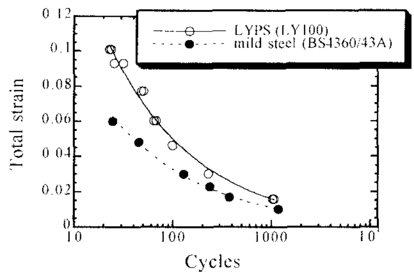

Fig. 4. Fatigue-life curve for LYPS (LY100) and mild steel (BS4360/43A)

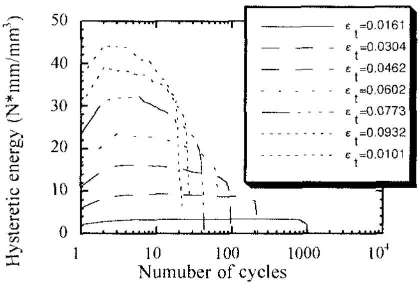

Fig. 5 Hysteretic energy-number of cycles relation

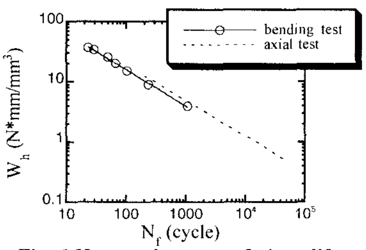

Fig. 6 Hysteretic energy-fatigue life

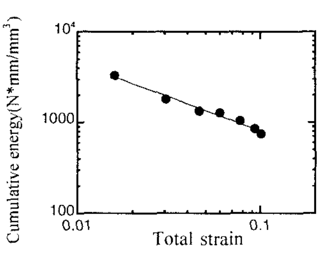

Fig. 7 Cumulative energy-total strain

4. ENERGY-BASED MODEL

The relationship between the hysteretic energy per cycle, and the number of cycles is shown in Fig. 5. This relationship is almost the same as the corresponding stress amplitude-number of cycles relationship[2]. The cyclic softening and hardening tendencies thus correspond to decreasing and increasing amounts of hysteretic energy, respectively. Fig. 6 shows the hysteretic energy W_h for one cycle at half-life to fatigue life, where the axial test[1] results are also shown. It is demonstrated that the bending test results at large strain can be the extension of the axial test and energy model is a reasonable index to represent the fatigue life in multiaxial stresses state. Regression of the data by a power function log-log coordinates yields the following equations:

Bending test: $W_h = 397.23(2N_f)^{-0.609}$. (3)

Axial test: $W_h = 427.79(2N_f)^{-0.590}$. (4)

For seismic application, the main concern is the cumulative hysteretic energy that a damper can dissipated within its fatigue life. The total energy dissipated until specimen failure $\sum W$ was calculated by numerical integrating of the area enclosed within the hysteretic loops for the entire test history. Here, the following form of energy-based fatigue model is proposed[2]:

$$\sum W = W_t(\varepsilon_t)^{\alpha}, \quad (5)$$

where, W_t, α are material constants. Regression of Equation(5) yields the following equation:

$$\sum W = 142.25\varepsilon_t^{-0.751}. \quad (6)$$

Fig. 7 shows the relationship between cumulative hysteretic energy and total strain amplitude. It is indicated that the total dissipated energy decreases with the increase of strain amplitude. The comprise strain amplitude of seismic dampers will have to be studied further.

4. CONCLUSION

The investigation presented in this paper provides useful information in view of very low-cycle fatigue behavior of LYPS. The behavior of the test specimens considered in this study conforms well to the commonly used strain-life models for low-cycle fatigue. The proposed energy-based fatigue model is shown to be applicable for multiaxial stress state and complicated strain history, which can be applied to design energy dissipation devices under various configurations.

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