Investigation of the Effect of Heat Treatment on the Microstructure, Hardness and Wear Behavior of Pearlitic Rail Steel

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The aim of this work is to study the relationship between the microstructure, hardness and wear behavior of R260 pearlitic rail steel obtained via different heat treatment conditions. The as-received samples were reheated to austenite temperature in the range of 800-1000ºC for 1 hour and then subjected to isothermal treatment in a salt bath at temperatures of 400-600ºC for 5 minutes, and then water quenched to room temperature. The microstructure was examined using optical microscopy and scanning electron microscopy. Vickers microhardness and a pin-on-disc tribometer were tested. The results showed that the microstructures after isothermal heat treatment consisted of proeutectoid ferrite, pearlite grain, and some bainite ferrite plates. Increasing the austenitization temperature from 800 to 1000ºC increased the austenite grain size. The pearlite colony size and the pearlite interlamellar spacing increased with increasing isothermal temperatures. The hardness decreased with increasing austenitization and isothermal temperatures. In the wear tracks of rail samples, fatigue cracks, adhesives and delamination were observed. The present investigation showed that austenitization at 900°C, followed by an isothermal at 500°C, achieved the lowest wear rate.

Keywords: *Pearlitic rail steel, Isothermal heat treatment, Microstructure, Hardness, Wear*

1. Introduction

Pearlitic steel still shows its importance for railroad tracks due to its excellent mechanical properties and wear resistance. The strength and wear resistance of pearlitic steel depend on the proeutectoid ferrite content, prior austenite grain size, pearlite colony size, cementite morphology and pearlite interlamellar spacing[1,2)]. The reduction of pearlite interlamellar spacing in steels could also increase resistance to sliding wear[3)]. To get finer interlamellar spacing in pearlite, refinement by using proper heat treatment is a common practice. The objective, therefore, of the present work is to study the influence of isothermal treatments on the microstructures, hardness and sliding wear resistance of R260 pearlitic rail steel.

2. Experiment

2.1 Materials and heat treatments

The nominal compositions of the R260 rail steel were 0.73wt.%C, 0.35wt.%Si, 1.05wt.%Mn, and Fe. As-received samples were austenitized at temperatures of 800, 900 and 1000ºC for 1 hour, followed by isothermal treatments at 500ºC in a salt bath for 5 minutes, followed by water quenching, to study the effects of austenite temperature on the austenite grain size. While samples were austenitized at 900°C and subjected to isothermal treatments at 400, 500 and 600°C to determine the influence of isothermal temperatures on the pearlite colony and interlamellar spacing.

2.2 Microstructural examination

The microstructural observation was investigated using optical microscopy (OM) and field scanning electron microscopy (FE-SEM). Specimens for OM and FE-SEM were prepared according to a metallography standard procedure. The size of the pearlite colony and austenite grain were measured using the linear intercept method. The grain size of austenite was determined using ten optical micrographs. A pearlite colony was characterized by area, in which the pearlite lamellae had the same orientation. The pearlite interlamellar spacing was measured by drawing a straight line normal to the direction of the pearlite lamellae under x10000 magnification.

2.3 Hardness and wear testing

Vickers microhardness testing was performed on the polished specimens using a 50 gf load (HV0.5). The average value was based on ten different areas. Wear tests were carried out under dry conditions using a pin-on-disc tribometer according to ASTM G-99. The rail discs were tested against WC-Co pins with a radius of 6 mm. The wear track width measurement was observed using SEM and an equation specified in ASTM G-99 was used to calculate the wear volume loss of the disc. After pin-on-disc tests, the worn surface was characterized by SEM.

3. Results and Discussion

3.1 Microstructure

Figure 1 shows the microstructures of rail samples after isothermal heat treatment, including proeutectoid ferrite (PF), pearlite grains, and some bainitic ferrite (BF) plates, which occur on prior austenite grain boundaries. BF plates could be observed clearly next to some PAGBs, as illustrated in Figure 2. The prior austenite grain size at room temperature could be determined due to the presence of PF networks. It was found that the average austenite grain size of the samples at the austenitized temperatures at 800, 900 and 1000°C under the same isothermal temperature of 500°C, were 30, 46, and 58 µm, respectively. It can be seen that the austenite grain size increased with increasing austenite temperature. Furthermore, the austenitization temperature also has an influence on bainitic ferrite transformation.

It was found that the pearlite colony sizes of the samples at the same austenitized temperature of 900°C under the isothermal temperatures of 400, 500 and 600°C were 3.7, 3.9 and 4.3 µm, respectively. The size of the pearlite colony increased as the isothermal temperature increased. This is due to the increase of driving force caused by the increase in undercooling. Larger undercooling accelerates the nucleation rate but leads to the growth restriction effect[1]. The pearlite interlamellar spacing tended to increase with increasing the isothermal temperature (Figure 3).

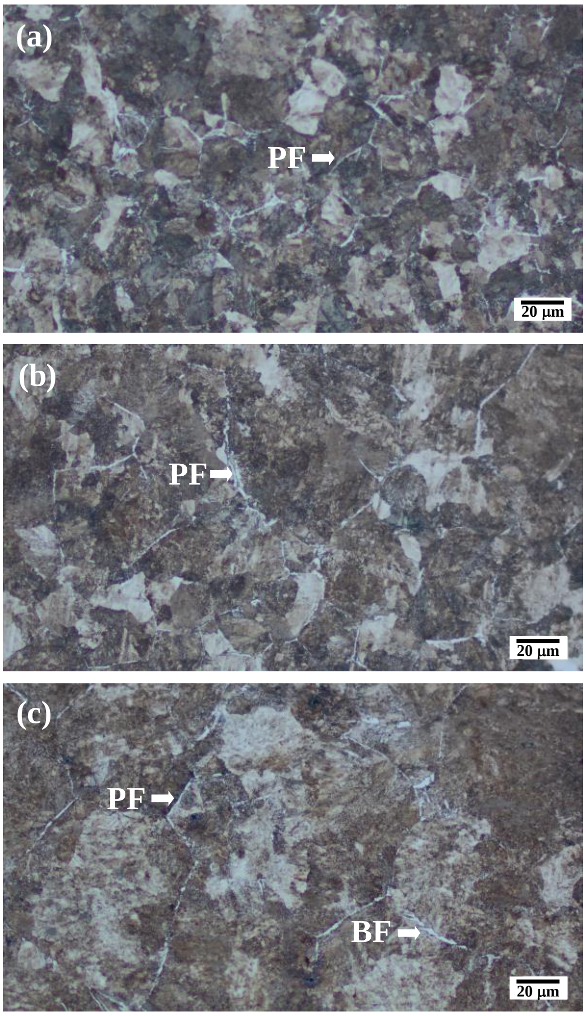

Figure 1 OM micrographs show the microstructure of the samples obtained at isothermal temperature of 500ºC and austenitization at different temperatures (a) 800ºC, (b) 900ºC, and (c) 1000ºC.

3.2 Hardness and wear properties

It was found that the hardness of the samples at the austenitized temperatures at 800, 900 and 1000°C under the same isothermal temperature of 500°C, were 393, 398 and 318 HV0.5, respectively. The hardness decreased with increasing austenitization temperatures. This may be due to the increase in austenite grain size and the presence of bainitic ferrite plates. Furthermore, the hardness values of samples also decreased from 418 HV0.5 to about 374 HV0.5 with the increase in the isothermal temperature from 400°C to 600°C.

At the same isothermal temperature of 500°C, the wear rate of the sample austenitized at 900°C showed the lowest value, followed by the samples austenitized at 800°C and 1000°C, respectively. This is due to the narrowest interlamellar spacing. Regarding the effect of different isothermal temperatures (austenitization temperature of 900°C), the wear rate of the sample isothermally treated at 500°C showed the lowest value, followed by 400°C and 600°C, respectively. This result shows that PF films and BF plates result in greater material losses due to dry sliding[4,5].

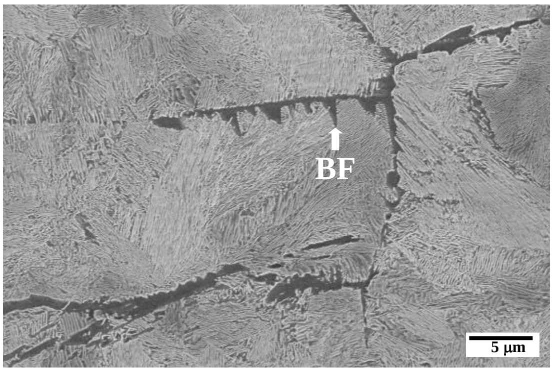

Figure 2 SEM image shows the needle-like BF formed at the prior austenite grain boundaries (austenitization temperature 900°C, isothermally temperature 400°C)

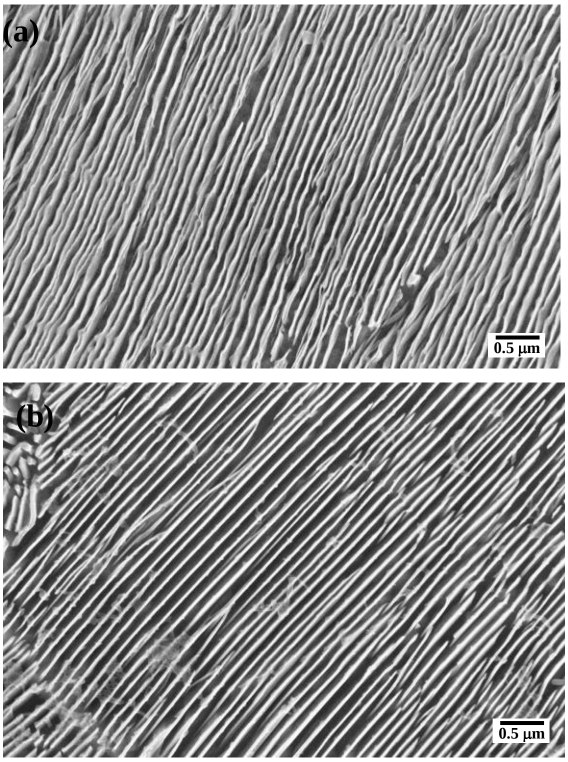

Figure 3 SEM images show the pearlite interlamellar spacing of sample obtained at austenitization temperature of 900ºC and different isothermal temperatures (a) 500ºC, and (b) 600ºC.

4. Conclusions

The present work found that the increase in austenitization temperature increased the austenite grain size. Pearlite colony size and interlamellar spacing increased with increasing isothermal temperatures. The hardness could be improved by decreasing austenite grain size, pearlite colony size and pearlite interlamellar spacing. After austenitization at 900°C, followed by an isothermal at 500°C, a minimum wear rate could be achieved. In addition to the pearlite's microstructural scales, proeutectoid ferrite, and bainitic ferrite also had an effect on the wear resistance.

Acknowledgments

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References

1) X.C. Li, H.H. Ding, W.J. Wang, J. Guo, Q.Y. Liu and Z.R. Zhou: Tribol. Int. **163** (2021) 107152.
2) X. Shi, X. Zhang, G. Diao, Z. Wen, X.S. Jin and Q. Yan: J. Mater. Eng. Perform. **31** (2022) 341-352.
3) A.P.G. Chaves, D.M.A. Centeno, M. Masoumi and H. Goldenstein: Mat. Res. **23** (2020) 1-8.
4) A.K. Jha, B.K. Prasad, O.P. Modi, S. Das and A.H. Yegneswaranm: Wear **254** (2003) 120-128.
5) Y. Wang, T. Lei and J. Liu: Wear **231** (1999) 1-11.