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Tensile deformation behavior of high strength anti-seismic steel with multi-phase microstructure

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ABSTRACT

To investigate the tensile deformation behavior of high strength anti-seismic steel with multi-phase microstructure, tensile tests with strains of 0.05, 0.12 and 0.22 were performed at room temperature. Microstructure of tested steels was observed by means of optical microscopy (OM), transmission electron microscopy (TEM) and scanning electron microscopy (SEM). Tensile mechanical properties of tested steels were obtained, and the influence of bainite content on deformation behavior was also discussed. Meanwhile, the deformation mechanism of steel with three kinds of microstructures of bainite, pearlite and ferrite was analyzed. Results show that tested steel with high volume fraction of bainite exhibits a continuous deformation behavior, and this may be attributed to a higher bainite volume fraction and a lower mobile dislocation density. The morphology of microstructure will influence the mechanical properties of tested steels. An increasing content of bainite can improve the tensile strength, but reduce the plasticity and toughness of the tested steels. In the deformation process of 0.039Nb steel, the ferrite and bainite have priorities to deform, and the deformation exhibits co-deformation of all microstructures in the later stage of deformation. In the deformation process of 0.024Nb-0.032V steel, the ferrite and pearlite have priorities to deform, and the deformation exhibits co-deformation of all microstructures in the later stage of deformation.

1. Introduction

As one of the common and unpredictable natural disasters, many casualties and enormous property damages were caused by earthquake. Thus, more attentions on anti-seismic property have been paid to building structures[1]. Anti-seismic steel, which plays a vital role in reinforced concrete structures, has been widely used in the construction industry. Steels undergo extremely great alternating loads and can be destroyed easily when the earthquake happens. The failure models of steels during strong earthquakes are often high strain low cycle fatigue and strain aging brittleness. Sheng and Gong[2] verified that low cycle fatigue was the failure model of concrete building structural steels under earthquake loads by investigating the seismic ruin of Tangshan happened in 1976 in China. The anti-seismic property of steel is directly related to the safety of people's life and property in the earthquake area. Therefore, it is very necessary to develop new types of anti-seismic steels and improve the anti-seismic property of these types of steels. The main anti-seismic properties of steel consist of a high ratio of tensile strength versus yield strength, a uniform yield strength, a long uniform deformation period after yielding, and an optimum combination of strength and plasticity. Besides, strain aging sensibility and welding property are suggested to determine the anti-seismic properties of steel[3]. In addition, according to the Chinese national standard GB 1499.2—2007, the anti-seismic property of 500 MPa grade steel must also meet the following requirements: (1) the ratio of measured tensile strength versus measured yield strength of steel is no less than 1.25; (2) the ratio of measured yield strength versus the eigenvalues of yield strength stipulated by the national standard of steel is less than 1.30; (3) the elongation of steel at maximum force is no less than 9.0%.

To achieve the goal of improving the anti-seismic property of steel, ideal microstructure combination is needed. Nowadays, the combination of micro-al-

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loying technology with controlled rolling and controlled cooling method to obtain multi-phase microstructure has been mainly adopted to improve the anti-seismic property of steels. The presence of bainite in the microstructure via the addition of Nb element can achieve optimum anti-seismic property when compared with traditional anti-seismic steel with microstructure of ferrite and pearlite. By means of Nb, V or Nb-V micro-alloying method with controlled rolling and controlled cooling technology in plain-carbon-based steel, the microstructure combination of steel with ferrite, pearlite and a small amount of bainite exhibits excellent anti-seismic property. Based on amounts of studies, it was found that different Nb contents[4], different microstructure combination and microstructure content[5-7], the morphology[8] and distribution of microstructure[5-7,9] would influence the deformation behavior of steels. Garcia-Mateo and Caballero[8] analyzed the deformation mechanism of ultra-high-strength bainitic steel and pointed out that the excellent combination of yield strength and ultimate tensile strength was related to the existence of fine bainitic plates and retained austenite. Choi et al.[10] considered that the bainite formation and the balance of all phases obviously influenced tensile deformation behavior of Fe-1.0Mn-0.09C steel with multi-phase microstructure. Furthermore, more attentions have been paid to the study of the deformation behavior of steel with multi-phase microstructure in recent years. Although there are amounts of studies on relationship between microstructure and deformation behavior of dual-phase steel, relevant reports on triple phase steel during tensile deformation process are lacked.

According to the previous studies on anti-seismic properties of 500 MPa grade steel, it was found that steel with microstructure of ferrite, pearlite and bainite exhibited excellent anti-seismic property. However, the deformation behavior on such kind of steel was rarely reported. Therefore, the present study aimed to investigate the deformation behavior and mechanism on steel with three kinds of microstructures of bainite, pearlite and ferrite. Besides, the effect of volume fraction of bainite on deformation behavior was also discussed.

2. Experimental Procedure

The experimental materials used in this study were two kinds of low-carbon Nb microalloyed hot-rolled steels produced by a steel company in China, and both of their diameters were 25 mm. The chemical compositions of the tested steels are illustrated in Table 1.

The steel billets were uniformly heated in the heating furnace at the temperature of 1150－1180 ℃ for 30 min. Meanwhile, the controlled rolling and controlled cooling technology was executed during manufacture processing of the steel billets. Tensile tests were performed in air at room temperature, using a universal testing machine at a constant strain rate of 10^{-3} s^{-1}. According to the Chinese national standard GB/T228—2002, the tensile specimens had gauge dimensions of 8 mm (diameter) and 40 mm (length).

Table 1

Chemical compositions of the tested steels (wt. %)

Steel	C	Si	Mn	S	P	Ni	Cr	Cu	V	Nb
0.039Nb	0.22	0.53	1.43	0.022	0.030	0.019	0.021	0.080	0.004	0.039
0.024Nb-0.032V	0.24	0.50	1.48	0.024	0.027	0.030	0.084	0.090	0.032	0.024

Specimens for scanning electron microscopy (SEM) and transmission electron microscopy (TEM) observation were transversely sectioned in the deformed area of specimens, and the surface for observation was perpendicular to the rolling direction. The specimens for SEM observation were mechanically polished and then etched in 4 vol. % nital. The substructures of ferrite and the morphology of pearlite were observed by TEM. The corrosion solution composed of 6 vol. % perchloric acid and 94 vol. % glacial acetic acid for TEM specimen preparation was used.

Two groups of specimens were subjected to total tensile strains of 0.05, 0.12 and 0.22 respectively. The quantitative analysis results for volume fraction of different microstructures of steels were measured precisely by means of metallographic analysis software Image Tool V3.0. Vickers micro-hardness measurements were conducted on transverse plane using micro-hardness tester.

3. Results and Analysis

3.1. Original optical microstructure

Fig. 1 shows the original optical microstructures of the tested steels, and these two kinds of steels are composed of ferrite, pearlite and bainite. The microstructures of 0.039Nb steel are composed of a large volume fraction of bainite, ferrite and a small volume fraction of pearlite, while the microstructures of 0.024Nb-0.032V steel are composed of a large volume fraction of pearlite, ferrite and a small volume fraction of bainite. From Fig. 1(a), it can be found that the ferrite is highly irregular in shape, and a large amount of quasi-polygonal ferrite and a small amount of acicular ferrite can be observed, while