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Dynamic Continuous Cooling of Ti-IF Steel for Chemical Dangerous Goods Transporter Based on Internet of Things Technology

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Instruments such as Gleeble-3500 thermal simulated test machine, optical microscope and Blowell hardness gauge were adopted in the experiment to conduct an intensive research on the dynamic continuous cooling transformation (CCT) law, the microstructure characteristics and the hardness changing law of Ti-IF steel, to measure the dynamic CCT curve and to analyze the influence of the pass deformation in different temperature ranges on the cooling transformation of Ti-IF steel, theoretically supporting the practical development of the rolling technology.

1. Introduction

As the Chinese economy enters a new normal, new requirements on the quality of deep drawing steel sheet have been proposed by the automobile manufacturing industry that is also involved in a wave of adjustment and transformation (Wang, 2016). As a typical example of third-generation deep drawing steel sheet, Ti-IF steel has been widely applied in the production of complex metal sheets for the automobile industry. Moreover, the controlled rolling and controlled cooling technology that exerts a decisive impact on the ultimate performance of the product in the actual production has become an important approach to fully tap the potential of deep drawing steel on the basis of existing materials with the development of modern rolling technology. Therefore, the transformation law of experimental steel in the process of deformation and cooling should be mastered to prepare reasonable rolling process parameters (Wang et al., 2003; Wang, 2006)
In this experiment, double-pass compression was performed on the Ti-IF steel with the use of Gleeble-3500 thermal simulated test machine, so as to research the microstructure transformation law and the hardness changing law of the experimental steel in different cooling temperatures, to measure the dynamic CCT curve of Ti-IF steel and to analyze the influence of the pass deformation on the phase inversion temperature of Ti-IF steel, theoretically supporting the formulation of the rolling technology of Ti-IF steel.

2. Experimental Material

Experimental materials were taken from continuous casting of Ti-IF steel produced by a steel mill, whose chemical compositions were shown in Table 1.

Table1: Chemical composition of Ti-IF steel (mass fraction, %)

C	Ti	S	Mn	Si	N
0.0020	0.060	0.0050	0.20	0.008	0.0010

3. Experimental Procedure

3.1 Dynamic Thermal Simulation

Double-pass rolling manufacturing was adopted in the dynamic thermal simulation experiment. The concrete plan is shown in Figure 1. A sample taken along the thickness direction was cut into test specimens at the size

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of Φ 10 × 20 mm. Test specimens were heated up to 1260 ° C at the speed of 10 ° C·s-1 before maintaining for 5 min; after that, those specimens were deformed for the first time with the reduction rate of 45% at the deformed speed of 5s-1 after cooling to 1080 °C at the rate of 10 °C·s-1; and then, the second deformation was conducted with the reduction rate of 35% at the deformed rate of 20s-1. At last, the deformed test specimens were cooled to room temperature at the cooling rate of 0.5, 1, 3, 5, 7, 10, 12, 15 and 20 °C·s-1, respectively.

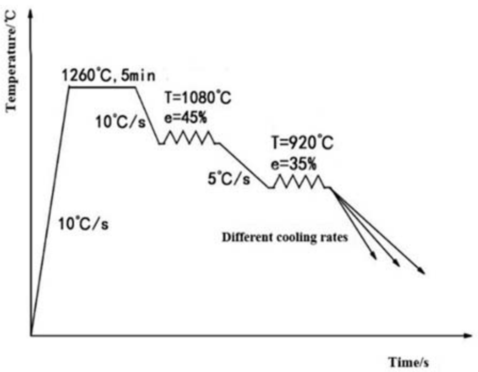


Figure 1: Test process of dynamic continuous cooling transformation

Meanwhile, the microstructure evolutions of different experimental results were observed with the Axiovert-200MAT metallographic microscope. And the hardness of each test specimen was measured for three times with an HBRV (M)-187.5D1 digital Blowell hardness gauge to calculate the average value.

3.2 Static Thermal Simulation

Other sample taken along the thickness direction was cut into test specimens at the size of Φ 6×75 mm. Test specimens were heated up to 1260 ° C at the speed of 10 °C·s-1 and kept maintaining for 5 min and then cooled to 950 °C at a speed of 10 °C·s-1. At last, the deformed test specimens were cooled to room temperature at the cooling rate of 0.5, 1, 3, 5, 7, 10, 12, 15 and 20 °C·s-1, respectively.
The dynamic and static CCT curve were drawn through collecting temperature, swell value and time variation value at different cooling speeds.

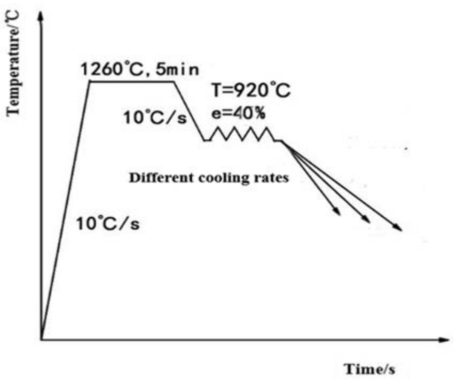
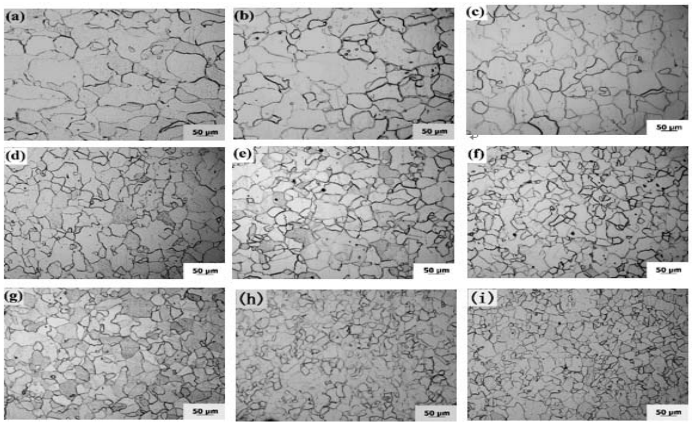


Figure 2: Test process of static continuous cooling transformation

4. Results and Discussion

4.1 Organization Characteristics of Dynamic Transformation

With a carbon content of only 0.002%, the experimental Ti-IF steel is within the range of ultra-low carbon steel. New grains preferentially generate in the austenite grain boundary due to the impact of grain boundary energy and atomic activity and develop gradually under the driving of interface energy. No obvious difference can be observed in the microstructure at different cooling speeds because of low content of C; the microstructure mainly consists of ferrite. A scarce amount of cementite would be precipitated along the ferrite grain boundary if the temperature is reduced below the saturation point of ferrite solubility of carbon (Qi et al., 2003).



(a)0.5°C·s-1; (b)1°C·s-1; (c)3°C·s-1; (d)5°C·s-1; (e)7°C·s-1; (f)10°C·s-1; (g)12°C·s-1; (h)15°C·s-1; (i)20°C·s-1

Figure 3: Microstructures at different cooling rate

Microstructure transforming characteristics of double-pass deformed austenite in the continuous cooling process were shown in Figure 3 and Figure 4. When the cooling rate ranged from 0.5 to 3°C·s-1, there was enough time for diffusing iron carbon atoms and complete recrystallization due to low cooling speed. Therefore, the grain boundary was smooth and polygonal with an average size distribution of about 60μm. Also, the grain was large in different sizes. However, when the cooling speed was increased to the range of 5 to 12 ° C·s-1, the nucleation driving force would be increased due to the enlargement of super-cooling degree. In that case, recrystallized grains that were tiny and not fully developed were presented in the grain boundary and inside the grain with an average size of about 40 μm in refinement. When the cooling speed was in the range of 15 °C·s-1 to 20°C·s-1, grains would be decreased continuously with an average size of about 25 μm. Grain sizes were uniform as a whole, although there were still recrystallized grains not developed completely.
By and large, the grain size was decreased remarkably as the increment of the cooling speed and decreased slowly as the cooling rate reaches up to 12 °C·s-1 or above.

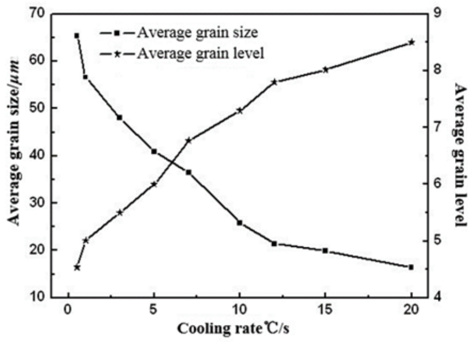


Figure 4: Curve of grain size and cooling rate

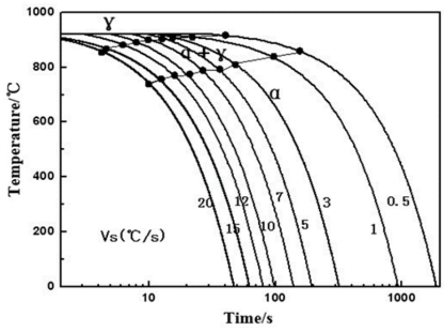


Figure 5: Dynamic CCT curve under double pressure

4.2 Hardness of Dynamic Transformation

And in terms of Ti-IF steel, excessive hardness might result in reducing the deep drawing performance of the finished steel; however, low hardness might lead to burrs on the press products, decreasing product precision (Shi, 2012). Hence, reasonably controlling hardness was an important factor to ensure the quality of steel sheets. Under such circumstance, the hardness of each test specimen at different cooling speeds in the dynamic and continuous cooling transformation were measured through averaging the testing values of repeated measurements. Data collected were shown in Table 2. It could be observed from the table that three measured values were stable as a whole although there were fluctuations in a certain range. The grain size decreases and the hardness value gradually rose along with the improvement of the cooling speed.

For dynamic continuous cooling transformation (CCT), reasons for the increase in hardness were various. Through analysis of the sample microscopic structures under different cooling rates, it could be noticed that, with the increase of cooling rate, the refining capacity of grains increased, the diffusion capacity of carbon nitrides reduced, second-phase particles were relatively fine and diffused and the “pinning effect” was found more significant during the pressure working process, resulting in increased hardness (Yu et al., 2005). Secondly, with the increase of cooling rate, the force driving the occurrence of phase transition also increased and the strengthening effects of ferrite transformation brought about the increase in matrix hardness. In addition, the rolling pass reduction increased the energy stored in the crystal, at relatively large cooling rate, the elastic straining and crystal defects (vacancies and dislocations) generated during thermal deformation could not soften in time, thus weakening the restitution effects, for which there would be rather large distortion energy reserved in the structure and the matrix would be reinforced as well, eventually leading to the increase in hardness. However, due to the external stress produced by the double-pass reduction under the dynamic thermal simulation that promoted the precipitation and coarsening of second-phase particles, the precipitates’ “pinning effect” on the grain boundaries was weakened, which, to a certain extent, would impede the enhancement of the matrix (Cui and Tan, 2007).

Table 2: Brinell hardness of dynamic thermal simulation specimen

Cooling rate /°C·s-1	First data/HB	Second data/HB	Third data/HB	Average/HB
0.5	60.3	61.2	63.2	61.6
1	62.1	61.0	64.4	62.5
3	63.4	64.2	63.5	63.7
5	64.5	65.2	64.6	64.8
7	67.2	66.3	67.9	67.1
10	69.6	68.5	69.1	69.0
12	71.0	70.8	70.3	70.7
15	72.0	74.1	72.9	73.0
20	74.5	75.7	76.4	75.5

4.3 Dynamic CCT Curve

The dynamic CCT curve referred to the deformation-treated characterization curve of the continuous cooling transformation of overcooling austenite of steel, which, in its nature, was a reflection of the transformation points and structural types of steel after deformation under specific cooling conditions. Combined with corresponding microscopic structures and the transformation points located by thermo-dilatometry, the author drew the dynamic CCT curve of Ti-IF steel with double-pass reduction (Graph 4). The starting points and ending points of phase transformation under different cooling rates were shown in Table 3.

Table 3: Temperature of dynamic phase transformation

Cooling rate/°C·s-1	Starting point/°C	Finishing point/°C	Cooling rate/°C·s-1	Starting point/°C	Finishing point/°C
0.5	891	824	10	875	770
1	890	822	12	870	764
3	883	815	15	868	760
5	880	805	20	865	748
7	876	780			

It could be seen from the experiment results that, the structure of Ti-IF steel’s dynamic continuous transformation was relatively simple—without pearlite, bainite or other structures. Under low cooling rates, the temperature for the phase transition from austenite to ferrite was higher and the entire transition process was longer. With the increase of cooling rate, the starting point of phase transition dropped gradually and the transition starting time and ending time shortened; in the meantime, the transition temperature range expanded.

However, from Graph 5 and Table 3, we learned that when the cooling rate rose from 0.5°C·s-1 to 20°C·s-1, the Ar3 point dropped by 26°C from 891°C to 865°C, presenting a rather mild reducing trend in transition temperature. The reason behind lay in the fact that the phase transformation from austenite to ferrite fell within diffusive transformation; therefore, when the cooling rate increased, though the undercooling degree and the nucleation rate increased, the velocity of atom diffusion decreased and the nucleation and growth rate reduced, thus resulting in lower phase transformation temperature (Zhao, 2008; Li et al., 2016). Moreover, the temperature range of overcooling austenite was larger in two-phase regions, which was between 60 and 120 ℃.

4.4 Influence of Pass Deformation

The transformation temperature of static continuous cooling of Ti-IF steel was shown in table 4 and the static CCT curves in figure 5. Contrasted with Table3 and Figure 5, it could be seen that under the influence of the pass deformation, phase change starting temperature increased by 3.5 ℃, its finishing temperature increased by about 9 ℃, and the temperature range of dynamic transformation was narrower slightly. At the same time, the starting and the end time of phase transformation was advanced; the incubation period was shortened; and the time for phase transformation was slightly reduced.

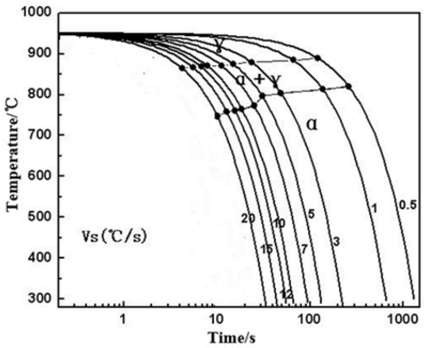


Figure 5: Static CCT curve

This was due to the temperature of the phase transformation was above the austenite recrystallization temperature, with the double pressure, the process of recovery and recrystallization could proceed repeatedly. And then the austenitic grain become refiner, the area of grain boundary was increased, the speed of austenite decomposition was faster, the rate of ferrite shape was higher and the stability of austenitic was lower. So the phase transition temperature was increased, the time shorter and the phase transformation section reduced (Gao, 2007).

Table 4: Temperature of static phase transformation

Cooling rate/°C·s^{-1}	Starting point/°C	Finishing point/°C	Cooling rate/°C·s^{-1}	Starting point/°C	Finishing point/°C
0.5	889	820	10	870	765
1	884	813	12	868	761
3	879	804	15	867	758
5	875	796	20	865	747
7	871	773	-	-	-

5. Conclusions

(1) The higher the cooling speed in the dynamic continuous cooling process of Ti-IF steel, the smaller the grain size, the greater the hardness and the more even the relative size will be. When the cooling speed is increased to 5 °C·s^{-1}, incompletely- transformed recrystallized grains can be observed.

(2) The starting point of phase transformation is decreased, while the starting time and the end time are shortened gradually with increasing temperature range of transformation as the cooling speed increases.

Furthermore, the temperature range of the supercooled austenite in the two-phase region is relatively large, ranging from 60 to 120°C.

(3) With the involvement of pass deformation, the dynamically and continuously transformed phase transformation temperature range is slightly reduced; the phase transformation temperature is increased; the starting time and the end time of phase transformation is advanced; the incubation period is shortened; and the time for phase transformation is slightly reduced.

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References

Cui Z.Q., Tan Y.C., 2007, Metallography and Heat-treatment, Beijing: Mechanical Industry Press.

Gao Y., 2007, Study on Relationship between Recrystallized Structure and Properties of Ti+P+IF steel, Liaoning: University of Science and Technology Liaoning, 7-10.

Jiao X., Ning T., 2018, A dynamic logistics strategy for dangerous goods based on cloud computing, Chemical Engineering Transactions, 67, 685-690 DOI: 10.3303/CET1867115

Li C.G., Yuan G., Kang J., 2016, Transformation Behavior of Ti Microalloyed Low Carbon Steel during Continuous Cooling, Transactions of Materials and Heat Treatment, 37(5), 76-81.

Qi S.Z., Lu J.X., Su L.F., 2003, Ranormation of microstructure of 800MPa a grade HSLA steel during the continuous cooling, Steel Rolling, 20(1), 5-7.

Shi Y.Q., 2012, Metal Plastic Forming Technology and Die Design, Beijing: Tsinghua University Press.

Wang J.D., 2016, Research on Market Structure and Performance of China’s Automobile Manufacturing Industry, Shandong: Shandong University, 2016:1-5.

Wang J.Q., ZHAO H., XIA Y.F., 2003, Development and application of ferrite rolling to Ti-IF steel in hot continuous rolling line, Iron and Steel, 20(1), 5-7.

Wang Y., Wu G., Yang O., Cen H., Zou B., Chen C., Lin S., Pang G., Wang Z., 2018, Design and implementation of the management and detection system of dangerous production raw materials based on odor sensor technology, Chemical Engineering Transactions, 68, 349-354 DOI: 10.3303/CET1868059

Yu H., Xiong Y.X., Kang Y.L., 2005, Dynamic Continuous Cooling Transformation and Microstructure Evolution of IF Steel by Simulating TSCR, Journal of University of Scicence and Technology Beijing, 27(1), 73-74.

Zhang J.C., 2006, The Study of Heat Deformation Behavior on Ti+P-IF Steel and Ti-IF Steel, Anshan: University of Science and Technology Anshan, 1-5.

Zhao N.Q., 2008, Solid Phase Transformations in Alloys, Changsha: Central South University Press.