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Materials

Effects of heat treatment on structures and properties of high speed steel rolls

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Abstract: The effects of quenching temperature, cooling pattern, temper temperature and temper times on the structure and properties of high speed steel (HSS) rolls have been investigated. The results show that, when the quenching temperature is lower than 1050°C the hardness of HSS increases with the quenching temperature increasing in oil cooling, but when the quenching temperature exceeds 1100°C the hardness decreases. In the conditions of salt bath cooling and air cooling, the effect of quenching temperature on the hardness is similar to the above law, but the quenching temperature obtaining the highest hardness is higher than that in oil cooling. When the temper temperature below 350°C the hardness of HSS has a little change, when above 475°C the hardness will increase with the temper temperature increasing, and the highest hardness is obtained at 525°C. When the temper temperature continues to increase, the hardness decreases. Twice temper has little effect on the hardness, but three times temper decreases the hardness. HSS in air cooling has lower hardenability, oil cooling can easily produce crackle, and HSS quenching in salt bath has high hardenability and excellent wear resistance.

Key words: high speed steel; roll; quenching; temper; cooling pattern; hardness

1 Introduction

High-carbon high speed steel (HSS) rolls replacing high chromium cast iron rolls are one of the main developing directions of rolls [1-3]. Increasing vanadium content in high-carbon HSS, MC carbide with high hardness increases. It makes the HSS rolls have excellent wear resistance. The service life of HSS rolls is many times longer than that of high chromium cast iron rolls [4,5]. The structure and properties of HSS rolls have direct connection with heat treatment process [6]. The study on HSS rolls just now begins in China. However, the heat treatment of HSS rolls has little study, which restricts their development and application. By investigating the effects of quenching temperature, cooling pattern, temper temperature and temper times on the structure and properties of HSS rolls, the best heat treatment process of HSS rolls has been obtained. As a result, satisfied effects have been obtained in production.

2 Experimental procedure

HSS was melted in a 250 kg-medium frequency furnace. After deoxidized with aluminium at 1620°C, the melt steel was poured off. The composition (mass fraction, %) of HSS is: C, 2.12; V, 5.32; Cr, 4.82; W, 5.25; Mo, 4.94; Co, 1.75; Nb, 2.21 and Ni, 1.12. The sample was cast in water glass sand moulds, casting into a Y-type test block, machining into 15 mm×15 mm×25 mm in a line cutting machine. The heat treatment was done in an RJX-18-13 type resistance furnace, and the measurements of hardness and retained austenite were achieved using an HR-150A type hardnessmeter and an SCAY-1 type austenite measuring device respectively.

3 Results and analysis

3.1 Effects of quenching temperature and cooling pattern on the hardness of HSS

Figure 1 shows the effects of quenching temperature and cooling pattern on the hardness of HSS. In the condition of oil cooling, the hardness increases with the quenching temperature below 1050°C. When exceeding 1100°C, the result is just right opposite. In the conditions of salt bath cooling and air cooling, the effects of quenching temperature on the hardness are similar to oil cooling. However, the quenching temperature obtaining the highest hardness is higher than that in oil cooling.

Not only structure factors but also the contents of saturated carbon and alloy elements in martensite and retained austenite affect the quenching hardness of HSS. When the quenching temperature is low and the

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contents of carbon and alloy elements in high temperature austenite are small, the quenching martensite has low saturated carbon and alloy elements, and the hardness is low. While exceeding 1100°C, high temperature austenite has superabundant carbon and alloy elements. The stability of austenite increases. For the quenching structure has much retained austenite (**figure 2**), the hardness decreases. Quenching between 1050°C and 1100°C, the contents of the saturated carbon and alloy elements in martensite and retained austenite are appropriate, and the hardness peak values are obtained. Because the cooling speeds in salt bath cooling and air cooling are smaller than that in oil cooling, at the same quenching temperature the amount of retained austenite in the quenching structure is smaller than that in oil cooling, and the quenching temperatures obtaining the hardness peak value are higher than that in oil cooling.

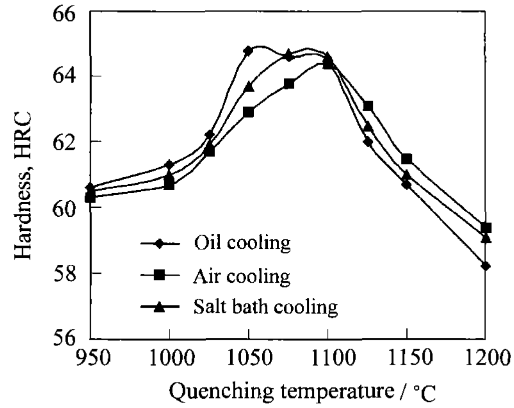

Figure 1 Effect of quenching temperature and cooling pattern on the hardness of HSS.

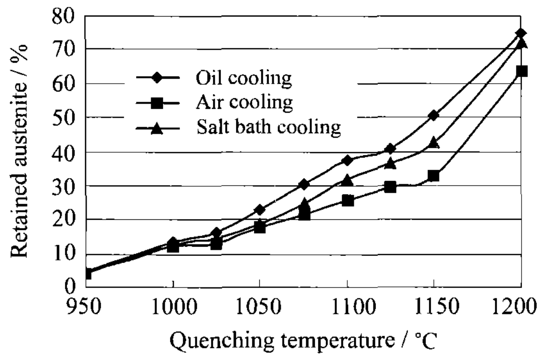

Figure 2 Effect of quenching temperature and cool pattern on retained austenite.

3.2 Hardenability of HSS

Figure 3 is the hardenability of HSS in different cooling conditions. Oil cooling HSS has the best hardenability, followed by salt bath cooling HSS. The air cooling HSS has the lowest hardenability. The difference in hardenability between oil cooling and salt bath cooling HSSs is small. HSS containing many alloy elements has preferable hardenability in oil cooling and salt bath cooling. In the condition of air cooling, because of low cooling speed, the hardness at 30 mm apart from the roll surface is lower than HRC 60. The working layer of the roll is usually larger than 30 mm. The air cooling quenching of HSS cannot meet the requirement. In the oil cooling quenching condition, fast cooling speed leads to large thermal stress that promotes the appearance of crackle. Salt bath cooling HSS has high hardenability, unlikely to produce crackle, and its application in production is feasible.

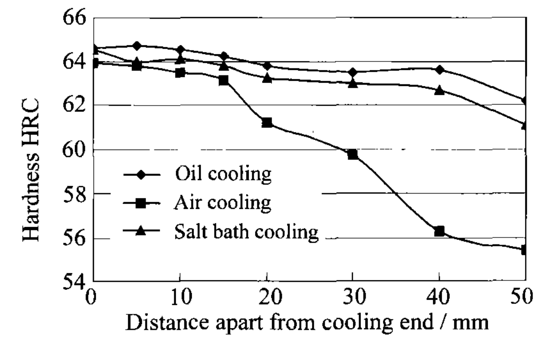

Figure 3 Effect of cooling pattern on the hardenability of HSS.

3.3 Effect of temper treatment on the hardness of HSS

Figure 4 (a) shows the effect of temper temperature on the hardness of HSS. Below 350°C the change of temper temperature has little affect on the hardness. When the temper temperature exceeds 350°C, the hardness decreases. Then it begins to increase at 475°C and reaches the peak value at 525°C. Below 350°C the hardness does not change because the separating amount of carbide in martensite is small and austenite cannot decompose. Tempering at 350-475°C, supersaturated carbon separates out in the form of carbides. However, the amount of carbides is small. Dispersion-hardening does not come into. The carbon content in martensite decreases. All these factors lead to the decrease in hardness. Tempering at 525°C, martensite changes into temper martensite containing many fine alloy carbides, and retained austenite changes into martensite when cooling, which leads to the hardening of steel. As the temper temperature increases more, alloy carbides begin to gather and grow up, resulting in the decrease in hardness.

The sample quenching at 1110°C containing much retained austenite and having much martensite that comes from the transformation of retained austenite during temper-treatment has the best hardened effects. The decrease of hardness is gentlest as the temper temperature exceeds 525°C. The sample quenching at 1050°C has smaller retained austenite. The decrease of hardness is fastest as the temper temperature exceeds 525°C. The difference between the HSS and conventional HSS is that the temper temperature obtaining the highest hardness decreases. The main cause is that the HSS has a lower quenching temperature. The quenching temperature of conventional HSS usually exceeds 1150°C [7]. High temperature austenite containing small carbon and alloy elements has low stability that leads to the quenching structure containing smaller retained austenite. Besides the low stability of retained austenite by temper cooling, it is easy to transform martensite at low temper temperature, and the temper temperature obtaining the highest hardness decreases. After one time temper, the hardness of the HSS reaches the highest value. The hardness has little change after twice temper. After three times temper, the hardness decreases because of the collection and growing up of alloy carbides separating from martensite (figure 4(b)).

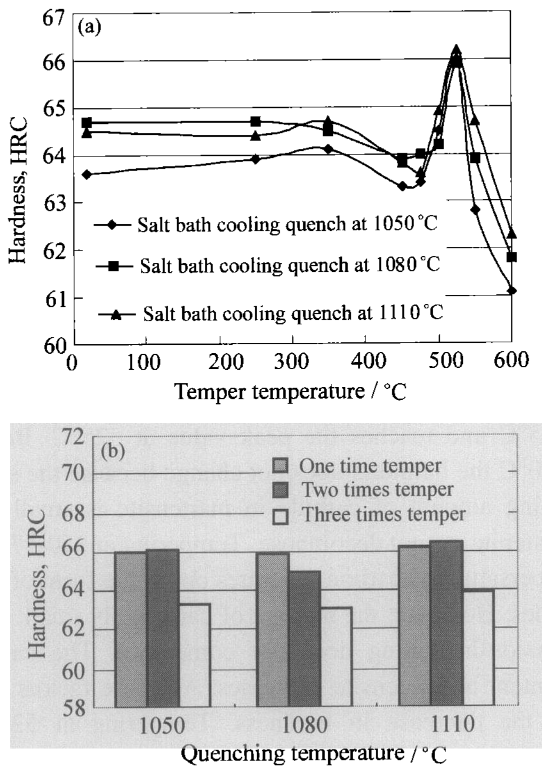

Figure 4 Effect of temper heat treatment on the hardness of HSS: (a) effect of temper temperature on the hardness of HSS; (b) effect of temper times on the hardness of HSS (tempering at 525°C).

3.4 Effect of heat treatment on wear resistance of HSS

Wear tests were done in a high temperature wear test machine, which was improved through an ML-10 wear test machine. **Figure 5** is the diagram of the wear test device, it is made up of mechanical drive part, heating part and temperature controlling part. The size of the wear specimen was ϕ6 mm×25 mm, and the load was 100 N.

The effects of heat treatment on the wear resistance of HSS are shown in **figure 6**. As the heating temperature rises, the wear volume of HSS increases. When the heating temperature is below 600°C the wear volume increases slowly and when the heating temperature excels 600°C the wear volume increases rapidly. The main reasons are that there are a lot of W, Mo, Cr, V *etc.* alloy elements in HSS, and the red hardness of HSS is high. When the temperature reaches 600°C, the hardness still keeps above HRC 60, but the temperature is above 600°C, the hardness descends obviously. So the wear volume of HSS is minor below 600°C and the wear volume increases rapidly above 600°C. In the same temper temperature and temper times, the wear volume of higher quenching temperature HSS is less than that of lower quenching temperature HSS. Moreover, in the condition of the same quenching and temper temperature, the wear volume of twice temper HSS is the smallest, and that of three times temper HSS is the largest.

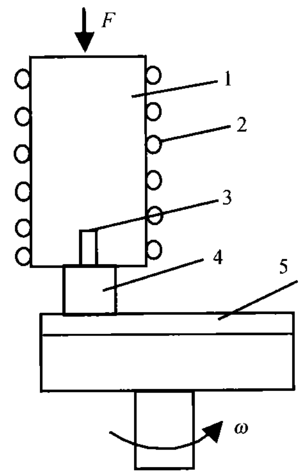

Figure 5 Diagram of the wear test device, 1 — sample holding part; 2 — heating part; 3 — wear sample; 4 — temperature controlling part; 5—antiwear ring.

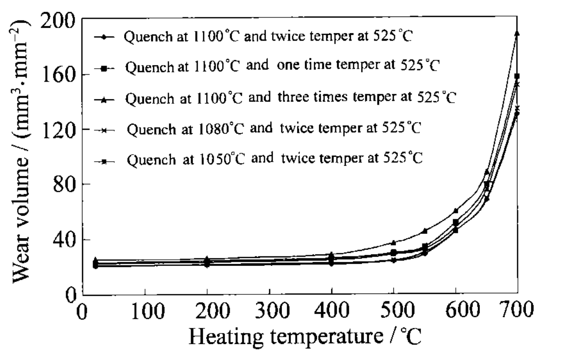

Figure 6 Effects of heat treatment on the wear resistance of HSS.

3.5 Properties and application of HSS

HSS rolls were manufactured in the centrifugal casting method. **Table 1** shows its composition. Its outer diameter is ϕ300 mm, its inner diameter is ϕ140 mm, its length is 100 mm. The annealing treatment process of the HSS rolls is 880-900°C×4 h, furnace cooling. After annealing, their hardness is HRC 28-34, having excellent working ability. After rough working, the HSS rolls begin to quench and temper. According to the above results, the heat treatment of the HSS rolls is 1080-1100°C×3 h salt bath cooling, then 520-530°C×6 h air cooling (two times). **Figure 7** is the structure of the HSS rolls. It has characteristics of fine structure and well-distributed carbides, that are very favorable to increase the wear resistance of the HSS rolls. **Table 2** is the properties of the HSS rolls, compared with those of high chromium cast iron (Hi-Cr) rolls.

Table 1 Composition of the HSS rolls (mass fraction) %

C	Cr	W	Mo	V	Co	Nb	Ni
1.8-2.5	4.0-6.0	4.0-6.0	4.0-6.0	3.0-8.0	1.5-3.0	1.5-3.0	0.8-1.2

Table 2 Properties of the HSS rolls

Roll materials	Hardness, HRC	Red hardness, HRC	Tensile strength / MPa	Impact toughness / ($J\cdot cm^{-2}$)	Fracture toughness / ($MPa\cdot m^{1/2}$)	The hardness at 30 mm apart from the roll surface, HRC
HSS	65.3	62.6	944	12.7	32.9	63.6
Hi-Cr	63.8	57.9	863	8.5	30.6	60.2

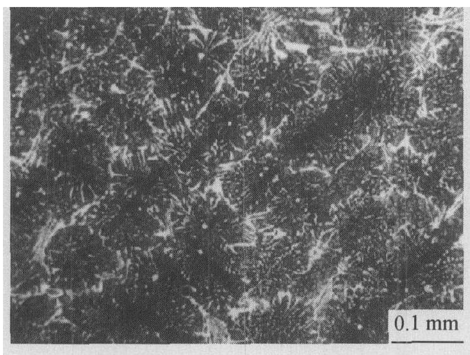

Figure 7 Heat treatment structure of the HSS rolls.

When the HSS rolls were applied to pre-finish rolling stands in high speed wire rod mills, the rolled material was carbon constructional steel. The rolling speed of pre-finish rolling stands was 35-42 m/s. The results of on-line service investigation indicate that the rolling steel quantity of the HSS rolls was 3214 t/mm, but that of Hi-Cr rolls was only 340 t/mm. The surface of the rolled metal is finished and clean, and the size precision is very high. The application of HSS rolls can improve the working rate of rolling mills, decrease the labor intensity of workers, reduce the production cost of rolled metal and obtain good economic benefits.

4 Conclusions

(1) In the condition of oil cooling and the temperature below 1050°C, the hardness increases with quenching temperature. When exceeding 1100°C, the result is just opposite. In the conditions of salt bath cooling and air cooling, the effects of quenching temperature on the hardness are similar to those in oil cooling. However, the quenching temperature obtaining the highest hardness is higher than that in oil cooling.

(2) In the condition of salt bath cooling and the temperature below 350°C, the change of temper temperature does not affect the hardness of HSS. When exceeding 350°C, the hardness of HSS decreases. It begins to increase at 475°C and reaches the peak value at 525°C.

(3) The difference between high-carbon HSS and conventional HSS is that the temper temperature obtaining the highest hardness decreases. After one time temper, the hardness of high-carbon HSS reaches the highest value. The hardness has little change after twice temper. After three times temper, the hardness decreases because of the collection and growing up of alloy carbides separating from martensite.

(4) In the same temper temperature and temper times, the wear volume of higher quenching temperature HSS is less than that of lower quenching temperature HSS. In the condition of the same quenching and temper temperature, the wear volume of twice temper HSS is the smallest, and that of three times temper HSS is the largest.

(5) The mechanical properties of HSS are more excellent than those of Hi-Cr HSS. When HSS rolls applied to pre-finish rolling stands in high speed wire rod mills, their service life is 8.5 times longer than that of Hi-Cr rolls. In addition, the surface of rolled metal is finished and clean, and the size precision is very high.

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