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Study on Rolling Process and Fatigue Performance of Hot Rolled High Strength Steel for Wheel

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In this paper, the effects of rolling parameters on the mechanical properties of the experimental steels are analyzed by means of thermal simulation, controlling rolling and cold control in the laboratory. As the wheel's work under random loads, the failure modes of the wheels are mainly caused by the damages of strength and fatigue, in which more than 80% are caused by fatigue damage. So that the life of wheel's fatigue is the most important performance index of the wheel. At present, the domestic research on the fatigue performance is automobile wheel steel, especially for different organizations of automotive wheels with high strength steel fatigue performance differences are still relatively less. On the basis of hot rolling experiment, the fatigue test of high strength steel for different wheels is carried out by using high frequency fatigue testing machine. The fatigue performance of different high strength steel is studied by drawing the fatigue life curve. The main conclusion is as the following. The final cooling temperature is 630°C, the Rm increases from 766°C to 820°C, Rm increases from 720MPa to 748MPa, Rp0.2 increases from 463MPa to 525MPa, and the elongation reaches 20.0%. The change is not obvious. When the finishing temperature is 870°C, Rm is lower, 655MPa, Rp0.2 is 415MPa, but the elongation that is 26.98% is higher.

1. Introduction

In order to meet the needs of weight-reduction, saving energy, environmental protection and safety, high strength steel with low carbon gets more and more attentions by domestic and foreign scholars (Jha, et al., 2013). High strength steel that has low carbon with its good strength and ductility matching, high initial work hardening rate, high impact energy absorption capacity and low yield ratio and other advantages gradually becomes an important material for automobile manufacturing (Kim, et al., 2014). Among them, hot-rolled low-carbon high-strength steel was obtained through the control rolling, cold control (Shin, et al., 2016). The production process is simple, and it is easy to mass production, compared with hot-rolled cold-rolled steel, it is more practical and employs low cost (Hu, et al., 2014).

With the development of modern machinery, the wheels are required to have a high cycle of cyclic load and never breaks (Zeng, et al., 2016). In comparison with the static load damage, the dynamic damage begins from the local and gradually accumulates until the fatigue damage occurs (Makino, et al., 2014). The wheels are to be operated under dynamic load or subjected to long-term periodic alternating stresses (Wang, et al., 2017). In addition, it also leads to the importance and necessity of high strength steel fatigue research (Daamen, et al., 2014). The life of the wheel fatigue is the most important performance index of the wheel, which is determined by the design of wheel's structure, manufacturing process and the use of materials (Majumdar, et al., 2017). At present, the research on the fatigue performance of automobile wheel for automobile wheel, especially the analysis of the fatigue performance differences of high strength steel for automobile wheel of different organizations is still relatively less (Zheng, et al., 2015). The mechanical properties of high strength steels that had low carbon with silicon (Si), manganese (Mn), chromium (Cr) and other alloy systems under different technological conditions were obtained by different hot rolling process (Kahziz, et al., 2016). In order to study the effects of the performance of experimental steel that was influenced by the parameters of different hot rolling process. The fatigue properties of different experimental steels were determined by fatigue test, and the fatigue limit was calculated when the cyclic stress ratio r was -1 and the number of cycles was 1×107.

At present, the main materials for the manufacture of wheels are steel and aluminium (Mirza and Chen, 2014). In the passenger car wheel market, at least 60% of the share is occupied by aluminum alloy wheels (Xu, et al., 2016). The characteristics of steel and the manufacturing process determine that the steel wheels are difficult to achieve as diverse as the cast aluminum wheels (Qin, et al., 2017). The advantage of steel wheels is its low cost and reliability (Guan and Yu, 2013). In recent years, steel makers and steelmakers around the world have stepped up their research into new materials, structures and processes (Lipiński and Wach, 2015). On the premise of guaranteeing the strength, the weight reduction of the steel wheel and the appearance of the steel wheel are well done (Mayer, et al., 2015). The steel wheel has the capability of comprehensively contend with the aluminum wheel (Chatterjee, 2017). The steel wheel will recapture part of the lost market (Chen, et al., 2017). In China, steel wheels still occupy the mainstream, and most of the domestic cars still use steel wheels (Bian, et al., 2015).

2. Experimental Materials and Methods

The continuous cooling curve of steel can help readers understand the phase transition process of austenite during cooling directly and clearly (Schmiedt, et al., 2017). It is one of the important basis for setting rolling process parameters (Torres, et al., 2016). The establishment of static CCT and dynamic CCT curves of steel and the study of thermal transformation, phase transformation behavior and micro-structure are necessary for the formulation of rolling process (Lin, et al., 2013). By controlling the amount of deformation, the temperature of deformation and the cooling rate after rolling, the micro-structure of hot rolled high strength steel and its strong plasticity can be improved (Shabani and Mazahery, 2014). In this chapter, the continuous cooling transformation curve of the experimental steel is measured by means of a laboratory phase change instrument and a thermodynamic simulator. The influence of cooling rate and deformation on the phase transformation behavior and phase transformation structure is analyzed, which provides a theoretical basis for the formulation of reasonable rolling process.

2.1 Experimental Materials and Equipment

The hot rolling test of high strength steel with low carbon was carried out on φ450mm rolling mill with maximum rolling force of 4000kN.And the speed of rolling was 0-1.5m/s, the main motor power was 400kW and the heating equipment that was electric heating box furnace was 50 kW. The chemical composition of experimental steel was in table 1, and the sizes of the experimental steel are 30mm*30mm*10mm.

Table 1: Chemical composition of the tested steel (masss, %)

C	Si	Mn	Cr	P	S	N	O
0.12	0.52	1.40	0.51	0.08	0.001	0.005	0.003

2.2 Research Methods

The first was hot rolling process of experimental steel program. The rolling weight reduction of the test steel was as follows: 30 mm→20 mm→12 mm→7.2 mm→4.3 mm→3.8 mm. The first two passages were rolled in the austenite recrystallization zone, another three passes were rolled in the austenite no recrystallization zone. The specific rolling schedule was shown in figure 1.

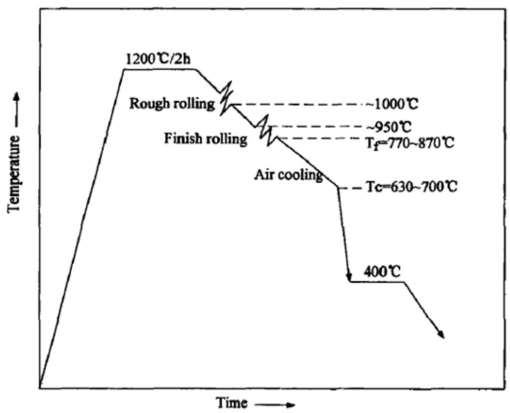

Figure 1: Hot rolling test process

As it was shown in figure 1, the finishing temperature of the test steel in the recrystallization zone was about 1000°C, the start temperature the recrystallization was about 950°C, and the finishing temperature of the test steel in the non-recrystallization zone was set at 770-870°C. After finishing, the test steel was cooled to 630-700°C, the experimental steel ferrite phase change occurred. And then put it into the salt bath furnace isothermal, and the temperature of salt bath furnace was set to 400°C.

The second was mechanical performance test. The mechanical properties of the test steel were measured by tensile test on the CMT5105-SANS through microcomputer control electronic universal testing machine. And the thickness was 3 mm, the loading speed was 3 mm/min, and the gauge was A40.

2.3 Experimental method of fatigue performance study

The fatigue test of the tensile test was carried out according to the national standard GB3075-82 (metal axial fatigue test method) with cyclic stress ratio r of -1 (Charpentier, 2015).

In this paper, the fatigue experiments used conventional fatigue test method, and only one sample was tested at each stress level. When measured the fatigue limit, it was required that at least two specimens reached the circulation base and without damage in order to ensure the reliability of the experimental results. The S-N curve was plotted according to the life of fatigue and the conditional fatigue limit at each stress level (Sarigecili, et al., 2014).

3. Results of the study

3.1 The actual process parameters and mechanical properties of different hot rolling process

The prerequisite of obtaining excellent properties of hot-rolled low-carbon high-strength steel was to strictly control the process of controlling rolling and controlling cooling (Gui et al., 2016). In this paper, the experimental steel with different organizational properties was obtained through making different hot-rolling process parameters. The finishing rolling temperature were 766°C, 820°C, 870°C, and the final cooling temperature were respectively set to 630°C, 660°C, and 700°C. And the isothermal temperature of the salt bath was set to 400°C. The actual hot rolling process parameters were shown in table 2.

Table 2: Practical processing parameters of hot rolling experiments of the tested steel

Process	Rough Rolling/°C		Fine Rolling/°C		Final cooling Temperature /°C	Salt Bath Temperature /°C	Austempering Time of Salt Bath/min
	Start Rolling	Finish Rolling	Start Rolling	Finish Rolling			
II-1	1060	1050	950	766	628	400	60
II-2	1060	1050	950	820	631	400	60
II-3	1060	1050	950	870	630	400	60
II-4	1060	1050	950	770	660	400	60
II-5	1060	1050	950	775	696	400	60
II-6	1060	1050	950	770	630	400	5
II-7	1060	1050	950	770	630	400	15
II-8	1060	1050	950	770	630	400	30

The mechanical properties of the experimental steel were shown in table 3.

(1) Mechanical properties of experimental steels at different finishing temperatures

The finishing temperatures of the processes II-1, II-2 and II-3 were 766°C, 820°C and 870°C, respectively.

The mechanical properties of the test steels at the finish rolling temperature of 766°C were determined by tensile test, which the tensile strength Rp0.2 was 463MPa, the tensile strength Rm was 720MPa, the elongation δ was 19.83%, the yield ratio Rp0.2/Rm was 0.64, and strong plasticity was 14278 (MPa.%). When the finish rolling temperature were at 820°C, the mechanical properties were as the following, the Rp0.2 was 525MPa, Rm was 748MPa, δ was 20.0%, Rp0.2/Rm was 0.7, and the strength and ductility was 14960, the strength was the highest. When the finish rolling temperature was 870°C, the strength was lower, and the Rp0.2 was 415MPa, Rm was 655MPa, and the elongation of 26.98% was better. So, the strong plasticity was the highest to reach 17671 (MPa.%). The effect of finish rolling temperature on mechanical properties was shown in figure 2.

Table 3: Mechanical properties of different processes of experimental steel

Process	Yield Strength/MPa	Tensile Strength/ MPa	Yield Ratio	Elongation/%	Strength and Ductility/ MPa%
II-1	463	720	0.64	19.83	14278
II-2	525	748	0.70	20.00	14960
II-3	415	655	0.63	26.98	17672
II-4	513	790	0.65	19.28	15231
II-5	478	780	0.61	19.03	14843
II-6	565	753	0.75	16.93	12748
II-7	513	713	0.72	19.15	13654
II-8	565	770	0.73	16.00	12320

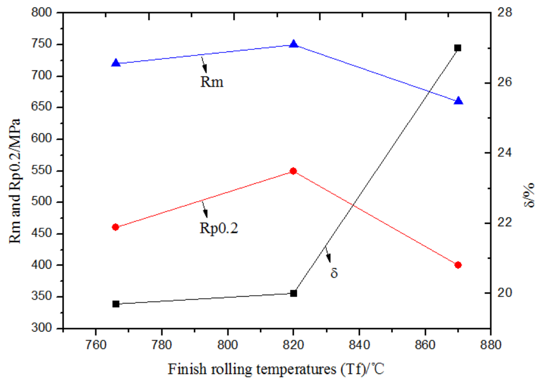

Figure 2: Effect of finishing temperature on mechanical properties

(2) Mechanical properties of experimental steels at different final cooling temperatures

The final rolling temperature of process II-1, II-4 and II-5 was 770°C, and the final cooling temperature were 628°C, 660°C and 696°C respectively.

According the experiment, the mechanical properties of the process II-1 were as the following. The Rp0.2 was 463MPa, Rm was 720MPa, δ was 19.83%, Rp0.2/Rm was 0.64, and the strong plasticity was 14278 (MPa %). The mechanical properties of the composites II-4 were as the following. The Rp0.2 was 513MPa, Rm was 790MPa, δ was 19.28%, Rp0.2/Rm was 0.65 and the strong plasticity was 15231.2 (MPa). The mechanical properties of the composites II-5 were as the following. The Rp0.2 was 478 MPa, Rm was 780 MPa, δ was 19.03%, Rp0.2/Rm was 0.61, and strong plasticity of was 14843 (MPa.%). The effect of the final cooling temperature on the mechanical properties of the test steel was shown in Finger 3. The strength of process II-4 and process II-5 were higher than that of process II-1. And the elongation decreased and the strong plasticity increased. The strong plasticity of process II-4 was the highest, and the comprehensive mechanical properties were the best.

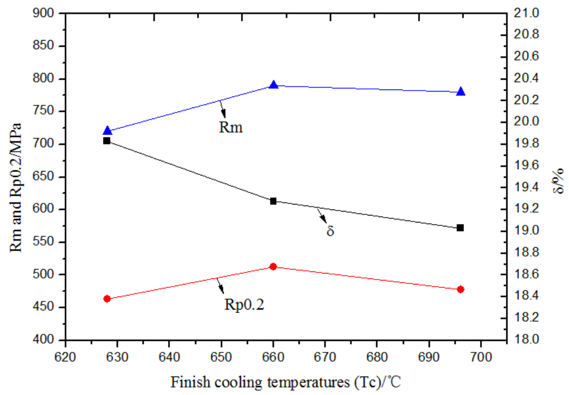

Figure 3: Effect of final cooling temperature on mechanical properties

4. Conclusion

In this paper, low-carbon silicon-manganese-based chromium and phosphorus high-strength steel are the objects of this study. The influences of the rolling process parameters on the mechanical properties of experimental steel are analysed through the laboratory low-carbon high-strength steel hot rolling experiment. On the basis of the experiment of hot-rolled high-strength steel, the fatigue test of high strength steel for wheel of different organizations was carried out by using high-frequency fatigue testing machine. The fatigue performance of different strength steel was studied by drawing the fatigue life curve.

The main conclusion is as the following. The final cooling temperature is 630°C, when the finishing temperature rises from 766°C to 820°C, Rm increases from 720MPa to 748MPa, Rp0.2 increases from 463MPa to 525MPa, and the elongation reaches 20.0%. When the finishing temperature is 870°C, Rm is lower, 655MPa, Rp0.2 is 415MPa, but the elongation is higher about 26.98%.

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