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Analysis of the Microstructure and Properties of 33MnCrB5 Steel for High-speed Plows at Different Quenching Temperatures

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Abstract

In order to investigate the differences in the microstructure and properties of 33MnCrB5 steel for high-speed plows after quenching. In this study, a heat treatment process with different quenching temperatures was applied to 33MnCrB5 steel, and the differences in microstructure and mechanical properties of 33MnCrB5 steel under this process were investigated. The results show that the microstructure of 33MnCrB5 steel in the original hot-rolled state mainly consists of a banded microstructure with alternating distribution of ferrite and pearlite. Different from the hot-rolled state 3MnCrB5 steel, the quenched-tempered 33MnCrB5 steel is mainly composed of small and uniformly distributed slate martensite, with an average grain size distribution in the range of 6.6 μm~7.0 μm, which is significantly lower than that of the original hot-rolled state 33MnCrB5 steel (13.26 μm and 13.29 μm). The results of mechanical property tests showed that when the quenching temperature was in the range of 820 ℃ to 880 ℃, the Rockwell hardness of 33MnCrB5 steel is not much different, and its elongation gradually decreased. The yield strength and tensile strength do not change much, and when the quenching temperature reaches 910 ℃, the yield strength and tensile strength decrease significantly. When the quenching temperature is 850 ℃, the yield strength and tensile strength of 33MnCrB5 steel are the highest, which are 1555 MPa and 2001 MPa, respectively. The above research results are expected to provide a reference for the optimization of the heat treatment process of 33MnCrB5 steel used in high-speed plows.

Keywords

High-speed Plough; 33mncrb5 Steel; Quenching; Entrepreneurial Microstructure.

1. Introduction

According to the calculation, when the speed of high-speed plough reaches more than 10 km/h, the economic benefit of cultivated land operation can be maximized [1,2]. Therefore, high-speed plow has been widely used in large-scale cultivation operations. As the core soil touching parts of high-speed plows that mainly play the role of soil crushing and soil turning, the plow shovel tip, plow shovel and grill and other parts are mainly subjected to high-speed impacts and intense friction from the soil, gravel and root mass in the service process, and the form of failure is dominated by abrasive wear and accompanied by impact fracture failure [3-5]. According to incomplete statistics, in the common failure cases of agricultural machinery, wear as a form of failure accounted for more than 80% of the cases [6], and the failure caused by the wear and failure of the earth-touching parts of the plough body accounted for more than 50% [4].

The strength and wear resistance of the material are important factors affecting the speed of high-speed ploughing operation. In the early days, domestic and foreign high-speed plow steel with 65Mn steel, but 65Mn steel plastic toughness, wear resistance is relatively poor, there is overheating sensitivity, prone to quenching cracks, tempering brittleness, as well as cold deformation of the plasticity of the low and other shortcomings [7]. It has been found that 65Mn hot rolled steel plate has banded segregation, uneven structure after heat treatment, which is easy to cause uneven hardness after quenching [8], and it is easy to produce soft spot defects [7]. In the actual production process, decarburization is very easy to occur. After quenching and tempering, a good heat treatment structure is not obtained, which not only affects the wear resistance, but also may cause uneven deformation and even surface cracks [10]. During the working process of the high-speed plow, the plowshare will be subject to soil particles, plant roots and stems, gravel and brick debris impact and wear, easily lead to the plowshare pit or even cause the collapse of the plowshare edge; poor working conditions require higher hardness and wear resistance, but also have a certain impact resistance and high strength. Obviously, the mechanical properties of 65Mn steel has been unable to meet the performance requirements of high-speed plow. In the past 10 years, the high-speed plow manufacturing enterprises represented by Germany Leiken one after another 65Mn steel to replace the boron steel represented by 33MnCrB5. The existing 33MnCrB5 steel still has the problems of low hardness after heat treatment and insufficient matching of strength and toughness, which will lead to a reduction in the service life of high-speed plows.

Therefore, this study takes 33MnCrB5 steel as the research object, and analyzes and discusses the microstructure characterization and basic mechanical properties test results of 33MnCrB5 steel after quenching + tempering treatment and original 33MnCrB5 steel, hoping to provide reference for the improvement of subsequent heat treatment process of 33MnCrB5 steel for high-speed plough.

2. Experimental Procedure

The test material is a plough tip blank based on 33MnCrB5 steel provided by Zhengzhou Longfeng Agricultural Machinery Equipment Manufacturing Co., Ltd. The chemical composition of 33MnCrB5 plough tip substrate was tested by SPECTRO direct reading spectrometer. The spark discharge power of the instrument was 3 kW and the energy resolution was 125 mW. The test results are shown in Table 1:

Table 1. Chemical composition of 33MnCrB5 steel for plow tips (% mass fraction)

Composition	C	Si	Mn	Cr	Ti	Al	Ni	B	Fe
33MnCrB5 steel	0.338	0.275	1.23	0.593	0.048	0.007	0.090	0.0038	Bal.

The chemical composition data of 33MnCrB5 steel in Table 1 are imported into Jmatpro software to simulate the CCT curve of 33MnCrB5 steel. The purpose is to obtain the critical phase transition temperature of 33MnCrB5 steel and provide a basis for the subsequent formulation of heat treatment process. It can be seen that the martensitic transformation starting temperature Ms of 33MnCrB5 steel is 340.6 °C, and the martensitic transformation termination temperature Mf is 224.4 °C. Andrews [11] searched the data of Britain, Germany, France, the United States and other countries. Through the regression analysis of a large number of test data, the empirical formula for calculating Ac1 and Ac3 temperature according to the chemical composition of steel was obtained:

$$Ac1(°C)=723 - 10.7Mn - 13.9Ni + 29Si + 16.9Cr + 290As + 6.38W \tag{1}$$

$$Ac3(°C)=910 - 203C1/2 - 15.2Ni + 44.7Si + 104V + 31.5Mo + 13.1W \tag{2}$$

The element symbols in the formula represent its content (%.mass fraction of the same below), the applicable steel composition range: ≤0.6C, ≤4.9Mn, ≤5Cr, ≤5Ni, ≤5.4Mo. Based on empirical formulas (1) and (2) calculations of the approximate beginning of the austenitization temperature Ac1 = 726.6 °C, the complete austenitization temperature Ac3 = 802.9 °C.

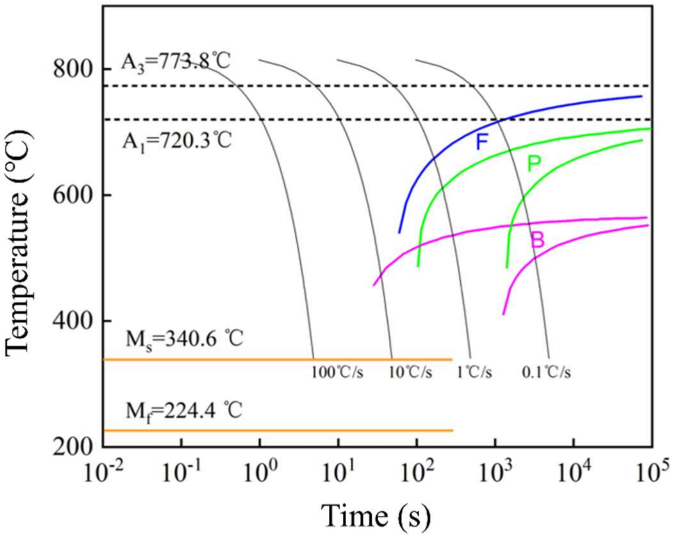

Fig. 1 Continuous cooling transformation (CCT) curve of 33MnCrB5 steel

In order to study the effects of different quenching temperatures on the microstructure and mechanical properties of 33MnCrB5 steel in the quenching-tempering (QT) process. A number of long strip specimens with specifications of 80×20×12 mm were cut from 33MnCrB5 hot rolled sheet along the line of rolling direction and coated with antioxidant paint to alleviate the decarburization phenomenon of the heat treatment process. The quenching austenitization temperatures in the QT heat treatment process were set to 820 °C, 850 °C, 880 °C and 910 °C, respectively, and all of them were water-cooled to room temperature after holding for 0.5 h. Then the specimens quenched at different temperatures were uniformly tempered at 180 °C, and all of them were air-cooled to room temperature after holding for 2.0 h. The quenched specimens were then tempered to room temperature at 180 °C. The uniaxial tensile test was carried out on Instron-8801 universal testing machine by using a plate-like tensile specimen with a pitch of 25 mm and a cross-section of 2 mm×5 mm at a tensile rate of 1 mm/min along the direction of rolling, and the strain was accurately measured by an extensometer with a pitch of 25 mm. The hardness test was carried out on a FR-3E digital Rockwell hardness tester with a loading load of 1470 N. The holding time was 10 s, and each specimen was tested five times to take the average value. The specimens were corroded using 4% nitric acid-alcohol solution, and microstructural characterization of the specimens was carried out using a Leica optical microscope (OM), and finally, the average size of the original austenite grains was counted using ImageJ software.

3. Results and Discussion

3.1 Comparative Analysis of Microstructure

In order to clarify the effect of quenching process on the microstructure of 33MnCrB5 steel, the microstructure analysis of the hot-rolled sheet of 33MnCrB5 steel in the pristine state was carried out, as shown in Fig. 2. From Fig. 2(a) and (d), it can be seen that the pristine state structure mainly consists of pre-eutectic ferrite bands (white) and pearlite bands (black) stacked on top of each other. From Fig. 2(a), it can be seen that a more obvious non-uniform secondary band-like structure was produced along the rolling direction. The reason for the appearance of band-like structure is mainly due to the formation of dendritic crystals of compositional segregation in the solidification process of the ingot, and in the subsequent rolling process along the deformation direction of the extrusion elongation, the formation of carbon and alloying elements of the enriched and depleted band, and in the process of the phase transformation, the failure to decomposition of the austenite by the ferrite is divided into bands, and then the formation of pearlitic dominated by the bands, and thus the formation of ferrite and pearlite each other alternating band-like structure [12]. The band-like structure of ferrite and pearlite alternates with each other [12]. Banding is a serious defect within the steel, and its presence leads to an inhomogeneous microstructure of the steel, which in turn seriously affects the properties of the steel, leading to a reduction in plasticity, impact toughness and strength [13,14]. Fig. 2(b) and (e) for the corresponding original austenite grain boundary statistics OM diagram, it can be seen that the grain of the original state 33MnCrB5 hot rolled sheet presents uneven size (mixed crystal phenomenon) and diffuse distribution of equiaxed grains, using Image J software for grain size statistics, the results are shown in Fig. 2(c) and (f), the average grain size along the rolling direction of 13.26 μm. The average grain size along the rolling direction is 13.26 μm, and the grain size perpendicular to the rolling direction is 13.29 μm. The grain size is too large leading to the low comprehensive mechanical properties of the material, and further grain refinement is needed.

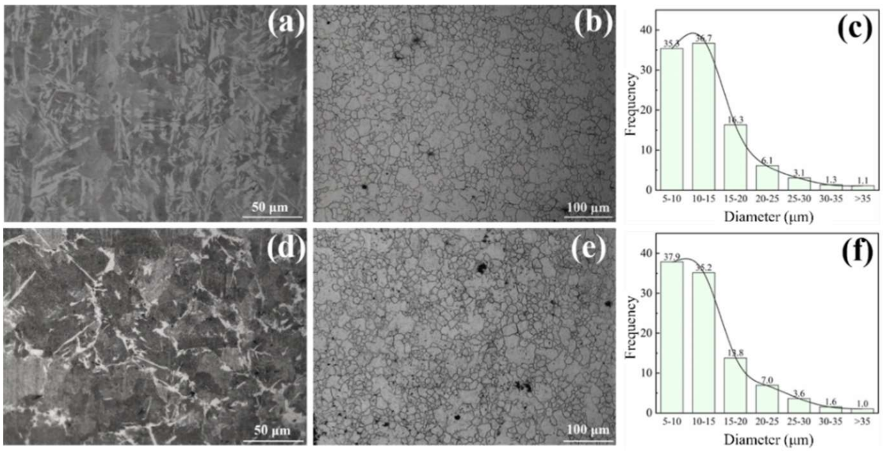

Fig. 2 The OM image of the original microstructure(a,d), the OM image of the original austenite(b,e) and the grain size distribution map(c,f) of 33MnCrB5 steel : (a), (b) and (c) rolling direction; (d), (e) and (f) perpendicular to the rolling direction

The metallographic microstructure of 33MnCrB5 steel in the quenched state after treatment with different quenching temperatures is shown in Fig. 3. The microstructure after treatment with different quenching temperatures is a single slat martensite structure, and the slat martensite has high dislocation density and oversaturated solid solution carbon atoms, which leads to its high hardness and low toughness.

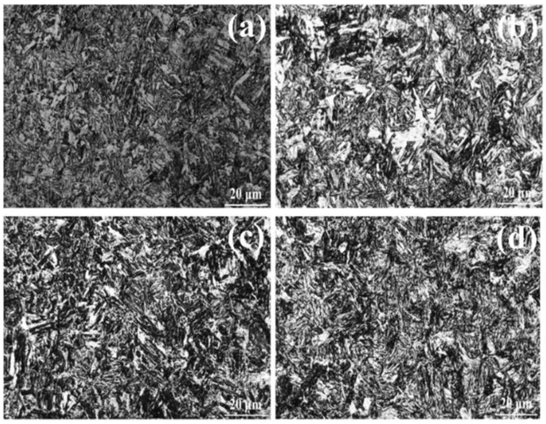

Fig. 3 OM images of 33MnCrB5 steel treated with different quenching temperatures: (a) 820 ℃; (b) 850 ℃; (c) 880 ℃; (d) 910 ℃.

In order to further observe the grain size change of 33MnCrB5 steel in quenched state after different quenching temperature treatments, relevant metallographic observation of the original austenite grains was carried out, and the results are shown in Fig. 4. Compared with the original state 33MnCrB5 steel original austenite grain, after different quenching temperature treatment, the grain is obviously refined and uniformly distributed. The fine primary austenite grains not only increase the nucleation rate of martensite but also reduce its growth space. In order to visualize the size of grain size under different quenching temperatures, Image J software was used to carry out grain size statistics, and the results are shown in Fig. 5, which shows that the proportion of proto austenite grains with sizes ranging from 5 to 10 μm in 33MnCrB5 steel does not change significantly with the increase of quenching temperature. The average grain size is 6.6 μm when the quenching temperature is 820 ℃, 7.0 μm when the quenching temperature is 850 ℃, 6.7 μm when the quenching temperature is 880 ℃, 6.9 μm when the quenching temperature is 910 ℃, and there is no great difference in the average grain size at different quenching temperatures.

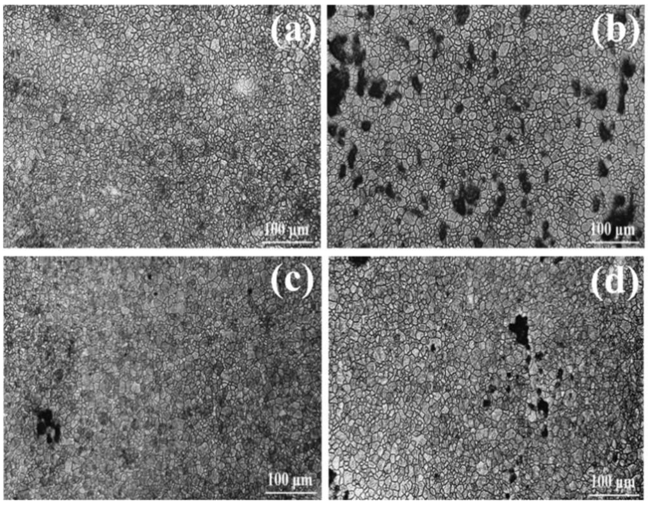

Fig. 4 OM image of the original austenite grain of 33MnCrB5 steel after different quenching temperatures: (a) 820 ℃; (b) 850 ℃; (c) 880 ℃; (d) 910 ℃.

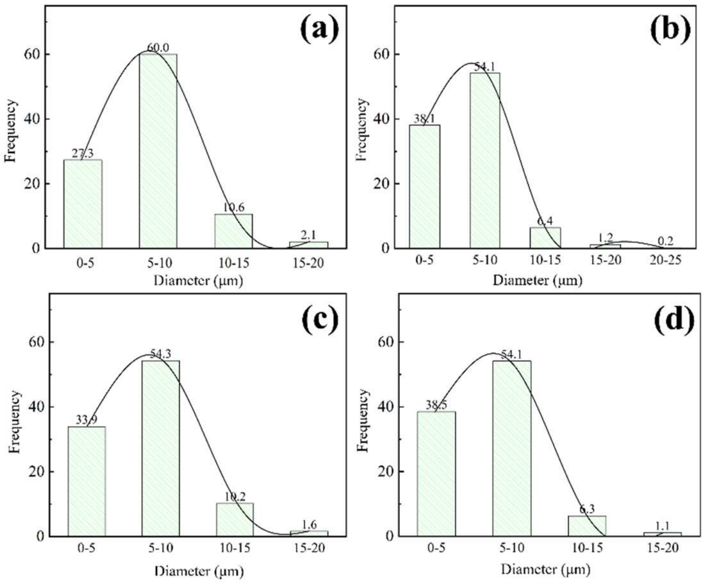

Fig. 5 Grain size distribution statistics of 33MnCrB5 steel after different quenching temperatures: (a) 820 ℃; (b) 850 ℃; (c) 880 ℃; (d) 910 ℃.

3.2 Mechanical Properties Analysis

Fig. 5. and Table 2. show the tensile strength and related mechanical property parameters of 33MnCrB5 steel after treatment with different quenching temperatures. It can be seen that when the quenching temperature is in the range of 820 ℃~880 ℃, the difference between the yield strength and tensile strength is not large, and when the quenching temperature reaches 910 ℃, the yield strength and tensile strength decrease significantly. Among them, when the quenching temperature is 850 ℃, the yield strength and tensile strength of 33MnCrB5 steel are the highest, which are 1555 MPa and 2001 MPa, respectively. Qualitative analysis of the Hall-Petch relationship [15] shows that grain refining can significantly improve the strength of steel, which is mainly through the reduction of the grain size to improve the area of grain boundaries per unit volume, which leads to the dislocation motion is strongly hindered, thus increasing the strength of the material.

In addition, it can be seen from Table 2 that the Rockwell hardness of 33MnCrB5 steel after different quenching temperatures does not differ much. However, the elongation varies, and the corresponding elongation is 8.5%, 8.3%, 7.8% and 6.1% when the quenching temperatures are 820 ℃, 850 ℃, 880 ℃ and 910 ℃, respectively. It can be seen that the elongation decreases gradually when the quenching temperature is in the range of 820 ℃~910 ℃.

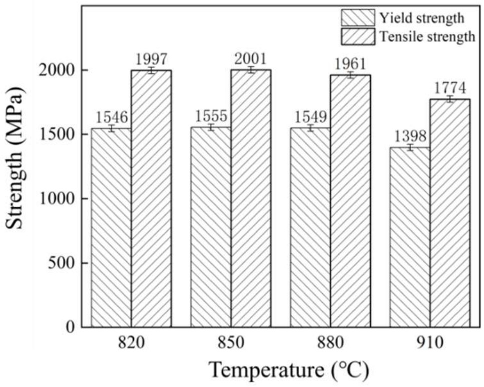

Fig. 6 Tensile strength of 33MnCrB5 steel treated with different quenching temperatures

Table 2. Mechanical properties of 33MnCrB5 steel treated with different quenching temperatures

Temperature /℃	HRC	Elongation /%
820	55	8.5
850	55.5	8.3
880	55.6	7.8
910	54.8	6.1

4. Conclusion

(1) The microstructure of 33MnCrB5 steel for high-speed ploughs after treatment with different quenching temperatures is different from the structure of the first eutectic ferrite band and pearlite band of 33MnCrB5 steel hot rolled sheet in the pristine state, all of which are in a single slat martensite. After quenching-tempering treatment the average grain size was reduced from 13.26 µm and 13.29 µm in the pristine state to within the range of 6.6 µm~7.0 µm.

(2) When the quenching temperature is in the range of 820℃~880℃, the yield strength and tensile strength of 33MnCrB5 steel do not change much, and when the quenching temperature reaches 910℃, the yield strength and tensile strength decrease significantly. When the quenching temperature is

850 ℃, the yield strength and tensile strength of 33MnCrB5 steel are the highest, which are 1555 MPa and 2001 MPa, respectively.

(3) When the quenching temperature in the range of 820 ℃~880 ℃, 33MnCrB5 steel Rockwell hardness difference is not significant, and its elongation gradually decreased.

References

[1] Wang Zhong, Zhou Meiyu. Analysis on the Development and Changes of Plow Tools in China from the Perspective of Ergonomics [J]. Agricultural Archaeology, 2022(1): 140-147.

[2] Liu Yaming, Zheng Xuan, Hu Can, el.. Research Status and Development Trend of High Speed Turnover Plough in Xinjiang [J]. Agricultural Engineering Technology, 2019, 39(36): 55-59.

[3] Wang Guanghong, Wang Cong. Development and research status of wear resistant parts of agricultural machinery [J]. Heilongjiang Science, 2018, 9(24): 66-67.

[4] Su Bin-bin, Xu Yang, Jian Jian-ming. The Actuality of Development and Research of Wear Resistant Part for Agricultural Mechinery [J]. Heat Treatment Technology and Equipment, 2013, 34(5): 53-58.

[5] Li Qingchao, Zheng Xuan, Meng Xiangjin, Liu Jinbao, Zhang Luyun, Liang Yuchao. Application status and improvement suggestions of mouldboard plough in the cornfield of Northern Xinjiang [J]. Journal of Chinese Agricultural Mechanization, 2021, 42(07): 202-208.

[6] Song Yuepeng, Wang Wei, Gao Dongsheng, Li Fade, Xu Lingfeng, Gao Xue. Research status of agricultural machine cutting tools treated by surface engineering technology [J]. Journal of Chinese Agricultural Mechanization, 2018, 39(01): 27-31.

[7] Yu Jiangtao, Li Junwei, Ma Yunhai. Overview of friction and wear and solutions of soil-engaging components of agricultural machinery [C] // The 19th Annual Conference of China Association for Science and Technology-Sub-5 'Intelligent Manufacturing Leading the Revitalization of Northeast Industrial Base' Exchange Seminar Papers. Changchun: China Association for Science and Technology, 2017.

[8] Liao Guiyu. Technical characteristics of new ploughing machine [J]. Agricultural Machinery Using & Maintenance, 2020(1):1.

[9] Liu Jinbao, Zheng Xuan, Meng Xiangjin, Tang Zhihui, Yang Huaijun, Zhang Luyun. Current situation and prospect of research on plough surface [J]. Journal of Chinese Agricultural Mechanization,2021, 42(03):13-21+39.

[10] Chen Lianshen, Cao Hongzi, Tian Yaqiang, Song Jinying. Analysis on Common Plate Defect in 65Mn Steel for Metallurgical Saw Blade [J]. Foundry Technology,2016,37(04):622-625.

[11] Andrews,K.W. Empiricalfomulae for the calculaton of some ransformation temperatures[J].lournal of the lron and Steel Institute,1965,(203):721-727.

[12] Liu yunxu. Reason of Formation, Harmful Effect and Removal of Band Structure in Low Carbon Alloy Steel [J]. Heat Treatment of Metals,2000(12):1-3.

[13] Krauss G .Solidification, Segregation and Banding in Carbon and Alloy Steels[J].Iron & Steel Technology, 2004(3):1.

[14] Khalid;Farooque; ul Haq; Khan. Role of ferrite/pearlite banded structure and segregation on mechanical properties of microalloyed hot rolled steel.[J].Materials Science and Technology.1999(10).

[15] Hall E O.The deformation and ageing of mild steel: III discussion of results [J]. Proceedings of the Physical Society, Section B,1951,64 (9): 747-753.