Study on service performance of 880 MPa-grade and 980 MPa-grade rail steels

Zhu M1,2, Xu G1,*, Zhou J H2, Wang R M2 and Gan X L1
1 School of Materials and Metallurgy, Wuhan University of Science and Technology, Wuhan, 430081, China;
2 Research and Development Center, WISCO, Wuhan 430080, China

Abstract: With the rapid development of economy in China, the requirement for railway passenger and cargo transportation becomes higher and higher. Increasing speed and developing heavy-haul transportation can effectively improve the transportation capacity of railway. The requirement for rail steels with higher ability of abrasion resistance becomes urgent. Two kinds of rails, i.e., 880 MPa-grade and 980 MPa-grade rail steels, were laid on cargo line with 500 m short radius curve. The service performances of the tested steels were continuously tracked and analyzed during operation of total 22.5 million tons loads. Macro morphology, light band width, surface hardness and profile of rails were investigated. The results show that the performance of 980 MPa-grade rail steel is superior to that of 880 MPa-grade rail steel at same circumstance. Therefore, 980 MPa-grade rail should be selected in the cargo line with small radius curve.

1. Introduction
With the continuous and rapid development of China's economy, the demand for passenger and cargo flow is increasing, and the demand for railway transportation is becoming higher and higher [1-2]. At the end of 2016, China's railway mileage has reached 124,000 kilometers. Railway transportation plays an important role in China's passenger and freight transportation, which directly relates to the development of the national economy.

China's passenger and freight transportation speed up in large areas, and high-speed heavy haul railway develops rapidly, which makes rail service life seriously reduce [3-4]. At the same time, the difficulty of maintenance of rail damage due to the increased traffic density is constantly increasing, resulting in more potential traffic safety hazards [5]. The situation of rail damage is increasingly grim [6]. Rail is an important part of the orbital structure in railway transportation, which supports and guides the train [7]. Rail abrasion [8-9] is the main type of damage in the curve section of railway, and rail abrasion has become the main factor in the damage of curve rail. In the process of using rails, the earliest defects occur in curved segments [10], especially in the small curve radius rail line (r≤800 m). The wheel and rail angle contact and the rail force is complex. Under the wheel-rail alternating stress cycle, the rail is prone to fish scale injury, severe abrasion, and so on [11]. In order to improve the service life of rail and reduce the safety hazard, some investigations have been conducted on rail wear.

Sato Yoshihiko [12] studied the service situation of the rails and proposed the method of service life extension of the rail. Krylov [13] introduced the maintenance operation of sinkansen in Japan structure. Bo [14] claimed that the main factors that produce curved rail side grinding are the wheel's impact angle on rails and the two-point contact of the wheels. Wang et al. [15] carried out a long-term investigation and analyzed the differences between the high speed and heavy-haul railway damage. So...
far, the wear situation of 880 MPa-grade and 980 MPa-grade on the rail line of small curve radius \((r \leq 800 \text{ m})\) is rarely reported. At present, the 880 MPa-grade and 980 MPa-grade rails are mostly used in China, which accounts for 90% of the annual total amount of rail. In order to study the performance of rail service of different strength levels, especially in small curve radius rail line, prolong the service life of rails and promote the rational use of rails, improve the comprehensive use efficiency, 880 MPa-grade and 980 MPa-grade rails are selected in the present study to lay on the small curve radius railway respectively. The service performance of two different rails were observed and analyzed during transportation of total 22.5 million tons of loads. The abrasions of rails in small curve radius railway were investigated.

2. Experimental methods

On a railroad line in Wuhan, China, three rails of 60 kg/m with a length of 12.5 meters and different strength of 880 MPa (U71Mn) and 980 MPa (U75V, U68CuCr) rails were continuously inserted on the 500 m curve radius railway line. Rails were bonded by the splints. The test line is used for cargo transportation. The axle weight of the trains is 23 t and the annual total weight is 13 Mt. The properties of test rail are shown in Table 1. Firstly, the contact and force between wheel and rail in the line segment and the curve segment were simulated by finite element software. Actual test time is 1.5 years. Macro morphology, light band width, surface hardness and profile of rails were tracked and analyzed for three times corresponding to three different conditions of total weight of 40000 tons, 0.92 million tons and 22.5 million tons (corresponding to the running time of 1 day, 1 month, 1.5 years, respectively). The rail performances of different strength levels under the same test condition were compared and analyzed.

| Steel grade | Rm (MPa) | A (%) | HBW10 / 3000(HB) |
|-------------|----------|-------|------------------|
| U71Mn       | 940      | 13    | 268              |
| U75V        | 1040     | 12    | 301              |
| U68CuCr     | 1045     | 12    | 302              |

3. Experiment results and discussions

3.1. Analysis of force bearing point on rails

By means of digital simulation, the contact and force between wheel and rail in the straight and curved segments are simulated. The results show that when the train is traveling in a straight segment, the contact and force mode between rail upper and lower stocks and wheel are the same. The wheel and the rail top contact, with the feature of the minimal wheel-rail contact stress and the very small lateral creep force, which is one of the ideal states of wheel-rail contact. However, when the train is in curve segment, in the contact area between upper rail gauge angle and the wheel rim root, there is relative sliding and rotation between the wheel and rail contact surfaces, which can usually produce a large wheel margin force and lateral creep, resulting in longitudinal and lateral forces. Therefore, the probability of wear and damage of rails on the curve segment is the largest [16-17].

3.2. Macroscopic morphology

The rails of 880 MPa and 980 MPa show different macroscopic morphology after service for 1.5 years with load. There is no obvious change in rail bottom and rail waist for three rails. But the contact surfaces between rail head and wheel change obviously. The 880 MPa rail mainly manifests lateral grinding and vertical grinding of rail. The rail bottom distributes obvious steel scraps due to the abrasion of wheel and rail (see Figure 1), while there is no obvious fish scale, peeling off the block and so on the surface of rail head. In the early stage of service for 980 MPa rail, there is a small amount of fish scales which display 45° angle distribution to rail axial at work side. With the increase of the total weight through the rails, the number of fish scales increases and more phenomena of peeling off occur, as shown in Figure 2.

With the increase of total weight, the rail is subjected to the vertical pressure of train, and varying degrees of width spread appear on rails. When the total amount is 0.92 million tons, the thickness of
Width spread for U71Mn rail reaches to 1.8 mm, whereas the thickness of width spread for U75V and U68CuCr rails is 1 mm. With the further increase of the total weight, the width spreads are gradually worn out and the macroscopic topography of the rail mainly manifests lateral grinding and vertical grinding.

Figure 1. The macro morphology of 880 MPa-grade U71Mn rail.

Figure 2. The macro morphology of 980 MPa-grade U75V rail.

3.3. Hardness of the rail working face
The rail surface will produce plastic deformation due to the force because the rail and the wheel repeatedly contact. The proliferation and entanglement of dislocation produce a lot of sub-grains, leading to work hardening. With the increase of total weight, the hardness of rail head surface gradually increases. The higher the hardness of rail surface is, the faster the plasticity of rail surface decreases. The rail is more prone to wear and tear off the block in the process. It can be seen from Figure 3, the initial hardness of 80 MPa-grade (U71Mn) rail is low and the surface hardness increases faster than 980 MPa-grade rails (U75V and U68CuCr) with the increase of the total weight. The wear is easier to happen for 880 MPa-grade rail (U71Mn) due to the fast decrease of plasticity caused by more serious work hardening.

Figure 3. The hardness of rail surface.
3.4. Change of light band width

The width of light band is an indicator to measure the ability of pressure resistance of rails. The wider the light band is for the same original profile after passing the same total weight, the lower ability of capacity of pressure resistance of rails is and the more serious the rail deformation is. Under the load pressure, the greater the rail deformation is, the mire contact area of the vehicle is and the wider the light band is. Figure 4 shows the relationship between the width of light band and the total weight. It is observed that with the increase of total weight, the light bands for 980 MPa-grade (U75V and U68CuCr) and the 880 MPa-grade (U71Mn) rails significantly increase in the early stages and subsequently slowly increase. In the early stage of wear, the increase of bright band for 880 MPa-grade (U71Mn) rail is more obvious than the 980 MPa-grade (U75V and U68CuCr) rails. The reason is that the hardness of former surface is lower than the latter. The contact area between wheel and rail is larger under the load rail and it is more prone to produce light belts. It can be seen from the hardness of rail surface in Figure 3, although the final hardness of 880 MPa-grade rails is greater than that of 980 MPa-grade rails, the former light band is close to the latter total bright belt in the early stage of wear (920,000 tons, corresponds to a month). When the total weight reaches 22.5 million tons, the light belt of 880 MPa-grade rail is 8 mm wider than that of 980 MPa-grade rails.

![Figure 4. The total weight vs light band width.](image)

3.5. Rail profile

The initial profile of test rails is the standard profile of 60 kg/m rails in TB/T 2344, China rail national standard. Deformation and abrasion happen on the rail because of the service under load. The rail profile slowly changes due to continuous abrasion of wheel and rail. The performance of rail use can be directly reflected by measuring the profile of rail head.

The measurement position of vertical abrasion of rail is offset 10 mm to rail working side form rail head centerline. The measurement position of lateral abrasion of rail is offset 16 mm form rail head. The rail profiles were measured by rail profile instrument and amount of the lateral grinding and vertical grinding was calculated by comparing real rail profiles with the standard contour. The vertical grinding first appears in two strength grade rails in the early stare of service using process and no lateral grinding occurs. With the increase of total weight, the lateral grinding generally appears in both rails. The final rail profiles of 880 MPa-grade and 980 MPa-grade rails are presented in Figures 5 and 6, respectively. It indicates that when the total weight reaches 22.5 million tons, the side grindings of 880 MPa-grade (U71Mn) and 980 MPa-grade(U75V) rails reach 9.85 mm and 3.11mm, respectively. The vertical grindings develops slowly and reach 2.67 mm and 1.43 mm, respectively. Therefore, with the increase of the total weight, the wears of two strength-level rails are dominated by side grinding and the vertical grinding is small. In addition, the vertical grinding and lateral grinding amounts of 880 MPa-grade rail are far greater than those of 980 MPa-grade rail. This is because the wheels and rails mainly contact in the rail side during the train’s running on curve section, leading to more side
grinding. The wear of 880 MPa-grade rail is more serious because of low strength and low hardness [18].

The injury of rails is divided into slightly damage and serious damage. When the vertical abrasion of rail is >11 mm and the side wear is >19 mm, the rail is classified to serious damage [19]. The seriously damaged rails should be replaced immediately. According to the measurement of rail profiles in Figures 5 and 6, it can be seen that under the same total weight condition, the wear on work side of 880 MPa rail is more serious and crushed deformation happens. The rail profile of 980 MPa rail is mainly characterized by lateral grinding and the crushed deformation doesn’t happen. The rails should be replaced when side grinding further increases to 12 mm. Based on the wear trend, 880 MPa rail will be replaced ahead 980 MPa rail. It means that service life of 980 MPA rails is longer under same total weight.

![Figure 5. The profile of 880 MPa rail after total weight of 22.5 million tons.](image)

![Figure 6. The profile of 980 MPa rail after total weight of 22.5 million tons.](image)

4. Conclusion

The wear tests were conducted by laying the 880 MPa and 980 MPA-grade rails on the cargo line with small curve radius. The influence of total load on wear was analyzed and the following conclusions are obtained:

(1) The service performance data of 880 MPa and 980 MPA-grade rails in the cargo line with small curve radius are analyzed by continuous tracking of service performance. It shows that 880 MPa-grade rail wears faster and side grinding amount is 3 times of that 980 MPa-grade rail. The wear resistance of 980 MPa-grade rails is better, but they are prone to defects of fish scales and striping off.

(2) On the cargo line with small curve radius, 880 MPa-grade rail will be replaced early due to more serious wear. It is recommended to first select 980 MPa-grade rail.

5. Reference

[1] Yang L 2013 Technol. Forum. 434-5 (In Chinese)
[2] Yu X M and Feng L C 2013 Hot working Technol. 42 215-7 (In Chinese)
[3] Lin S and Dai H 2016 Hot working Technol. 45 252-4 (In Chinese)
[4] Chou J S, Kim C, Tsai P Y, Yeh C P and Son H 2017 Ksce J. Civil Eng. 1-16.
[5] Pessel S and Mensinger M 2016 *Transp. Res. Procedia* **14** 2006-2014
[6] Srivastava J P, Kiran M V R, Sarkar P K and Ranjan V 2017 *Procedia Eng.* **173** 1130-1137
[7] Liu L, Pan J Z, Zhou M Y, Chen C H and Zhao X J 2016 *Hot working Technol.* **45** 143-5 (In Chinese)
[8] Zhu W and Ma H 2016 *International Conference on Computer Science and Network Technology* 1498-1501
[9] Ashimov A A, Ashimov A A, Borovski Y V and Volobueva O P 2014 *J. Rail & Rapid Transit* **228** 581-589
[10] Kanematsu Y, Matsui M and Tsuijie M 2017 *QR of RTRI* **58** 50-56
[11] Pan R, Zhao X J, Pan J Z, Liu P T and Ren R M 2014 *Ordnance Mater. Sci. Eng.* **37** 85-6 (In Chinese)
[12] Nippon K H K 2001 *China. Railw. Sci.* **22** 6-15 (In Chinese)
[13] Krylov V V 1996 *J. Acoust. Soc. Am.* **100** 3121-34
[14] Yi B 2007 *Railw. Eng.* 91-3 (In Chinese)
[15] Liu Q Y, Wang W J and Zhou Z R 2007 *Lubr. Eng.* **32** 11-14 (In Chinese)
[16] JIANG Z Q, Si D L, Li W and Du X G 2014 *China. Railw. Sci.* **35** 9-10 (In Chinese)
[17] Chang W H 2011 *J. Railw. Eng. Soc.* **2** 71-3 (In Chinese)
[18] Zhou Q Y, Zhang J F, Guo Z W, Xi N S and Gao X P 2010 *China. Railw. Sci.* **3** 27-31 (In Chinese)
[19] Guo Z W 2011 *Railw. Eng.* 106-9 (In Chinese)