Materials Science & Engineering A 657 (2016) 82–85

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Short communication

Rolling contact fatigue of bainitic rail steels: The significance of microstructure

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ARTICLE INFO

Article history:
Received 5 November 2015
Received in revised form
16 January 2016
Accepted 19 January 2016
Available online 21 January 2016

Keywords:
Bainite
Microstructure
Rolling contact fatigue
Railway
Retained austenite

ABSTRACT

We elucidate the effect of microstructure on the rolling contact fatigue (RCF) performance of bainitic rail steel via microstructural characterization and simulated field tests. The RCF performance of bainitic rail steel is enhanced through microstructural design and the thin film-like retained austenite plays a significant role on RCF crack propagation.

1. Introduction

Recently, the rail transportation has rapidly developed. The speed and axle load of railway vehicles are becoming faster and heavier, which leads to more and more severe rolling contact fatigue (RCF) damage between wheel and rail [1,2]. The RCF damage (e.g., head checking and spalling, etc. [3]) is currently one of the largest risk factor affecting safety and maintainability of track. Therefore, the rail industry is exploring new materials and processes for rail production in order to improve the RCF properties of rail, improve the safety, and reduce the maintain cost of track. Until recently, the majority of rail steels were characterized by pearlite (alternate lamellae of ferrite and cementite) microstructure [1,2]. The performance of pearlitic rail steels can be improved by reducing the interlamellar spacing between the cementite [4]. However, high carbon content is added to produce fine interlamellar spacing, which is detrimental to weldability. Bainitic steels have lower carbon content and higher toughness than pearlitic steels, and so are promising candidates for next generation of rail steels [5–10]. More recently, the laboratory tests showed that the RCF properties of bainitic rail steel were superior to the pearlitic rail steel [1,11]. The bainitic rail steels have a complex microstructure depending on the alloying and heat treatments, e.g., the granular bainite (bainitic ferrite plus martensite/austenite islands), upper bainite (bainitic ferrite lath plus interlath cementite or retained austenite) and lower bainite (acicular bainitic ferrite plus cementite) [12–14]. It is reported that the microstructure affects the RCF properties of bainitic steels [15].

In the present study, the bainitic rail steels were subjected to different heat treatments to obtain different bainitic microstructures and their effect on the RCF performance was studied. The bainitic rail was operated on a heavy haul railway (upline). To the best of our understanding, the effect of microstructure on the RCF properties of bainitic rail steel has not been studied via simulated field tests.

2. Experimental

The chemical composition of bainitic rail steel was 0.22C–2.0Mn– 1.0Si– 0.8Cr– 0.8(Mo+Ni) (wt%). The carbon content of the steel is significantly less than pearlitic steel (generally, 0.7–0.9 wt%). The bainitic steel was melted, forged, and hot rolled to rail at a steel mill. After heat treatment, two bainitic rail steels with different microstructures (abbreviated B380 and B340 samples, respectively) were operated on a heavy haul railway (upline). The samples used for microstructural observation and mechanical properties tests were cut from the rail head. Microstructure was characterized using a scanning electron microscope (ZEISS EVO18, 20 kV) after mechanical polishing and etching in a 2% nital

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http://dx.doi.org/10.1016/j.msea.2016.01.052
0921-5093/

solution. A transmission electron microscope (JEOL 2010, 200 kV) was used to observe the morphology of retained austenite, specifically the nanometer-sized film-like morphology. The volume fraction of retained austenite (*RA* vol%) was measured by X-ray diffractometer (Rigaku Smartlab, Cu Kα radiation) at a step of 0.01° and a counting time of 2 s/step [16]. Standard tensile samples with a gage diameter of 5 mm and a gage length of 25 mm were used for tensile tests on a SUNS 5305 tensile machine (MTS Systems, P. R. China). Impact tests were performed with standard Charpy V-notch specimens ($10 \times 10 \times 55$ mm^3, standard EN 10,045) using a JB-30A impact test device at 20 °C. In order to clarify the relationship between the microstructure and RCF damage, the damaged rail taken from field was analyzed for RCF crack propagation, microstructural evolution and RA amount on the subsurface.

3. Results and discussion

Fig. 1 shows the microstructures of B380 and B340 bainitic rail samples. In the B380 sample, the microstructure consists of not only bainite ferrite and RA but also coarse blocky martensite-austenite (M/A) islands nearby the prior austenite grain boundary (Fig. 1a) [17,18]. The coarse M/A islands were observed by TEM and its size was about 0.2–1.0 μm (Fig. 1c). However, the coarse M/A islands were not observed in B340 sample. The microstructure of B340 sample consisted of bainite ferrite plates and interlath film-like RA (Fig. 1b and d). The film-like RA in B340 sample was further characterized in detail by TEM and its thickness was in the nanometer scale range (Fig. 1e and f). The volume fractions of RA in B380 and B340 bainitic rail samples were similar (8.4% and 8.7%, respectively).

Table 1 shows the mechanical properties of B380 and B340 bainitic rail sample. The tensile strength of both the samples was similar (greater than 1400 MPa), which is higher than of the conventional pearlitic rail steel [1,2]. However, the B340 sample had superior ductility and toughness than B380 sample.

After field test, the two rail steel samples exhibited different service performance: severe head checks and spalls (RCF induced defects) [19,20] were observed on B380 sample after 4.5 months of service (after about 150 million gross tons), whereas only small

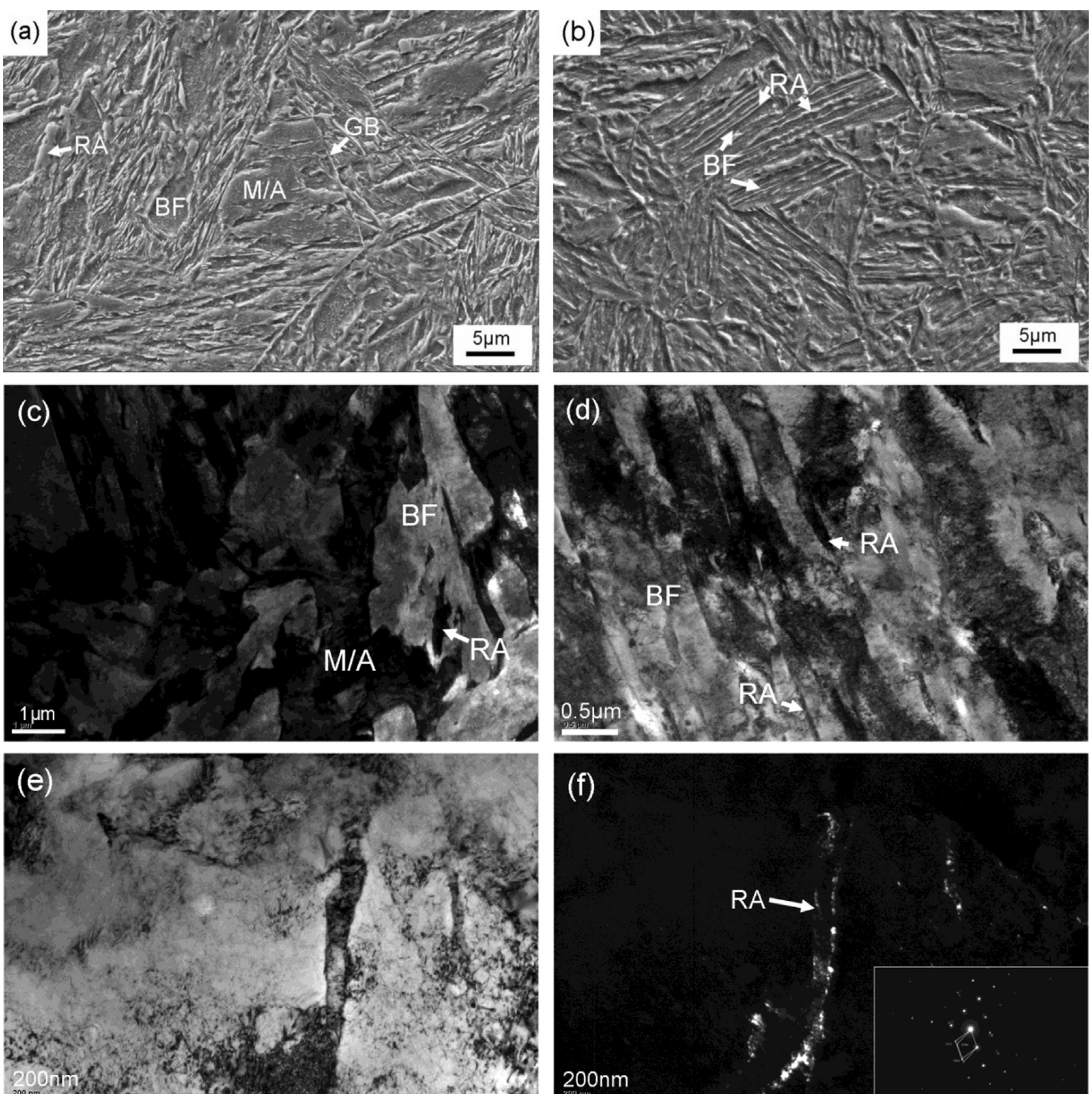

Fig. 1. (a, c) SEM and TEM micrographs of B380 and (b, d, e, f) B340bainitic rail samples, BF: bainite ferrite, (e) and (f) are the bright and dark field images of RA, respectively, RA: retained austenite, M/A: martensite/austenite island, GB: prior austenite grain boundary.