JOURNAL OF IRON AND STEEL RESEARCH, INTERNATIONAL. 2015, 22(4):337-343

Microstructure and Mechanical Properties of Precipitation Strengthened Fire Resistant Steel Containing High Nb and Low Mo

Zheng-yan ZHANG[1,2], Qi-long YONG[1], Xin-jun SUN[1], Zhao-dong LI[1], Jun-yu KANG[1], Guo-dong WANG[2]

(1. Department of Structural Steels, Central Iron and Steel Research Institute, Beijing 100081, China; 2. State Key Laboratory of Rolling and Automation, Northeastern University, Shenyang 110004, Liaoning, China)

Abstract: Through the thermo-mechanical control process (TMCP), a high Nb low Mo fire resistant steel with the yield strength (YS) of 521 MPa at room temperature (RT) and 360 MPa at elevated temperature (ET) of 600 ℃ was developed based on MX (M=Nb, V, Mo; X=C,N) precipitation strengthening. A series of tensile and constant load tests were conducted to study the mechanical properties at ET. The dynamic continuous cooling transformation (CCT) as well as precipitation behavior of microalloy carbonitride was investigated by means of thermal simulator and electron microscopy approaches. Results showed that the failure temperature of tested steel was determined as 653 ℃, and the granular bainite was obtained when the cooling rate was higher than 10 ℃/s. In the rolled state, a certain amount of M/A islands was observed. During heating from RT to ET, M/A islands disappeared, and cementites and high dense compound precipitates (Nb,Mo,V)C with size of less than 10 nm precipitated in ferrite at ET (600 ℃), which resulted in precipitation strengthening at ET.

Key words: fire resistant steel; elevated temperature property; microalloying; granular bainite; precipitation strengthening

Fire resistant steel was firstly investigated and developed by French researchers in the early 1970s[1,2], and researchers in Australia and Japan conducted further studies in the 1990s[3,4]. The sudden collapse of the World Trade Center towers during the terrorist attacks events in September 11, 2001 aroused people's consciousness of using fire resistant steel in the building construction[1,5]. Since then, fire resistant steel attracted more and more attentions from worldwide researchers. Recently, with the development of the high-rise buildings and the increase of the attention of the sense of fire resistant ability, the conventional steels for construction buildings have been replaced progressively by the fire resistant steels which not only have the same level of strength as the conventional counterpart, but also can provide a certain ability of fire resistance, that is, the yield strength at 600 ℃ should be no less than 2/3 of that at room temperature (RT)[6]. Generally, conventional fire resistant steel contains about 0.5% Mo and a little Nb[7], and its elevated temperature (ET) strength is increased by means of solid solution strengthening and Mo-containing precipitation strengthening[5,7]. However, the use of Mo rises the cost of fire resistant steel, so researchers employed Nb, V, etc. elements to partially replace Mo in fire resistant steel. Recently, Walp[8] and Bimal[9] developed low Mo (about 0.3 mass%) and even ultralow Mo (0.05 mass%) fire resistant steels via adding Nb and V. However, those fire resistant steels not only contain some other expensive elements such as Ni (about 0.1 mass%) but also have a lower strength level equated to Q345. Wan et al.[10] also studied the replacement of Mo in fire resistant steel via adding microalloying element Nb, and the main composition of this fire resistant steel is 0.1 mass% C-0.3 mass% Mo-0.03 mass% (Nb+V+Ti). Pan's work[11] focused on the role of V in fire resistant

Foundation Item: Item Sponsored by National Basic Research Program of China (2010CB630805)
Biography: Zheng-yan ZHANG, Doctor Candidate; **E-mail**: zzy040123@126.com; **Received Date**: May 19, 2014
Corresponding Author: Qi-long YONG, Doctor, Professor; **E-mail**: yongql@126.com

steel containing 0.06 mass% C and 0.3 mass% Mo. However, as Nb and V play an important role in fire resistant steel due to precipitation strengthening, precipitation behavior and characteristic of Nb or V microalloy carbonitrides from rolling state to the state at ET (600 ℃) were not fully investigated, neither was the microstructure evolution.

Compared with the conventional fire resistant steels, the new type of fire resistant steels reported in the present study possesses a new chemical composition namely via the design of ultralow carbon and the addition of high Nb (≤0.1%) low Mo (≤0.2%). The microstructure of tested steel comprises granular bainite and polygonal ferrite after thermomechanical control process (TMCP). Microalloying elements Nb, Mo, V, etc. which may form carbonitrides play a significant role in compensating the loss of the strength at ET. In addition, microstructure evolution as well as the precipitate behavior of microalloy carbonitrides including the distribution, size and composition was investigated both at RT and ET (600 ℃) in this paper.

1 Experimental Materials and Procedures

The tested steel was vacuum melted and cast into 25 kg ingot, which contains C 0.048, Si 0.17, Mn 0.80, Cr 0.50, P 0.0047, Al 0.05, Ni 0.01, Cu 0.02, Mo 0.19, Nb+Ti+V≤0.20, B 0.0002 and N about 0.003 (mass%), where C content is very low not only to make sure that Nb can dissolve, but also to ensure a good weldability. Ti and N form TiN which can prevent the initial austenite grain growth during soaking. Moderate addition of Mn and B can improve hardenability. The size of the forged ingot is 120 mm in length, 110 mm in width and 60 mm in thickness. Fig. 1 shows the schematic illustration of rolling process. After 1 h soaking, the tested steel was rolled in recrystallization region and non-recrystallization region. The start rolling temperature (SRT) and finishing rolling start temperature (FRST) are 1100 ℃ and 950 ℃ respectively. The finish rolling temperature (FST) is 880 ℃, followed by laminar cooling (the cooling rate ≥15 ℃/s) and the final cooling temperature (FCT) is about 400 ℃.

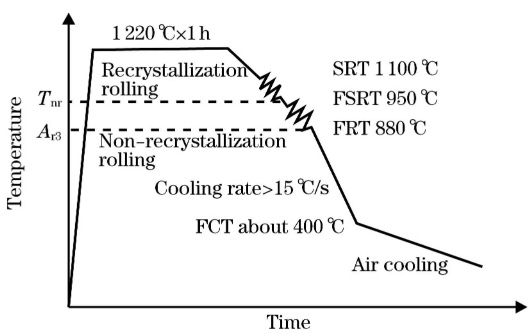

Fig. 1 Diagrammatic sketch of rolling process

The dynamic continuous cooling transformation (CCT) diagram was measured on a Gleeble-3800 thermal simulator, as shown in Fig. 2. The soaking temperature of 1220 ℃ for 3 min, the cooling rate of 1−80 ℃/s, the deformation temperature of 880 ℃, the strain of 40% and the strain rate of 5 s^{-1} were adopted. The transformation temperatures were obtained via dilatometric curves. Meanwhile, the optical microscope (OM) and Vickers hardness (49 N load) were employed to draw the dynamic CCT curves. Dogbone-shaped tensile specimens were machined with a gauge length of 40 mm and a diameter of 8 mm. The tensile tests (along transverse direction) both at RT and ET (300−650 ℃) were conducted according to the Chinese standards GB/T228—2002 and GB/T4338—2006, respectively. And the result of the tensile tests at each temperature is the average values of two measurements. As a simple and effective method, constant load test which is an essentially accelerated non-isothermal creep test was also widely employed to evaluate the ET property of fire resistant steel[5,12]. In present study, the constant load test was performed on a Gleeble-3800 thermal simulator using a specimen with a diameter of 10 mm and a length of 110 mm. During the process, 280 MPa stress (55% yield strength at RT) was loaded, then the specimen was heated from RT to 800 ℃ at the heating rate of 28 ℃/min. The failure temperature was obtained by analyzing the strain *vs*. temperature curve[5].

The microstructure evolution from RT to ET (600 ℃) was examined via S-4300 cold-field emission scanning electron microscope (SEM) and Tecnai F20 transmission electron microscope (TEM). The specimens taken from both rolled specimens and

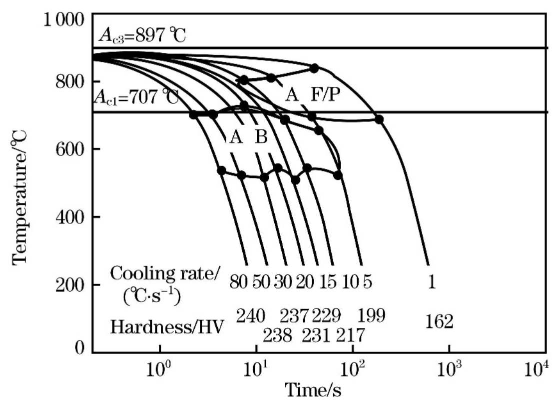

Fig. 2 Dynamic CCT diagram