Microstructure and mechanical properties of 25MnB and 25CrMnB steels: a comparative study for track shoe applications

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Abstract. The microstructure and mechanical properties of 25MnB and 25CrMnB track shoes are studied in this paper. The results show that, after proper heat treatment, both 25MnB and 25CrMnB can meet the requirements of mechanical properties for track shoes. The addition of Cr element refines the microstructure of the steel, so that the grain-size number of the plate portion of the track shoe is refined from 8.5 to 9.5. However, it also increases the hardness, strength, and toughness of steel. The impact toughness of 25CrMnB at room temperature and at 40°C is higher by 12.1 and 27.6% than those of 25MnB. Therefore, 25CrMnB steel is preferable for track shoes applications with large sizes, poor working conditions, and high load-bearing requirements.

1. Introduction
Track shoes are the running parts of track-type construction machinery and are usually required to have high strength, hardness, and good toughness. Since the 1990s, the material of the track shoes has experienced development stages such as ZGMn13, 40Mn2Si, 35MnTiB, and 25MnB. Compared with previous generations of track shoes, 25MnB steel has lower C and Si content. And after quenching and low temperature tempering, 25MnB can achieve high hardness, strength and excellent toughness. Due to its excellent comprehensive mechanical properties, 25MnB has been adopted by more and more construction machinery manufacturers [1-3]. In recent years, many domestic enterprises have independently developed steel for track shoes for construction machinery such as 23MnB, 25MnB and 25CrMnB. Since the steel used in construction machinery has not yet formed a series in the steel industry in China, the research on the performance difference of steel for different track shoes is rarely reported. Therefore, in this paper, 25MnB and 25CrMnB steels for track shoes are selected, and their microstructure and properties are compared. And the effect of the addition of Cr on the properties of steel for track shoes is explored. Provides performance data reference for the material selection design of the track shoe.

2. Experimental materials and methods
The 25MnB and 25CrMnB track shoes used in this test are 190-pitch three-tooth track shoes, and the plate part thickness is 8mm. The profiles are purchased by professional track shoe rolling mills. The 25MnB and 25CrMnB track shoes are quenched at 880~900°C, respectively, and tempered at 200 ~ 230°C. The chemical composition of 25MnB and 25CrMnB steels are shown in table 1. The main
difference between these materials is the Cr content.

| Sample  | C    | Si   | Mn      | P  | S   | Cr  | B     |
|---------|------|------|---------|----|-----|-----|-------|
| 25MnB   | 0.257| 0.238| 1.169   | 0.018| 0.007| 0.178| 0.0015|
| 25CrMnB | 0.249| 0.244| 1.183   | 0.019| 0.007| 0.511| 0.0015|

The samples were prepared in the grousers and flat parts from different material track shoes. After grinding and polishing, the microstructure was observed by a metallographic microscope. The grain size of the sample was evaluated in accordance with the requirements of GB/T 6394-2002. A 15 mm thick full-section hardness specimen was cut perpendicular to the direction of the grouser. Such hardness samples were randomly taken in 10 pieces in 25MnB and 25CrMnB track shoes, respectively. Rockwell hardness tests were performed on each sample, as shown in figure 1. Using wire cutting, 8 impact specimens and 3 tensile specimens were cut from the burrs of different material track shoes. The impact specimen was opened with a V-shaped notch and the depth of the notch was 2 mm. According to the GB/T 229-2007 standard, the samples were subjected to a normal temperature impact test and a -40°C impact test. The specimen was subjected to a tensile test, in accordance with the GB/T 228.1-2010 standard.

![Figure 1](attachment:image1.png)

**Figure 1.** Schematic diagram of the hardness test site of the track shoe.

3. Results and discussion

3.1. Research on microstructure of 25MnB and 25CrMnB track shoes
Figure 2(a) shows the microstructure of the 25MnB grouser. Figure 2(b) shows the microstructure of the 25CrMnB grouser. Both track shoes are low carbon low alloy steels with the main alloying elements Mn and B. Both of these elements can significantly increase the hardenability of the steel. After quenching the track shoes, almost all of the low carbon martensite structure is obtained. As can be seen from the figure 2, the microstructure of the two track shoes is similar. After low temperature tempering, the microstructures of the two track shoes are fine and uniform tempered martensite.

Figure 3 shows the grain size organization of the two grouser positions. According to the requirements of GB/T 6394-2002 standard, the grain-size number of different parts of the two track shoes are evaluated. The evaluation result is that the grain-size number of the 25MnB crawler tooth part is 8.5 and the grain-size number of the flat part is 8.5. The grain-size number of the 25CrMnB crawler tooth part is 9 and the grain-size number of the flat part is 9.5. The 25MnB and 25CrMnB track shoe profiles are rolled and their microstructures are uniform. The grain-size numbers of the 25MnB and 25CrMnB track shoes are generally not less than 11. After austenitizing at 860°C ~ 900°C, the grain size has been lengthening and coarsening in different degrees. Because of the higher content of Cr in 25CrMnB steel significantly lower diffusion rate of carbon in austenite can be achieved, leading to the slow formation of austenite, preventing austenite grain growth [4]. On the other hand, the Cr element can form a refractory carbide with carbon. When the steel is subjected to austenitizing, these refractory carbides can hinder the migration of grain boundaries and reduce the tendency of austenite grain growth. Thus, a finer quenched structure is obtained.
3.2. Mechanical properties of 25MnB and 25CrMnB track shoes

Hardness tests are performed on the hardness samples of the two track shoes. 230 hardness test data is available for each material track shoe. The statistical analysis results are shown in Table 2. As can be seen from Table 2, the hardness of the 25CrMnB track shoe is 44.2 HRC, which is higher than that of the 25MnB track shoe. In addition, the hardness of different parts of the 25CrMnB track shoes is more uniform, and the standard deviation and the range are lower than that of the 25MnB track shoes. Table 3 shows the impact energy and tensile test data of different material track shoes. It can be seen from Table 3 that the strength and toughness of the 25MnB and 25CrMnB track shoes are superior and meet the performance requirements of the track shoes. The 25CrMnB track shoe has better toughness and strength than that of the 25MnB track plate. The impact energy of the 25CrMnB track shoe is 77.8 J at room temperature, and the impact energy at -40°C is 53.7 J. The impact energy of the 25MnB track shoe is 69.4 J at room temperature, and the impact energy at -40°C is 42.1 J. The impact toughness of 25CrMnB is 12.1% at room temperature, which is higher than that of 25MnB. The impact toughness of 25CrMnB is 27.6% at -40°C, which is higher than that of 25MnB. The mechanical properties of 25CrMnB track shoes have improved significantly.

Table 2. Results of hardness test.

| Sample  | Number of samples | Sample mean | Standard deviation | Range |
|---------|-------------------|-------------|--------------------|-------|
| 25MnB   | 230               | 43.1        | 1.215              | 5.9   |
| 25CrMnB | 230               | 44.2        | 0.904              | 5.3   |
Firstly, due to the addition of the Cr element, some Cr element is dissolved in the steel matrix, leading to the lattice distortion and hindering slippage of dislocations during deformation. Some Cr element forms a carbide, which are dispersed in the crystal or grain boundaries of the steel matrix, hindering the slip of dislocations during the deformation process and the migration of grain boundaries. These are all beneficial to increase the strength and ductility of the steel. Secondly, the grain size test results show that the 25CrMnB steel has a finer microstructure. Refined grains can also significantly increase the strength, ductility and toughness of steel. Finally, during the tempering process, the Cr element slows down the diffusion rate of Fe and C atoms, making the martensite structure difficult to decompose, thereby improving the tempering stability of the steel. Therefore, under the same tempering process, steels with high Cr content can obtain better strength and hardness.

Based on the above analysis, under the same heat treatment process, 25CrMnB can obtain more excellent hardness, strength and toughness than that of 25MnB. These are consistent with our test analysis results.

3.3. Effect of Cr element on microstructure and mechanical properties of steel

Steel for construction machinery track shoes is generally required to have high wear resistance and good overall mechanical properties. Therefore, there is a high requirement for the hardenability and grain size of the steel for track shoes. Due to the high carbon content of the 40Mn2Si and 35MnTiB track shoes, the track shoes are prone to fine cracks after quenching. This causes the track shoes to be prone to breakage during usage. In recent years, low carbon steels with Mn and B as main alloying elements have become the main steels for track shoes.

The main effect of B on steel is to increase hardenability. Even if only a small amount of B (0.0005% to 0.003%) is added, it can be significantly improved. During the cooling process of the B-containing steel, it is inevitable that the B phase precipitates along the grain boundary, leading to the reduction of hardenability of the steel, which is the source of "boron brittleness". Although B has a low solubility in α-Fe and γ-Fe, the solubility increases with heating temperature. Therefore, in the quenching treatment, the austenitizing temperature of the B-containing steel should be increased as much as possible in order to obtain more solid solution B, ensuring the hardenability of the steel and reducing or even eliminating the "boron brittle" caused by the "phase B" [5]. However, excessive austenitizing temperature causes coarse austenite grains. Adding appropriate Cr element to B-containing steel can reduce the grain growth during austenitization and obtain fine austenite grains, reduce the heat treatment deformation, increase the resistance to crack propagation and the strength and toughness of the steel.

The Mn element in the steel can reduce the Martssite transformation temperature Ms point, thereby increasing the amount of retained austenite in the quenched structure. In order to stabilize the size of the track shoe and prevent deformation, a higher temperature should be selected to ensure the decomposition and transformation of the retained austenite in the tempering treatment. On the one hand, excessive tempering temperatures can reduce the hardness and strength of the track shoes. On the other hand, tempering temperatures will lead to temper brittleness. Therefore, the tempering temperature is generally selected to be above 200°C. The addition of Cr element is beneficial to stabilize the hardness of the steel after tempering, but it is not conducive to temper brittleness. Studies have shown that [6], when tempered in the interval of 250°C ∼ 350°C, 25CrMnB steel shows a toughness deterioration zone. In summary, the tempering temperature range of low carbon MnB steel for track shoes should be controlled within the range of 200°C ∼ 250°C.

In addition to increasing the strength and toughness of the steel, Cr element can significantly

| Sample | KV/ J | -40°C | Rm/ MPa | Rp/2/ MPa | A/% |
|--------|-------|-------|---------|-----------|-----|
| 25MnB  | 69.4  | 42.1  | 1533    | 1417      | 11.5|
| 25CrMnB| 77.8  | 53.7  | 1578    | 1440      | 11.5|

Table 3. Results of Mechanical properties.
improve the hardenability of low-carbon low-alloy steel [7]. Deng studied the hardenability of track shoes and found that [8], for the low carbon MnB series track shoes, when other elements in the steel content were the same, and reported that the addition of Cr could effectively improve the steel hardenability. At Cr>0.20%, the distance, at which the hardness value was sharply dropped, can be delayed until J13.0.

4. Conclusion

- The Cr element addition refined the microstructure of the low-carbon MnB steel used in track shoes. Compared with 25MnB steel, the grain-size number of the plate portion of the 25CrMnB track shoe was refined from 8.5 to 9.5.
- The addition of Cr element improved the hardness, strength, and toughness of low-carbon MnB steel used in track shoes. The impact toughness of 25CrMnB steel at room temperature was by 12.1% higher than that of 25MnB steel. The impact toughness of 25CrMnB steel at −40°C was higher by 27.6% than that of 25MnB steel.
- After a proper heat treatment, both 25MnB and 25CrMnB steels could meet the mechanical properties’ requirements for track shoes’ steels. 25CrMnB steel is recommended for track shoes with large size, poor working conditions, and high load-bearing requirements.

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