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Research on Heredity of Coarse Ferrite Grains

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Abstract
The changes in austenite grain size of the specimens with coarse ferrite grains under different heat treatment process were investigated. The focus was on studying the effect of annealing on refining coarse ferrite grains, as well as the influence of the ferrite grain size on the main technical indicators of gas carburizing. The results show that coarse ferrite grains may not necessarily cause the coarse austenite grains, but may result in mixed austenite grains. After annealing treatment, the coarse ferrite grains can be significantly refined and homogenized. Moreover, the coarse ferrite grains have no significant effects on hardness and intergranular oxidation of gas carburizing.
***Keywords:** grain size; coarse ferrite grains; austenite; gas carburizing*

1 Introduction

The grain size has significant effects on the properties of metals and is determined by grain growth and grain refinement [1]. Case hardening steels for automobile gears are generally inherent fine grain size. But during the forging process of the automobile gears, the phenomenon that the ferrite grains become coarser and resulting in the mixed grains still occasionally occurs. However, the gear blanks need to be heat treated such as normalizing, quenching and gas carburizing. During these subsequent heat treatment, whether the grain size of the gears will change and how the coarse ferrite grain size affects the austenite grain size, it is not clear. In this work, the changes of coarse ferrite grains after quenching or gas carburizing and the effects on the main technical indicators of gas carburizing are studied, as well as the changes of coarse grain size after annealing.

2 Experimental

2.1 Test materials

The specimens were taken from 20CrMnTiH3 hot rolled bars with a diameter of 80 mm. The chemical composition was listed in Table 1.

Table 1 Chemical composition of the specimens (wt. %)

Grades	C	Si	Mn	P	S	Cr	Ti
20CrMnTiH3	0.19	0.23	0.89	0.03	0.22	1.16	0.058

2.2 Test methods

(1) The bars with a diameter of 80 mm were heated to 1300 ℃ for 30 min, then forged into gear blanks, slowly cooled to room temperature. The specimen was taken from the outer circle of the gear blank (labeled as Specimen 0 #). After rough grinding, fine grinding, polishing, etching with 4% nitric acid alcohol, the ferrite grain size of the specimen was observed by optical microscope.

(2) Austenite grain size comparison: Two specimens were taken from the Specimen 0 #, labeled as Specimen 1 # and Specimen 2 #. Specimen 1# was heated to 860 ℃ for 1 h, then quenched in water. Specimen 2 # was annealed firstly (heated to 850 ℃ for 6 h, cooled to room temperature in the furnace), and then treated in accordance with the Specimen 1# processing. The austenite grain size of the specimens was observed by optical microscope after polishing and etching with a new grain corrosive at 75 ℃～80 ℃ for 13 min.

(3) Carburized layer comparison: Two specimens were continued to take from the Specimen 0 #, labeled as Specimen 3 # and Specimen 4 #. Specimen 3 # was treated as the procedure: carburized in a box-type furnace in accordance with the procedure show as the Figure 1, then tempered at 180 ℃ for 2 h. Specimen 4 # was annealed as the Specimen 2 #, grinded off the surface oxidized layer, and then treated as the Specimen 3 #. The case hardening, depth and microstructure of the carburized layer of the two specimens were measured.

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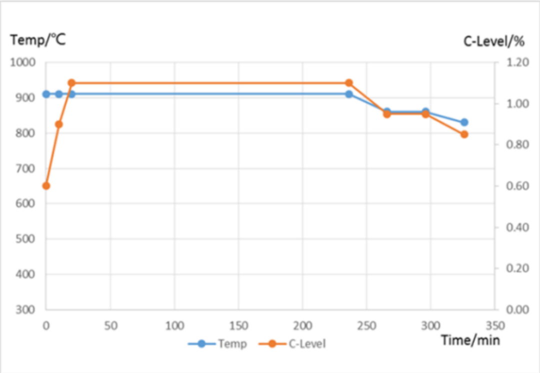

Figure 1 Carburizing process of the specimens

3 Results and Discussion

3.1 Effect of annealing on ferrite grain refining

As shown in Figure 2, after high-temperature heated, the microstructure of the specimen was a typical overheated structure. The grain boundaries tended to be significantly coarse and the grains grew up significantly. The minimum diameter of the ferrite grain was 100 μm and the maximum diameter was 450 μm, the average diameter was 210 μm, the grade of the average grain size was 1.5. After annealing, the ferrite grain size was obviously refined, and the average grain diameter was 25 μm with an average grain size of Grade 7.5 (Figure 3).

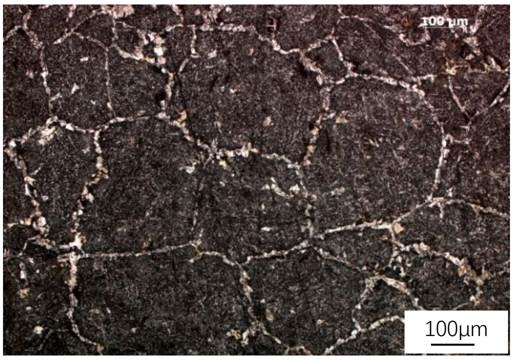

Figure 2 Ferrite grain size of specimen 0 # X100

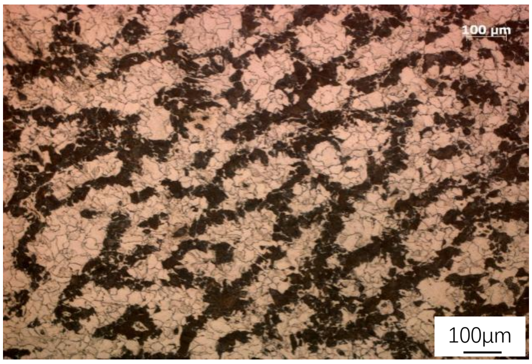

Figure 3 Ferrite grain size of specimen 2 # after annealing X100

As the specimen was insulated above Ac3 temperature, recrystallization occurs during the heat treatment of a deformed material and the grain structure is reconstruction [2]. At first the generation of small new grains is observed. The original coarse grains were reaustenitizing and tended to fine austenite grains in recrystallization process. It can be obtained fine grain in the subsequent cooling [3].

3.2 Effect of heat treatment regime on austenite grain size

Compared Figure 2 with Figure 4a), it can be seen that there was a huge difference between ferrite grain size and austenite grain size for the inherent fine grain steels. The ferrite grain size for the gear blank was only 1.5 while the austenite grain size could reach 7.5.

Therefore, for the forgings which need quenching and tempering or gas carburizing, the evaluation of grain size should be based on the austenite grain size rather than ferrite grain size. This is because that the estimation of grain size base on ferrite grain size is highly misleading, as there may be a phenomenon that ferrite grains grow up while austenite grains do not truly grow. In addition, coarse ferrite grains have obvious inheritance tendency. Parts with coarse ferrite grain size may cause mixed grains during subsequent quenching or gas carburizing. As shown in Figure 2 and Figure 4, the ferrite grains were obviously refined after annealing treatment, and correspondingly, the austenite grain size became significantly more uniform after quenching. Therefore, for parts with coarse ferrite grains, annealing is still necessary to refine the grains and prevent the occurrence of mixed grains.

In addition, it is generally believed that the higher the heating temperature, the larger the grain size. Although the carburizing temperature was 920 ℃ and the quenching temperature was 860 ℃, there was no significant difference in grain size between the two specimens.

It is because the Ti element is added to 20CrMnTiH3, which forms TiC or Ti (C/N) second phase particles in the steel to pin austenite grain boundaries and prevent grain growth [4]. Through EPMA, Yuxuan Shi et al. [5] confirmed that the second phase particles TiN with diameter of 3-4 μm were separate out in 20CrMnTiH3. According to Zener's theory, the relationship between grain radius R, second phase particle radius r, second phase particle volume percentage f and grain boundary angle θ satisfies the following conditions [5]:

$$R = \frac{4r}{3f(1+cos\theta)} \quad (1)$$

From equation (1), it can be seen that when a significant amount of second phase particles with a dispersed and uniformly distributed state separated out, they can prevent the austenite grains growth.

Based on the above experimental results, it can be concluded that annealing treatment can effectively prevent the structural heredity of the ferrite grains growth. This is because annealing treatment is beneficial for the precipitation of second phase particles [6-7]. The second phase particles can be pinned around grain boundaries, hindering grain growth and facilitating the formation of uniform and fine grains. Additionally, after annealing, an equilibrium microstructure is formed, and during the subsequent quenching process, the equilibrium microstructure is more likely to form a state of uniform and fine grains distribution [7].

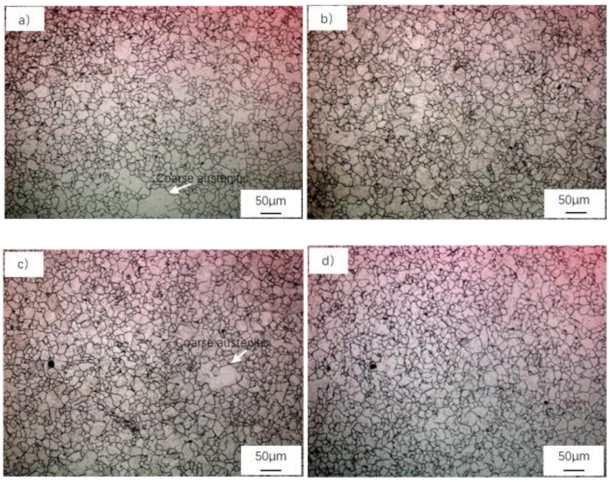

Figure 4 The austenite grain size of the specimens

a) Specimen 1 #: quenched; b) Specimen 2 #: annealed then quenched; c) Specimen 3 #: gas carburized; d) Specimen 4 #: annealed then gas carburized

Table 2 Austenite grain size of specimens under different heat treatment process

Specimen No.	Heat treatment	Results
1 #	Specimen with coarse ferrite grains was quenched.	The percentage of fine grain area was 90%, and the average austenite grain size can reach Grade 7.5. Some individual grains can reach 100 μm, the grain size reached Grade 3.5.
2 #	Specimen with coarse ferrite grains was annealed then quenched.	The austenite grains were significantly homogenized, the mixed grains were basically eliminated, and the average grain size can reach Grade 7.5.
3 #	Specimen with coarse ferrite grains was gas carburized.	There was no significant difference in austenite grain size from Specimen 1 #.
4 #	Specimen with coarse ferrite grains was annealed then gas carburized.	There was no significant difference in austenite grain size from Specimen 2 #.

3.3 Effect of grain size on hardness and intergranular oxidation of gas carburizing parts

The hardness and intergranular oxidation of Specimen 3 # and 4 # with gas carburizing were measured. It can be found that there was no significant difference between the two specimens in the main technical indicators of gas carburizing, including microhardness gradient, effective case hardening depth (The effective case hardening depth is defined as the distance perpendicular to the surface over which a hardness equivalent to 509 HV1 or greater is maintained in the hardened case.), and intergranular oxidation. Therefore, it can be concluded that the ferrite grain size has no obvious effect on hardness and intergranular oxidation of gas carburizing (the ferrite grain size of Specimen 3 # refers to Specimen 0 #, and the ferrite grain size of Specimen 4 # refers to Specimen 2 #).

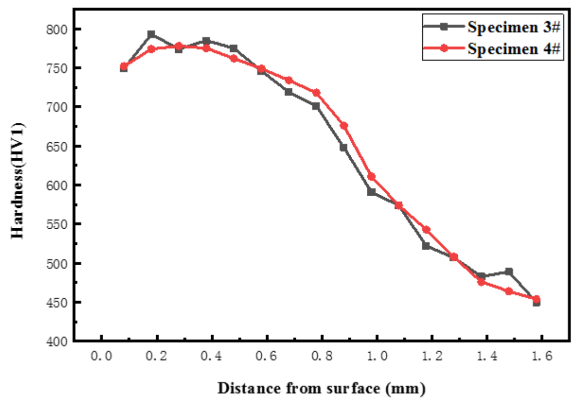

Figure 5 Com parison of microhardness gradient across the carburized case

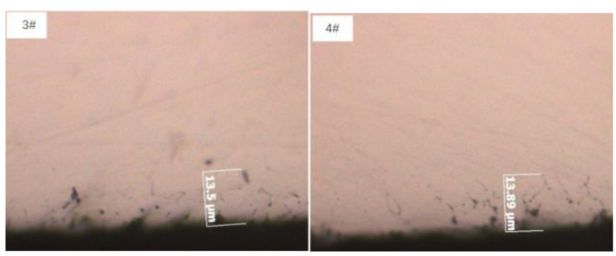

Figure 6 Intergranular oxidation of the specimens

4 Conclusion

(1) In the inherent fine grain steels, there may be significant differences between ferrite grains and austenite grains. For forgings which need to be quenching or gas carburizing, the grain size should be evaluated based on the austenite grain size.

(2) Parts with coarse ferrite grain size may exhibit mixed grains after quenching. However, after annealing treatment, the coarse ferrite grains can be refined and homogenized to avoid mixed grain size during quenching.

(3) The ferrite grain size has no significant effect on

the main technical indicators of gas carburizing, such as microhardness gradient, effective case hardening depth and intergranular oxidation.

Author Contributions: Wangzhan Fan and Weimin Gui conceived and designed the experiments; Youfeng Chen performed the experiments; Weimin Gui analyzed the data. Wangzhan Fan and Weimin Gui wrote the paper.

Conflict of Interest: The authors declare that there is no conflict of interest regarding the publication of this paper.

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