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Low cycle fatigue property and fracture behavior of low yield point steels

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HIGHLIGHTS

- This paper reports an experimental investigation of all grades of low yield point steels that have currently been developed in China (LY100, LY160, and LY225).
- The low cycle fatigue properties and fracture behaviors were studied.
- The experimental details are presented and the results and discussion, including observations and fatigue life, cyclic hardening behavior, cyclic stress–strain responses are provided.
- Fatigue life prediction based on the Coffin-Manson relationship and Kuroda model was developed.

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ABSTRACT

For seismic control and isolation techniques, low yield point steels are among the most reliable and ideal energy-dissipating materials. Structures under earthquake conditions are usually subjected to cyclic loads with large strain amplitudes, where excellent low cycle fatigue and fracture performance under repeated loading is an essential requirement. In the study presented in this paper, comprehensive and systematic investigation was conducted on the low cycle fatigue properties and fracture behaviors of low yield point steels (LY100, LY160, and LY225). Axial steel coupons were tested under different constant strain amplitudes ranging from 0.5% to 6% with increments of 0.5%. Following introduction of the experimental details, observations and fatigue life are reported. Then, based on the experimental data, the cyclic hardening behavior and the cyclic stress-strain response are thoroughly analyzed. Finally, with the aim of predicting the low cycle fatigue life, the material parameters of the Coffin-Manson relationship and Kuroda model are determined and comparative analyses are performed. This paper may provide a valuable reference for engineering applications and further research into the low cycle fatigue performance of low yield point steels.

1. Introduction

Earthquake is an important consideration in civil engineering structural design. In traditional seismic design, to protect structures from the destructive forces of earthquakes, seismic resistance relies primarily on the strength and stiffness of structures, a dependence that is uneconomical and unreliable. Since the mid-1980 s, seismic controlled structures and techniques have been proposed and studied by many researchers [1]. Besides, considering that the motion of earthquakes is a multi-dimensional random vibration in nature, the seismic responses of structures can also be mitigated by seismic isolation techniques (such as assembling rubber bearings between the structure and its foundation) [2]. As an ideal material utilized for energy dissipation, low yield point steel has been developed and is widely used in the field of seismic control and isolation [3,4]. When subjected to moderate-to-major seismic conditions, to protect the main structure, energy-dissipating members are designed to undergo large plastic deformation within small number of cycles over repeated large strain amplitudes, which may eventually lead to low cycle fatigue of materials [5,6]. Excellent low cycle fatigue resistance and fracture performance of those members are the most important guarantee for the overall seismic performance of structures. Therefore, investigation of the low cycle fatigue properties and fracture behaviors of low yield point steels has significant scientific and practical

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Table 1
Mechanical properties and chemical compositions of materials.

Grade	Mechanical properties						Chemical composition (wt.%)						
	E/MPa	f_y /MPa	f_u/MPa	A/%	f_y/f_u	ε_u/%	C	Si	Mn	P	S	Ti	Al
LY100	199,000	128	252	47.3	0.51	27.02	≤0.005	≤0.04	≤0.08	≤0.012	≤0.006	0.02–0.05	0.015–0.045
LY160	194,000	186	294	44.5	0.63	24.16	≤0.008	≤0.06	0.08–0.3	≤0.012	≤0.006	0.02–0.05	0.015–0.045
LY225	202,500	191	295	44.0	0.65	23.32	0.02–0.08	≤0.10	0.3–0.8	≤0.012	≤0.006	0.03–0.08	0.015–0.045

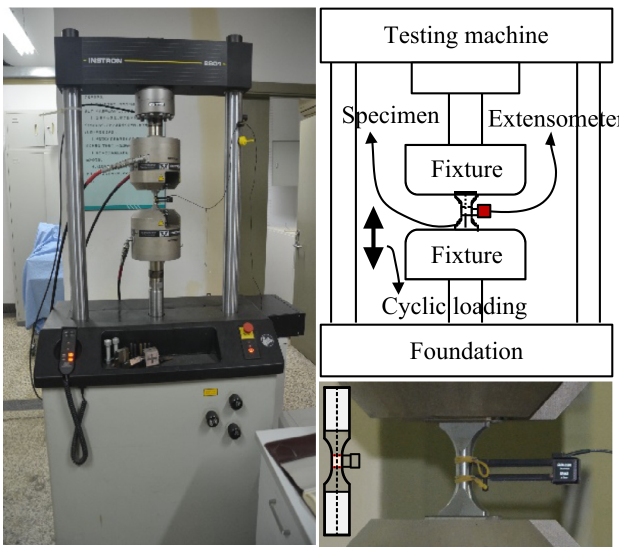

Fig. 1. Test setup.

values. Some researchers have conducted experimental investigations of the low cycle fatigue behaviors of low yield point steels and drew valuable conclusions [1,7,8]. However, because most of those studies have focused on a few specific grades of steel, limited information can be found for comprehensive and systematic research into the low cycle fatigue performance of low yield point steels, especially those fabricated in China.

This paper reports an experimental investigation of the low cycle fatigue properties and fracture behaviors of all grades of low yield point steel that have currently been developed in China (LY100, LY160, and LY225). The experimental details are presented and the results and discussion, including observations and fatigue life, cyclic hardening behavior, cyclic stress-strain responses, and fatigue life prediction are provided.

2. Experimental details

2.1. Materials

The materials considered in this study were the three low yield steels (LY100, LY160, and LY225) produced in China, with the mechanical properties and chemical compositions given in Table 1. The symbols $E, f_y, f_u, \varepsilon_u, A$ denote the elastic modulus, yield strength, ultimate strength, the strain corresponding to ultimate stress, and elongation, respectively. The chemical compositions of the materials were collected from mill certificates and the mechanical properties were determined based on the average values of the results from monotonic tensile tests. For a specific monotonic tensile stress-strain curve, the elastic modulus was taken as the slope of the curve ranging from 1/3 to 2/3 f_y. Obviously, as high performance steels that have been widely applied for seismic energy dissipation in building structures, these low yield point steels exhibited low yield strength, low yield ratio, large elongation, and good ductility.

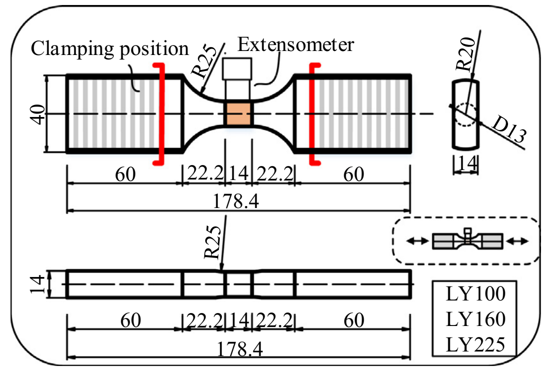

Fig. 2. Details of the specimens (mm).

2.2. Test setup and specimen details

The experiments were conducted using a universal fatigue machine INSTRON Model 8801, shown in Fig. 1. The allowed capacity of this machine was100 kN. Cylindrical steel coupons supplied in the form of plates (30 mm in thickness) along the rolling direction were adopted in the low cycle fatigue experiments. The coupons of the same grade of steel were fabricated from the same steel plate. The main reason for designing the coupons as cylinders rather than plates was to minimize the probability of undesired failure modes such as buckling of the specimen. The dimension and configuration details of the specimens are shown in Fig. 2. All the specimens were the same shape, 14 mm in thickness, 13 mm in diameter, and 14 mm in effective length section. In general, the geometry of the specimens could be interpreted as a combination of three segments: an effective length section, a transition section, and a clamping section. An electronic extensometer for measuring strain was utilized in the center of the effective length section. The gauge length of the extensometer was 12.5 mm and it provided a range of 40% in tension and 20% in compression. The applied load as well as the number of cycles to failure could be directly recorded by a computer connected to the loading and measurement system.

2.3. Loading protocol

The entire experimental processes of the fatigue tests were controlled by strain amplitude using an extensometer to measure the strain and guide the loading process. Fully reversed and push- pull cyclic loading with zero mean strain (i.e. the strain ratio $R = \varepsilon_{min}/\varepsilon_{max} = -1$) at a constant strain rate of 0.1% S^{-1} was adopted in the tests. A wide range of strain amplitudes (the absolute value of the maximum tensile or compressive strain) from 0.5% to 6.0% with the increments of 0.5% for each level were considered in the tests. For each coupon, the strain-controlled loading begun with a tensile excursion and continued until fracture.