# Development of rail technology for high speed railway in China

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## Abstract

**Purpose** – The purpose of this paper is to summarize the status and characteristics of rail technology of high-speed railway in China, and point out the development direction of rail technology of high-speed railway.

**Design/methodology/approach** – This study reviews the evolution of high-speed rail standards in China, comparing their chemical composition, mechanical attributes and geometric specifications with EN standards. It delves into the status of rail production technology, shifts in key performance indicators and the quality characteristics of rails. The analysis further examines the interplay between wheels and rails, the implementation of grinding technology and the techniques for inspecting rail service conditions. It encapsulates the salient features of rail operation and maintenance within the high-speed railway ecosystem. The paper concludes with an insightful prognosis of high-speed railway technology development in China.

**Findings** – The rail standards of high-speed railway in China are scientific and advanced, highly operational and in line with international standards. The quality and performance of rail in China have reached the world's advanced level. The 60N profile guarantees the operation quality of wheel–rail interaction effectively. The rail grinding technology system scientifically guarantees the long-term good service performance of the rail. The rail service state detection technology is scientific and efficient. The rail technology will take "more intelligent" and "higher speed" as the development direction to meet the future needs of high-speed railway in China.

**Originality/value** – The development direction of rail technology for high-speed railway in China is defined, which will promote the continuous innovation and breakthrough of rail technology.

**Keywords** High speed railway, Rail, Wheel–rail interaction, Intelligent operation and maintenance

**Paper type** Research paper

## 1. Introduction

The rail is a crucial component of the track structure. High-quality rail is essential for building a world-class high-speed railway and ensuring the safe, stable, comfortable and high-speed operation of high-speed Electric Multiple Units (EMUs). From the Beijing-Tianjin High-Speed Railway to the intelligent Beijing-Zhangjiakou High-Speed Railway, China high-speed railway technology has steadily developed and continuously innovated. Over the past decade, the rail technology of high-speed railways has also made continuous progress. Research work on the standard system, manufacturing, wheel–rail matching relationship and service performance has been carried out successively, forming a complete set of high-



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speed rail technology with independent intellectual property rights (Zhou, Zhou, Zhang, & Chen, 2006; Zhang, Zhou, Chen, & Liu, 2010, 2011; Zhou, Zhang, Liu, Tian, Chen, & Li, 2018).

The research work on high-speed railway rail technology abroad mainly focuses on the study of wheel rail relationships (Jin, 2022), such as wheel–rail wear (Li & Kalker, 1998; Jin, 2014), wheel–rail damage (René & Gregor, 2005), rail profile design (Magel & Kalousek, 2002), etc. There are relatively few systematic studies on high-speed railway rail technology.

This paper will summarize the related standards, product quality, operation and maintenance technology of rail technology in the past ten years of high-speed railway in China and put forward the key development direction of rail technology of high-speed railway in China.

## 2. Development of rail standards

The construction of the Qinhuangdao-Shenyang High-Speed Railway led to the initial formulation of China's provisional technical conditions for high-speed railway rails in 1998 (Zhou, Liu, Zhu, & An, 2006; Zhou, Zhou *et al.*, 2006). After research and revision, TB/T 3276-2011 "Rail for High-Speed Railway" was promulgated and implemented in 2011 (Zhang, Zhou, Chen, & Liu, 2011; Zhou *et al.*, 2018), which has formed the international advanced rail industry standard of China high-speed railway. Further integration and optimization of existing rail standards resulted in the release of TB/T 2344.1-2020 "Rail Part 1: 43kg/m - 75kg/m Rail" on July 1, 2020. This essentially completed the construction of China high-speed railway rail standard system.

The primary indicators for high-speed railway rails are presented in Tables 1–4. These indicators are equivalent to the internationally advanced EN standards (Zhou *et al.*, 2018).

## 3. Current rail quality of high-speed railway

Informed by internationally advanced high-speed railway rail standards, rail manufacturers in China have embarked on research into the refining, rolling and straightening technologies of high-speed rail. The 100-m fixed-length high-speed rails were successfully produced with high purity, high dimensional accuracy, high flatness and high surface quality, reached the international advanced level (Zhou *et al.*, 2018) and realized the independent intellectual property rights and all localization of high-speed railway rails in China.

In November 2020, China high-speed railway rails were exported for the first time to the Indonesia's Jakarta-Bandung High-Speed Railway. By the end of 2022, the operating mileage of China high-speed railways had exceeded 42,000 kilometers, all of which adopted the 100-m fixed-length rails that were independently developed and produced.

The quality of high-speed railway rails has remained consistent over time. For over a decade, the tensile strength of the U71Mn rail used in high-speed railways has been

| | Composition/% | | | | | Mechanical properties | | |
|---|---|---|---|---|---|---|---|---|
| Steel | C | Si | Mn | P | S | Tensile strength Rm(MPa) | Elongation A (%) | Hardness of the rail running surface (HB) |
| U71Mn | 0.65~ | 0.15~ | 0.70~ | ≤0.025 | ≤0.025 | ≥880 | ≥10 | 260~300 |
| U71MnH | 0.80 | 0.58 | 1.20 | | | ≥1080 | ≥10 | 320~380 |
| U75V | 0.71~ | 0.50~ | 0.70~ | ≤0.025 | ≤0.025 | ≥980 | ≥10 | 280~320 |
| U75VH | 0.80 | 0.80 | 1.05 | | | ≥1180 | ≥10 | 340~400 |

**Source(s):** Table courtesy of TB/T 2344.1-2020

**Table 1.**
Chemical composition and mechanical properties of TB/T 2344.1-2020

approximately 940MPa, and the hardness of the rail running surface has been about 270HB (as shown in Figure 1).

In the past five years, various rail manufacturers in China have proactively undertaken the optimization and upgrading of related production technologies, such as rail decarburization, refining, rolling, straightening and flaw detection (as shown in Figure 2). These efforts have effectively ensured a stable improvement in rail quality.



| Steel | C | Si | Mn | P | S | Tensile strength Rm(MPa) | Elongation A(%) | Hardness of the rail running surface (HB) |
|---|---|---|---|---|---|---|---|---|
| | Composition/% | | | | | Mechanical properties | | |
| R260 | 0.60~0.82 | 0.13~0.60 | 0.65~1.25 | 0.030 | 0.030 | 880 | 10 | 260~300 |
| R350HT | 0.70~0.82 | 0.13~0.60 | 0.65~1.25 | 0.025 | 0.030 | 1175 | 9 | 350~390 |

**Source(s):** Table courtesy of EN 13674-1-2017

**Table 2.** Chemical composition and mechanical properties of EN 13674-1-2017

| Location | Project | | Allowable deviation |
|---|---|---|---|
| Distance to rail end: 0~1.5 m | Flatness | Vertical direction (upward) | 0 ~ 1 m~≤0.3 mm/1 m<br>0 ~ 1.5 m~≤0.35 mm/1.5 m |
| | | Vertical direction (downward) | ≤0.2 mm |
| | | Horizontal direction | 0 ~ 1 m~≤0.4 mm/1 m<br>0 ~ 1.5 m~≤0.5 mm/1.5 m |
| Distance to rail end:1 m~2.5 m | Flatness | Vertical direction | ≤0.3 mm/1.5 m |
| | | Horizontal direction | ≤0.5 mm/1.5 m |
| Rail body | Flatness | Vertical direction | ≤0.3 mm/3 m and ≤0.2 mm/1 m |
| | | Horizontal direction | ≤0.45 mm/1.5 m |

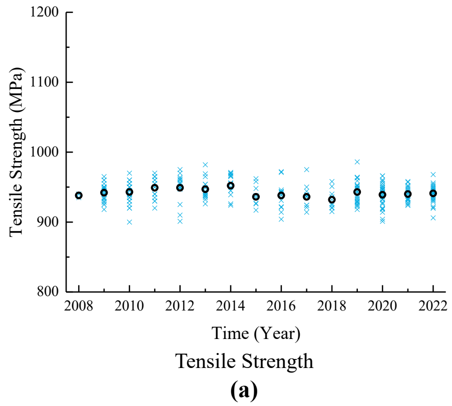
**Source(s):** Table courtesy of TB/T 2344.1-2020

**Table 3.** Main geometric dimensions of high-speed rail of TB/T 2344.1-2020

| Location/Dimensional properties | | d | Class A | L |
|---|---|---|---|---|
| BODY | Vertical flatness V | ≤0.3mm | | 3m |
| | | | and | |
| | | ≤0.2mm | | 1m |
| | Horizontal flatness H | ≤0.45mm | | 1.5m |
| ENDS | End“E” | | 2m | |
| | Vertical straightness | ≤0.4mm | | 2m |
| | | | and | |
| | | ≤0.3mm | | 1m |
| | | | and | |
| | | | e ≤ 0.2mm | |
| | Horizontal straightness | ≤0.6mm | | 2m |
| | | | and | |
| | | ≤0.4mm | | 1m |

**Source(s):** Table courtesy of EN 13674-1-2017

**Table 4.** Main geometric dimensions of high-speed rail of EN 13674-1-2017




**Source(s):** Authors' own work

**Figure 1.**
Change of mechanical properties of rail

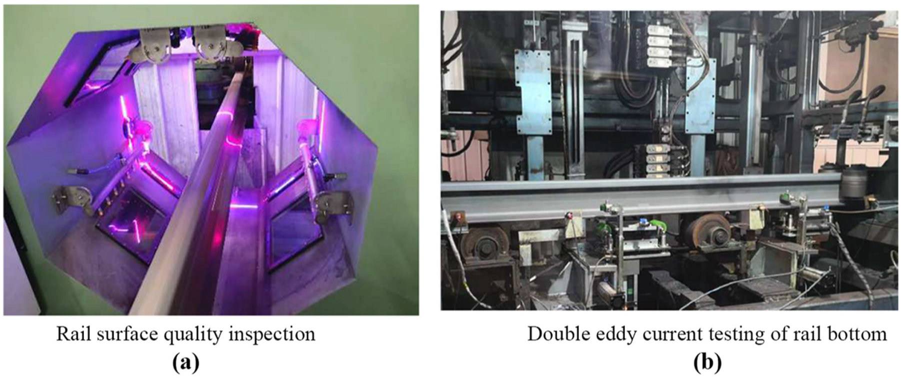



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**Figure 2.**
Rail quality inspection equipment

## 4. Operation and maintenance technology of high-speed railway rail

### *4.1 Theory on wheel–rail relationship*

(1) Research and development of 60N rail

In order to solve the stability issues of high-speed Electric Multiple Unit (EMU) during the initial operation stage of high-speed railway, an optimization design of the rail profile for high-speed railways was undertaken, resulting in the proposal of the 60D rail profile (Zhou, Tian, Zhang, Chang, & Hou, 2014). Following the successful application of the 60D profile, a new profile named the 60N was designed. The TB60 profie, 60D profie and 60N profie are given out in Figure 3. The 60N rails were first trialed on the Beijing-Guangzhou High-Speed Railway in 2011 and began to be fully popularized and applied on high-speed railways in 2015. The No.18 ballastless turnouts with 60N rails were first implemented on the Beijing-Shenyang High-Speed Railway in 2018 (as shown in Figure 4). This achieved a good consistency of rail profile between the turnout and the interval.

(2) Wheel–rail profile matching

China high-speed railway features five wheel profiles: LMA, LMB, LMC, LMD and LMB-10 and three rail profiles: 60N, 60D and TB60. The matching relationship between these wheel and rail profiles is quite complex (Zhou *et al.*, 2017; Zhou *et al.*, 2017). To evaluate the matching state of high-speed railway wheel–rail profiles, an evaluation method based on the improved analytic hierarchy process was proposed (Cheng *et al.*, 2019). This method comprehensively considers the wheel–rail contact geometric relationship, mechanical relationship and the safety and stability of the EMU operation, and realizes the quantitative evaluation of the matching state of the high-speed railway wheel–rail profile for the first time.

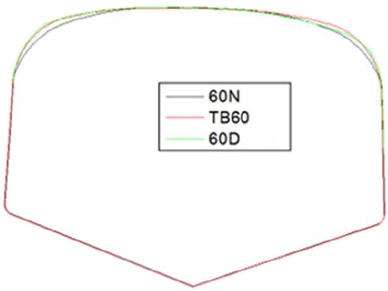
Using this method, along with long-term service tracking test data of wheel and rail profiles, the wheel–rail matching state of typical high-speed railways in China was evaluated. It was found that the 60N and 60D rail profiles are well-matched with the wheel profiles of various EMUs in China. Generally speaking, the 60N rail profile has better adaptability (Liu, Yang, Cheng, Zhou, & Zhou, 2021; Zhou *et al.*, 2014), which effectively improves the operational performance of EMUs.

Figures 5 and 6 show the profile and surface state of 60N rail in a section of Beijing–Guangzhou High-Speed Railway respectively.

As shown in Figure 5, after serving for more than six years, the actual profile of left rail and right rail basically coincides with the standard 60N profile in the range of $-15$ mm $- + 15$mm.

As shown in Figure 6, the surface states of left rail and right rail are in good condition without defects. The light band width is about 25 mm, which is distributed in the middle.

In addition, the hardness of the rail top surface ranges from 263 HB to 278 HB, and the work hardening of the rail is slight, which indicates that there is no plastic deformation on the rail.




**Source(s):** Authors' own work

**Figure 3.** Rail profile of high-speed railway

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**Figure 4.** No.18 ballastless turnout of 60N rail

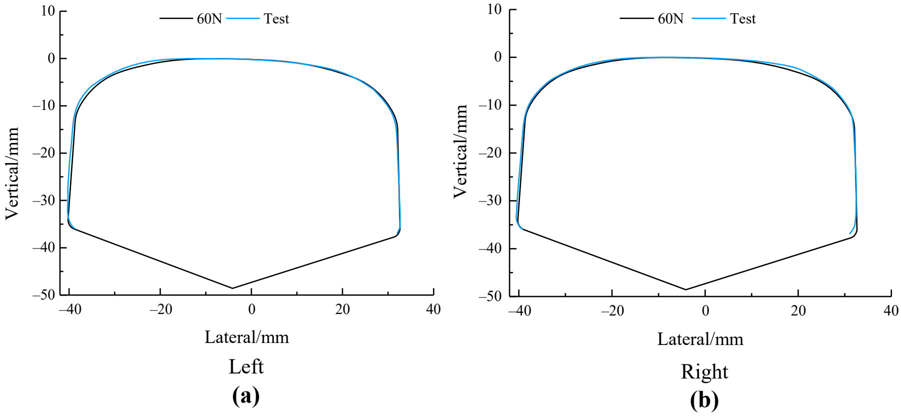



**Figure 5.**
Tested profiles of 60N rail compared with 60N profile

**Source(s):** Authors' own work

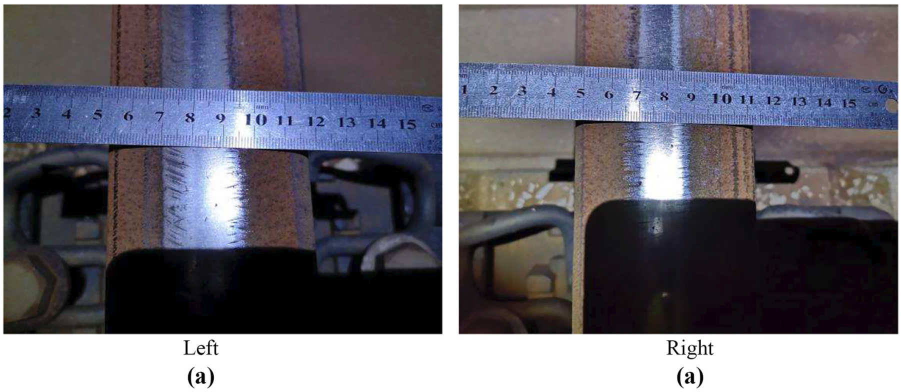



**Figure 6.**
Wheel–rail contact band of the 60N rail

**Source(s):** Authors' own work

According to the feedback, various types of EMUs have good operation performance when passing through this section, and no vibration warning or alarm has ever occurred. The service condition of 60N rail in this section is generally good, which also shows that 60N profile has good practicability in high-speed railway.

The matching relationship between wheel and rail profiles is crucial to ensure the stable operation of EMUs. To maintain a good wheel–rail matching relationship, it is necessary to implement comprehensive control measures for both wheels and rails. In terms of rail, it is particularly important to strictly control rail profile deviation. The Q/CR 681-2018 "Technical Specification for Acceptance of High Production Grinding of High-speed Rail and Turnout" stipulates the following regarding rail profile deviation after rail grinding. The profile deviation of the rail head in the transverse range of −25 mm − +25 mm and +25 mm − +32 mm should be −0.2 mm − +0.2 mm and −0.6 mm − +0.2 mm, respectively. This effectively ensures that the rail profile remains in a good state after grinding.

For the profile state of rails in service, it is also necessary to formulate corresponding deviation limits to assist in decision-making on the timing of rail grinding. By systematically sorting out the key factors affecting the running stability of EMUs, a simulation analysis based on measured data is carried out. The reasonable limit requirements for 60N profile deviation have been proposed (Yang, Cheng, Song, Hou, Liu, & Yu, 2021).

The area where the center of the rail top deviates from the working edge by +20 mm – +30 mm is considered as the key control area. The limit range of rail profile deviation in this area is −0.2 mm – +0.4 mm. As illustrated in Figure 7, the 60N + 0.4 profile and 60N −0.2 profile represent the deviation tolerance of the 60N rail profile. If the deviation exceeds the control range, abnormal vibrations may occur when the EMU operates at high speeds.

In order to verify the adaptability of rail profile deviation tolerance, the rail profile deviation before and after grinding in a certain section and the running performance of EMU are compared and analyzed, and the results are given in Figures 8 and 9 respectively. It should be noted that, the P1 to P12 in Figure 8 represent the different measuring points, and the interval between each measuring point is 100 m.

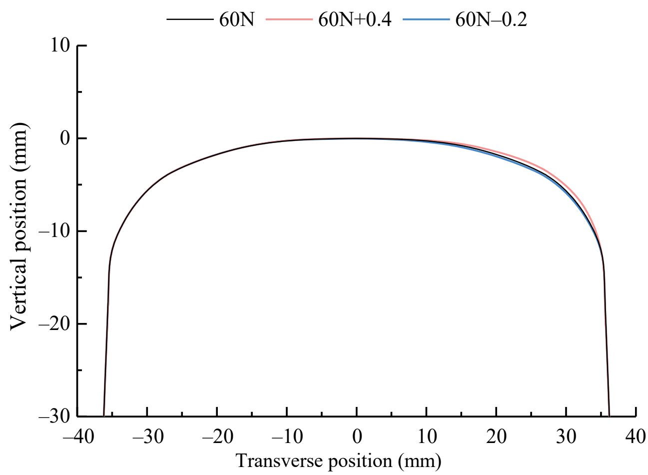
As shown in Figure 8, before grinding, the rail profile deviation of more than 50% measuring points exceeds the tolerance requirement of −0.2mm – +0.4mm. After grinding, the deviation of rail profile is within the tolerance limit.

The measured rail profile before and after grinding is input into the coupled dynamic model of EMU-track system, and the lateral acceleration of bogie frame is simulated and analyzed.

As shown in Figure 9 (a), the effective value of lateral acceleration of bogie frame after rail grinding is 0.89 m/s$^2$, which is nearly 50% lower than that before rail grinding.

As shown in Figure 9 (b), before rail grinding, there is an obvious main frequency of about 9 Hz in the lateral acceleration of the frame. The main frequency characteristic is close to the elastic modal frequency of the EMU car body, which is easy to cause local structural resonance of car body (Gong, Zhou, Sun, Sun, & Xia, 2017). After grinding, the overall vibration amplitude of the lateral acceleration of the frame in the frequency band of 6 Hz – 14 Hz is obviously reduced, and there is no main frequency characteristic of about 9 Hz.

This shows that controlling the rail profile deviation according to the given 60N rail profile deviation can effectively improve the running performance of EMU, avoid the local structural resonance phenomenon of EMU body and ensure the running quality of EMU and riding experience of passengers.




**Source(s):** Figure courtesy of Yang *et al*. (2021)

**Figure 7.** Tolerance of 60N rail profile deviation

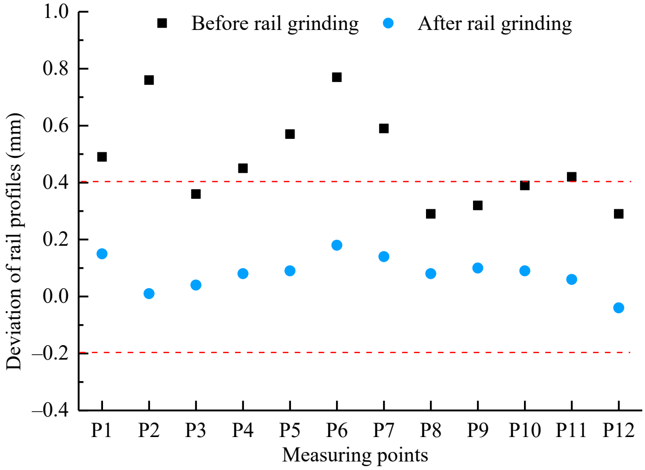



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**Figure 8.**
Deviations of profiles before and after rail grinding

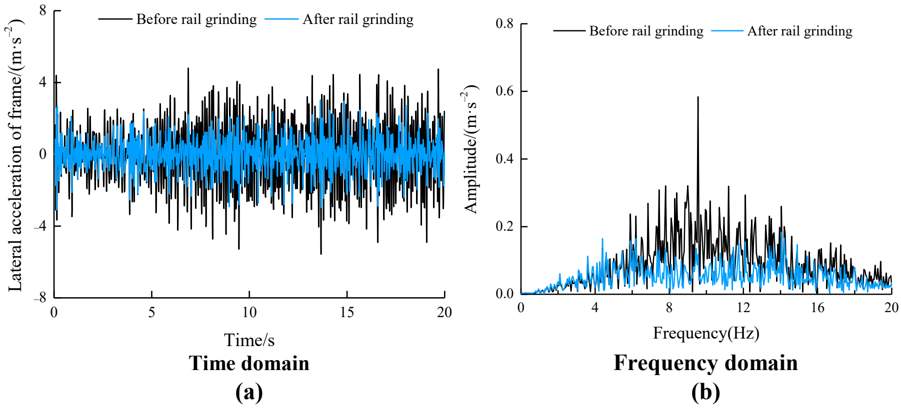


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**Figure 9.**
Simulation results of lateral acceleration of bogie frame

(3) Wheel–rail material matching

The matching relationship between these wheel and rail materials of high-speed railway in China is also complex, which involves five wheel materials (ER8, ER9, ER8C, SSW-Q3R and D2) paired with two rail materials (U71MnG and U75VG). According to the hardness matching of high-speed wheels and rails presented in Table 5 (Zhou, Liu, *et al.*, 2006; Zhang *et al.*, 2017), the hardness ratio of wheels to rails is generally less than or close to 1:1. The only exception is the hardness ratio of SSW-Q3R wheels (311 HB – 363 HB) to rails (260 HB – 320 HB), which is greater than 1:1.

Based on the service conditions of wheels and rails in high-speed railways (Li *et al.*, 2020), wheels with lower hardness tend to wear faster and are more susceptible to plastic deformation or rolling contact fatigue defects, leading to high impact loads. Existing research indicates that (Zhang *et al.*, 2017) appropriately increasing wheel hardness can reduce wheel wear and lower the comprehensive maintenance cost of the wheel–rail system. A reasonable wheel–rail hardness ratio is suggested to be between 1:1 and 1.15:1.

*4.2 Rail grinding technology*

Rail grinding is the primary technical method to maintain the good rail service status and wheel–rail matching status in high-speed railway. After years of scientific research and independent innovation, a comprehensive rail grinding technology system of high-speed railway in China has been gradually established.

(1) The classification of rail grinding

The rail grinding of high-speed railway in China is categorized into pre-grinding, preventive grinding and repair grinding. Preventive grinding is the primary method, supplemented by repair grinding. Together, these techniques ensure the good service status of the rails and the wheel–rail relationship in high-speed railway.

Pre-grinding refers to the grinding of newly laid rails. For newly constructed lines, pre-grinding is generally completed after the fine adjustment of the track system and before the line is opened for operation. The purpose of pre-grinding is to remove the decarburization layer on the rail surface, optimize the rail head profile, eliminate surface defects on the rails that may have occurred during production, welding, transportation, or construction, correct the rail head profile and improve the flatness of the rails and welded joints.

Preventive grinding refers to the periodic grinding of rails. In principle, it is conducted every 60 Mt through the total mass, generally not exceeding a four-year interval. The purpose of preventive grinding is to repair the profile of the rail head, improve the wheel–rail relationship, eliminate or delay the development of rolling contact fatigue, and prevent or delay the occurrence of issues such as corrugation.

Repair grinding refers to the grinding of rails that have developed issues. The aim is to correct the profile of rail heads and eliminate rolling contact fatigue cracks, peeling off blocks, corrugation and scratches on the rails. Repair grinding should be carried out promptly in cases of repeated abnormal vibration of the EMU, poor light band in sections, track impact index exceeding the limit, or rail disease sections exceeding the limit of disease remediation.

(2) Rail grinding equipment

Rail grinding equipment for high-speed railways in China primarily includes rail grinding trains, rail milling and grinding trains, turnout grinding trains and small grinding machines, etc. Each type of rail grinding equipment has its own technical advantages and complementary functions.

| Rail material | Rail surface hardness/HB | Wheel material | Rim hardness/HB | Wheel–rail hardness ratio |
|---|---|---|---|---|
| U71MnG | 260~300 | SSW-Q3R | 311~363 | >1 : 1 |
| | | ER8 | ≥245 | <1 : 1 |
| | | ER8C | ≥245 | <1 : 1 |
| | | ER9 | ≥255 | ≈1 : 1 |
| | | D2 | ≥260 | ≈1 : 1 |
| U75VG | 280~320 | SSW-Q3R | 311~363 | >1 : 1 |
| | | ER8 | ≥245 | <1 : 1 |
| | | ER8C | ≥245 | <1 : 1 |
| | | ER9 | ≥255 | <1 : 1 |
| | | D2 | ≥260 | <1 : 1 |

**Source(s):** Authors' own work

**Table 5.** Hardness matching between wheels and rails of high-speed railway in China

Field grinding work is gradually establishing a joint operation mode that involves efficient cooperation among multiple pieces of equipment.

Rail grinding trains primarily consist of conventional grinding trains and high-speed grinding trains. Conventional grinding trains use motor-driven grinding wheels to grind rails. As depicted in Figure 10 (a), the end face of the grinding wheel contacts the top face of the rail, and the motor drives the grinding wheel to rotate and grind the rails. Conventional grinding train has a good effect on rail profile grinding.

High-speed grinding trains, on the other hand, are passive grinding trains. As shown in Figure 10 (b), the circumferential surface of the grinding wheel contacts the top surface of the rail at a certain angle. The locomotive's traction uses the bearing of the grinding wheel itself to drive the grinding wheel to passively rotate and grind the rail. Rapid grinding of trains has a good effect on rail flatness.

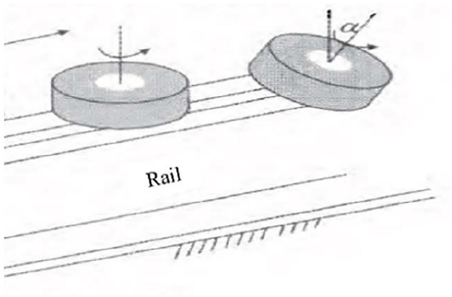
The grinding principle of a turnout grinding train is essentially the same as that of a conventional grinding train. It is primarily used for turnout rails, but it can also be used to rectify rail top surface issues of line rails such as scratching, stuffing, crack, spalling, corrugation, etc.

Rail milling and grinding trains are primarily used for repairing and grinding severe rail top surface damage, such as abrasion, crushing, fatigue cracking, peeling off blocks and other rail-related issues.

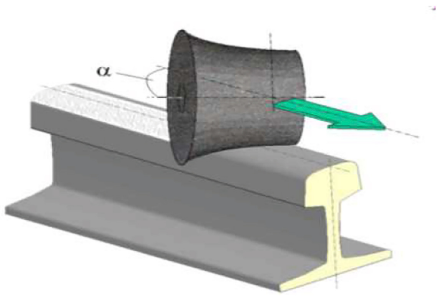
Small rail grinding equipment is primarily used for grinding rail welded joints and various sharp rails and turnouts. An internal combustion engine serves as the power source, enabling the equipment to adapt to grinding rail planes, side surfaces, arc surfaces and various angles.

(3) The standard of rail grinding

The management department of China high-speed railway has formulated a series of technical standards related to rail grinding. These include the "Administrative Measures for Rail Grinding of High-speed Railway", "Technical Specifications for Acceptance of Large-scale Mechanical Grinding of Rail and Turnout of High-speed Railway", and "Administrative Measures for High-speed Grinding of Rail of High-speed Railway", among others. These standards stipulate the organization and management of rail grinding, cycle and timing, target profile design and grinding operation requirements. They also put forward strict technical requirements for the acceptance of grinding quality in terms of rail profile, grinding depth, periodic grinding trace, roughness and other indicators.




Conventional grinding train
(a)




High-speed grinding train
(b)

**Source(s):** Authors' own work

**Figure 10.**
Grinding principle of rail grinding trains

In order to enhance the evaluation of rail grinding quality, the acceptance of high-speed railway grinding quality has gradually shifted towards quantitative evaluation. Currently, the high-speed railway rail profile quality index (Yu, Zhang, Zhang, Gao, & Tian, 2020) has been researched and proposed to evaluate the rail profile quality after grinding. In the future, with the support of the China Railway, the rail grinding quality index (GQI) of the high-speed railway will be studied and proposed. This will allow for a comprehensive and quantitative evaluation of the rail profile, surface state, periodic wear marks and other indicators of the high-speed railway.

As can be seen from the research results on the tolerance of rail profile deviation in Section 4.1, the application of high-speed railway rail grinding technology to control rail profile deviation and ensure rail profile quality will effectively ensure the good wheel–rail relationship and operational performance of high-speed railways.

In general, the rail grinding technology of high-speed railway in China is advanced, with a reasonable division of labor, clear responsibilities, strict standards and strengthened acceptance assessments. The acceptance of rail grinding quality is transitioning towards a comprehensive and quantitative evaluation.

### *4.3 Detection technology of rail service state*

(1) Rail profile detection technology

The rail profile is one of the key parameters of wheel–rail matching in high-speed railways. As shown in Figure 11, there are two types of profile detection methods currently: contact and non-contact.

The basic principle of contact rail profile detection equipment involves manually operating a roller to slide over the outer surface of the rail head. The relative coordinates of the roller's movement track are recorded, and the rail head profile is obtained through correction and curve fitting calculations. While contact rail profile detection equipment is portable and offers high measurement accuracy (0.01 mm), it is a single-point manual detection method. This means that the detection efficiency is low, and the detection data may struggle to reflect the overall profile state of the entire section.

(2) Rail surface state

The flatness and damage state of the rail surface impact the dynamic performance of the wheel–rail system under high-speed conditions. Currently, the primary method used for detection is non-contact detection method based on machine vision.

The high-speed railway rail surface state moving detection trolley uses high-precision laser 3D scanning technology to achieve continuous and dynamic acquisition of rail profile

Contact testing **(a)** | Non-contact testing (trolley) **(a)** | Non-contact testing (on-board) **(a)**

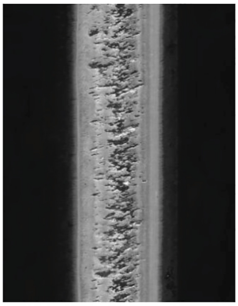
**Source(s):** Authors' own work

**Figure 11.** Schematic diagram of rail profile detection

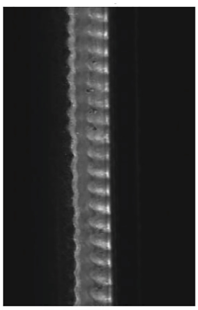
and smoothness. Simultaneously, an array high-definition camera is used to capture the rail surface light band and damage. Rail surface light band and defect recognition are achieved based on deep learning technology and image recognition processing methods.

As shown in Figure 12, the detection trolley can achieve an accuracy of 0.03 mm at a speed of 15 km/h. It can synchronously perform dynamic and continuous detection of rail head profile, rail top wave wear, rail bottom slope and rail surface state damage, greatly improving field operation efficiency. Figure 12 (b and c) show the detection results of rail surface damage and rail corrugation respectively. From 2021 to 2022, it was tested, verified and compared on

Track surface state dynamic detection trolley
**(a)**



Identification of rail surface damage
**(b)**



Identification of rail Corrugation
**(c)**

**Figure 12.**
Rail surface state detection equipment and results

**Source(s):** Authors' own work

the Beijing-Shanghai, Shanghai-Hangzhou and Shanghai-Nanjing High-Speed Railways, accumulating over 600 km in test mileage.



## 5. Prospect of high-speed rail technology

The "14th Five-Year Plan for Railway Science and Technology Innovation" issued by the National Railway Administration of the People's Republic of China highlights that "intelligent railway" is one of the main goals for railways by 2025. The "CR450 Technological Innovation Project" is one of the key projects in the field of railway technology and equipment during the 14th Five-Year Plan. In order to meet the requirements of the "intelligent railway" and support the smooth implementation of the "CR450 Science and Technology Innovation Project", high-speed railway rail technology will also develop around two key directions: "intelligence" and "higher speed".

### *5.1 Intelligent rail operation and maintenance technology*

Currently, the operation and maintenance work for high-speed rail system in China are predominantly reliant on rules and manual experience. However, with the advancement of technology, there have been initial attempts to incorporate artificial intelligence into the system. This includes strategies such as dynamic detection, which allows for real-time monitoring of the service status of the rail lines. Moreover, big data management has also been introduced as a way to handle the vast amounts of data generated by the rail system. The collected data can be used to optimize operations, predict potential problems and streamline maintenance activities.

The information generated from these intelligent systems is scattered and fragmented, often residing in separate databases or platforms. This disjointed data landscape makes it difficult to establish meaningful correlations among various types of information. Thus, there is a critical need for the construction of an intelligent operation and maintenance system that can integrate this diverse data and provide a unified view.

As the service life of high-speed railway rails extends year by year, the management departments are learning more about the intricacies of rail service status. This growing knowledge, coupled with advances in detection technology and information management technology, provides a solid foundation for the development of a smart operation and maintenance system. The technology has matured to a point where rapid processing, analysis and evaluation of rail status data is possible.

Intelligent operation and maintenance represent the primary direction for the future development of high-speed railway technology. This includes service status detection and evaluation, maintenance decision-making and big data management related to rail operation and maintenance. These elements, when combined, hold the promise of transforming the way high-speed railway operation and maintenance and paving the way for a more efficient and reliable rail system in China.

(1) Accurate detection evaluation and intelligent decision-making

Our study concentrates on the critical indicators of rail service state, with the primary objective of establishing an equilibrium mechanism that balances the speed of detection with its accuracy. The rapid evolution of technology has opened new avenues for improving the efficiency and precision of rail service state detection. However, achieving a balance between these two factors remains a challenge. We aim to find a solution that provides accurate results without compromising speed, thereby ensuring the optimal performance of the rail service. Further, we are also investigating a potential cooperation mechanism between dynamic and static detection methods. The integration of these two techniques can potentially yield a more comprehensive understanding of the rail service state. This approach will enhance our ability to accurately and efficiently detect any potential issues, leading to more effective maintenance and prevention measures.

After achieving accurate detection, we will study key evaluation indexes such as rail profile, rail flatness, surface state, remaining life and maintenance quality. We aim to establish comprehensive and quantifiable rail state evaluation indexes (such as service state index, overhaul index, grinding index, etc.) to facilitate rail state evaluation.

After gathering a significant amount of rail service state data, we will delve into the study of prediction methods for the rail service state of high-speed railways. We aim to establish a linkage mechanism between state prediction and maintenance decision-making, such as rail grinding, lubrication, rail replacement and overhaul. This will enable system platform integration and provide intelligent decision-making for management departments.

(2) Rail full life cycle health management

We aim to extend the single big data management, which currently encompasses rail production information, profile information and damage information, to span the entire life cycle of the rail. This holistic approach will ensure that every critical aspect – from production to welding, laying, maintenance and eventual replacement or reuse – is captured and managed effectively. Targeting each key stage in the rail's full life cycle, we intend to investigate various big data management modes and technical schemes. The ultimate goal of this endeavor is to establish a comprehensive health management platform for the entire life cycle of high-speed railway rails. This platform will centralize all relevant data, providing a unified and interactive system for managing and monitoring rail health.

By integrating intelligent assistance into the platform, we can enhance decision-making processes related to rail maintenance and repair. This includes predicting potential issues, recommending preventive measures, and guiding the implementation of repair activities. This intelligent, data-driven approach will significantly improve the efficiency and effectiveness of maintenance and repair operations, ensuring the long-term safety and stability of the high-speed railway system.

### *5.2 Rail technology adapted to higher speed*

Considering the wheel–rail matching status, and rail service status of high-speed railway in China, it is evident that the U71Mn steel and 60N profile essentially meet the rail application requirements of existing high-speed railways with speeds of 350 km/h and below in China. However, since wheel–rail interaction is highly sensitive to speed increases, higher speed conditions demand higher rail performance. Therefore, in line with the higher speed requirements of CR450 EMUs, it's necessary to demonstrate the technical adaptability of existing rails and to research and develop new materials and technologies under higher speed conditions:

(1) Technical adaptability of existing rails

With a focus on the long-term safe and stable operation requirements of the CR450 EMUs, we will conduct an in-depth analysis of the current situation regarding various factors that affect high-speed railway rail service. This includes studying the material composition of the rails, profile, ride comfort and surface state, as well as the adaptability of technical standards.

Our ultimate goal is to identify potential areas for optimization, which can lead to an improvement in the overall performance of the rail system. Based on the results of our research, we will propose technical schemes that can enhance the operation of the CR450 EMUs. We believe that these proposed strategies will foster a safer, more stable and efficient high-speed railway service in the long run.

(2) Research and development of new materials and technologies

Our research will focus on optimizing the composition of carbon and alloy elements in rail materials, with the ultimate goal of enhancing the rail's overall performance. By fine-tuning the ratio of these elements, we aim to strategically reduce the rail's strength grade, leading to increased wear. This will effectively improve the rail's scratch and fatigue resistance, making it more reliable for long-term use. The optimized composition will render the rail more amenable to welding and grinding processes, enhancing its adaptability to maintenance and repair activities.

As a side effect of material optimization, the rail's surface hardness will decrease, thus aligning more closely with the optimal hardness range for wheel–rail matching.

In tandem with material optimization, we will also focus on rail profile optimization design. This involves tweaking the physical shape and size of the rail to ensure a better fit with the train's wheels. By doing so, we aim to create a harmonious wheel–rail relationship, where both components work together seamlessly, enhancing overall performance.

Ultimately, our goal is to establish a superior performance wheel–rail material and profile matching relationship. By optimizing both the materials used in rail production and the rail profile, we can significantly improve the performance, safety and longevity of the rail system. This holistic approach to optimization promises to greatly enhance the efficiency and reliability of the high-speed railway system.

## 6. Conclusion

Indeed, with significant breakthroughs and advancements in standards, quality, wheel–rail matching and service performance research, the development of China high-speed railway rail technology over the past decade has been remarkable. The standards and quality of rails in China have reached internationally advanced levels, effectively meeting the construction needs of high-speed railways. The profiles of high-speed wheel–rails have become more reasonable, and research into hardness matching have deepened. The rails are in good service condition, ensuring the safe, fast and stable operation of high-speed trains.

As research into China high-speed railway technology continue to deepen, rail technology will evolve around two key directions: adapting to higher speeds and intelligent operation and maintenance. This will further enhance the efficiency, safety and reliability of China high-speed rail network, contributing to the country's infrastructure development and economic growth.

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