Experimental Research on Wind-Cooling Quenching of 20Mn2CrSi Steel

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Abstract: Compared to aluminum alloy wheels, steel wheels have been widely used in the automobile industry due to the low cost and high plasticity and toughness. In this report, wind-cooling quenching of the wheels made of 20Mn2CrSi steel is studied. The CCT curves of 20Mn2CrSi are firstly drawn based on the thermal expansion experiment. Then the samples with different thicknesses (4mm, 6mm, 11mm) are tested under air cooling and wind cooling conditions to find out their optimum transfer time of quenching, and the cooling rates of the surfaces and internal of the sample under wind-cooling condition. The Vickers hardness of the samples after wind-cooling quenching are also measured by a Vickers hardness meter. The results show that the cooling rate is slow when the air volume during cooling is 900m3/h, making the hardness of the samples fail to meet the use standard. Therefore, in order to improve the cooling rate and reduce the thermal stress and structural stress during quenching, water atomization quenching method is proposed, which can provide a certain reference value for the quenching process of 20Mn2CrSi steel wheels.

1. Introduction
With the development of the economy, the need for the automobile is increasing. The number of vehicles in China has reached 281 million by 2020. As an essential part of the car, a wheel is a structural component that connects the tire and axis. Bearing heavy load, the wheel is a significant joint of an automobile transmission. Generally, the wheel is made up of two parts: a hub and a spokes. Compared to aluminum alloy wheels, steel wheels have been widely used in the automobile industry due to the low cost and high plasticity and toughness. Therefore, currently, most of the wheels of the trucks are made of steel.

In this report, the wheels made of 20Mn2CrSi are used to do the air-cooling quenching experiment. The thicknesses of the wheels are different, including 4mm, 6mm, and 11mm. Using the subscale test method, the sizes of the samples are designed as 70mm*60mm*4mm, 70mm*60mm*6mm, and 70mm*60mm*11mm, respectively. The CCT curves of the material are drawn based on the thermal expansion test, while the air-cooling test determines the optimum transfer time of quenching. The wind-cooling quenching test is done on the three specimens to measure the cooling rate on the surface centers, edges, and cores of the samples. The hardness of the surface centers and the edges of the samples are measured by a Vickers hardness meter.
2. Experiments and results

2.1. Thermal expansion experiment

2.1.1. Materials and methods
The 20Mn2CrSi steel samples with the size of 100mm*100mm*9mm are annealed in the furnace. Firstly, heat the furnace for 2h to 900°C and then put the samples inside and keep for 25min after the temperature reaches 900°C again. Then turn off the heating module and take out the samples for air cooling when the temperature is lower than 400°C. After annealing, the sample is processed into 20 cylinders with 4mm in diameter *10mm in height by wire cutting. Ac1 and Ac3 are obtained after heating from room temperature to austenitizing temperature by an automatic phase transformation instrument. After holding for 10 minutes, the samples are cooled to room temperature at the rate of 0.1°C/s, 0.5°C/s, 1°C/s, 2°C/s, 5°C/s, 10°C/s, 20°C/s and 50°C/s, respectively.

2.1.2. Results
Based on the thermal expansion experiment, the CCT curves are shown in figure 1.

According to CCT curves, the starting and finishing transformation temperature of austenitizing is 760°C and 882°C, respectively, while that of martensite is 355 and 253°C, respectively. To avoid the formation of high-temperature microstructure, the critical cooling rate of quenching is determined as 10°C/s.

![Figure 1. The CCT curves.](image)

2.2. Air cooling experiment

2.2.1. Materials and methods
The sizes of the three 20Mn2CrSi steel sheet samples are 70mm*60mm*4mm, 70mm*60mm*6mm and 70mm*60mm*11mm, separately. The pre-embedded K-type thermocouple is used to measure the cooling procedure of the temperature sensing point of each specimen. The diameter of the thermocouple is 2mm, while the length of the wire is 3m. Both channels are sampled simultaneously, during which process a PLC data collector is used to record the cooling data. To measure the cooling data inside the specimen, holes with the diameter of 4mm are punched in the 4mm steel plate thickness direction of 2mm, 6mm steel plate thickness direction of 3mm and 11mm steel plate thickness direction of 2.5mm, 5.5mm, 8.5mm, respectively. The thermocouple is embedded in the holes for temperature measurement.

The samples connected with thermocouples are placed horizontally in the furnace for heating after heating the electric heating furnace to 950°C. After the temperature of each sensing point is stable, the samples are taken out and placed horizontally on the air-cooling table for air cooling. The upper side of the specimen is specified as the front side and the bottom side as the backside.

Figure 2 shows the arrangement of thermocouples on the front side of the three samples, of which
the arrangements are the same. Figure 3 shows the arrangement of thermocouples on the backside of the samples.

![Figure 2. The arrangement of thermocouples on the front side of the three samples.](image)

![Figure 3. The arrangement of thermocouples on the back side of the three samples.](image)

2.2.2. Results

The curves in figure 4 show the temperature drops for the air-cooling of the samples.
As shown in figure 4, the temperatures at all the sensing points of both 4mm and 6mm steel sheets are almost the same, of which the average cooling rate is 1.76℃/s and 1.34℃/s, respectively. Based on the CCT curves, the temperature at which phase transformation occurs during austenite cooling under this cooling rate is about 710℃, while the time for the two samples to cool down to 710℃ is 53s and 55s, respectively. The temperature drops at the three temperature sensing points on the core of the specimen with the thickness of 11mm are almost the same. However, they are still slower than the sensing points on the surface. The average air-cooling rate of the surface is 0.49℃/s, while that of the core is 0.47℃/s. It takes 60s for the surface to cool down to 710℃ but 82s for the core.

2.3. Wind-cooling experiment

2.3.1. Materials and methods

The material, size and arrangement of thermocouples used in the wind-cooling experiment are the same as those used in the air-cooling experiment. The experimental installation is shown in figure 5. The specimen is taken out from the furnace and placed on the wind-cooling table, at which the steel sheet is cooled down by the wind from top to bottom by one side by the wind generated from the fan. After cooling, the fan is turned off, and the sample is removed. The flow from the fan is 900m3/h. To concentrate the air volume, a cuboid wind duct is designed at the outlet of the fan, of which the size is 90mm*76mm*153mm and the wall is 2mm thick. At the wind duct outlet, a wind plate is designed so that the surface of the sample can contact the wind evenly. The size of the wind plate is 86mm*72mm*2mm, with 56 6mm-diameter holes distributed on the matrix. The distance between the holes is 10mm, while the distance between the upper surface and the wind duct is fixed as 150mm.
2.3.2. Results
The curves in figure 6 indicate the temperature drop of the samples under wind cooling condition.

As shown in figure 6, the cooling curve of each temperature sensing point of the 4mm-thick sample is almost the same, and the average cooling rate of wind cooling is 3.75°C/s. The temperature changes at the edges of the surface are almost collinear with that at the surface center. The cooling rate at 3mm of the center is the lowest, with an average of 3.13°C/s, following the average cooling rate of 3.14°C/s on the backside. The cooling rate on the front side is the fastest, with an average cooling rate of 3.17°C/s. The cooling curves at different depths of the 11mm thick sample are almost the same, with
an average cooling rate of 2.19℃/s. The average temperature drop on the edges of the backside is 2.21℃/s, while that of the backside center is 2.24℃/s, comparing to 2.63℃/s on both the edges and the center of the front side. Although the cooling rate of the front side center is the same as that of the edges of the front side, the temperature on the edges drops faster than that on the center when the temperature is higher than 400℃. However, the cooling speed of the edges becomes noticeably slower than that of the center when the temperature is lower than 400℃. It is because of the eddy current generated on the edges due to the faster gas flow. The vortex can take away a large number of heats from the edges of the sample under high-temperature conditions, which eventually tends to be the air temperature as the temperature of the specimen decreases. As a result, the effect of swirl in taking away heat is weakened.

After the wind-cooling test is finished, the Vickers hardness meter is used to measure the hardness on both front side and backside surfaces and edges of the samples. The pressure is applied as 100N. The result is shown in table 1.

Table 1. The hardness on the surfaces of the samples

| Thickness (mm) | Front side | Backside |
|---------------|------------|----------|
|               | Center(HV) | Edge(HV) | Center(HV) | Edge(HV) |
| 4             | 248.2      | 250.6    | 224.4      | 224.7    |
| 6             | 231.9      | 233.8    | 209.2      | 206.4    |
| 11            | 203.1      | 209.8    | 191.4      | 194.5    |

3. Conclusion
Based on the thermal expansion experiment, the temperature of Ac3, Ac1, Ms and Mf of 20Mn2CrSi is determined, and the CCT curve of the material was drawn. The critical cooling rate of quenching is determined as 10℃/s.

From the air-cooling experiment, the optimum quenching transfer time of the 4mm, 6mm and 11mm-thick 20Mn2CrSi steel sheet is found to be 53s, 55s and 60s, respectively. Considering the different thickness on different parts of the steel wheel, the quenching transfer time of the whole steel wheel is decided to be 53s.

According to the wind-cooling test, when the flow rate of the fan is 900m3/h, it is difficult for the steel wheel with different thicknesses on different parts to reach the critical cooling rate of quenching if only quenched by the form of wind. According to the CCT curves, due to the slow speed of the wind cooling, the lower quenching-cooling speed makes the austenite transform into bainite and martensite, resulting in lower hardness, which does not meet the use requirements. Therefore, compared to water quenching, the water atomization quenching method is proposed to reduce structural stress and thermal stress during cooling and the deformation or cracking of the wheel during quenching.

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