THE INFLUENCE OF ANNEALING PARAMETERS ON MICROSTRUCTURES IN LOW CARBON STEELS

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SYNOPSIS

In order to offer the client to form the hub of wheel, low carbon steels with lower strength and good ductility were produced. In addition, annealing process was applied to enhance formability. Ideal spheroidal microstructure was the goal of the annealing treatment. However, abnormal grain growth sometimes occurred during the high temperature process, leading to the orange-peel effect on the surface after the metal forming process. As a result, avoiding the negative effect during the annealing process becomes an important topic.

In this study, spheroidizing the structure without coarse grains was the aim. After several heat treatments with experimental heating furnace, the microstructures were observed and analyzed. During the annealing process, high temperature offered the driving force for grain growth. Coarse grains grew exaggeratedly with the sacrifice of fine grains. At high temperature, structures were spheroidized and the hardness decreased, but abnormal grain growth appeared. At low temperature, no coarse grains formed, but the level of spheroidization was too low. By setting the appropriate temperature with enough holding time, the abnormal grain growth was suppressed and the microstructures also satisfied the requirement.

Keywords: Annealing treatment, Spheroidization, Abnormal grain growth

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1. Introduction

During the annealing treatment, grain growth usually occurred due to the high temperature process. The energy of the total grain boundary area is reduced, and the average grain size increases. However, some of the grains grow more rapidly than the others, which is different from the normal distribution grain size of normal grain growth. This phenomenon is defined as abnormal grain growth [1, 2]. Under the abnormal grain growth, the larger grains grow with elimination of the smaller ones by the migrating grain boundaries. If strain is introduced to the material, the abnormal grain growth will be more obvious. The coarse grains grow along the strain direction, engulfing the neighboring fine grains with exaggerated appearance.

The factors that affect abnormal grain growth include temperature, pinning effect and texture effect [3]. At high temperature, diffusion is stimulated and the grain boundaries migration becomes easier, leading to the acceleration of abnormal grain growth. The solute (solute drag) and second phase particles (Zener pining) also affect the abnormal grain growth process [4]. The solute atoms or second phase particles segregate at grain boundaries, hindering the grain boundaries migration. The texture in microstructure influences the grain growth process due to the preferred orientation of grain boundaries migration. Above all, temperature is the most important. That is why finding suitable annealing parameter is the goal of this study.

Coarse grains in microstructure lead to "orange-peel effect." The mechanism is resolved as follows. According to Schmid's law, the strength of materials can be calculated with specific orientation in the single crystal [5]. The formula is $\sigma_{CRSS} = \sigma \cos\lambda \cos\chi$ (σ indicates the external stress; λ is the angle between the external stress direction and slip direction; χ is the angle between the external stress direction and slip plane; Schimd factor is defined as $\cos\lambda \cos\chi$) [6]. Because the angle between slip direction and slip plane is 90°, the maximum of Schmid factor is 0.5 as both the angle of λ and χ are 45°. When the critical resolved shear stress (σ_{CRSS}) is over the yield strength of the material, dislocations start to slip, and the plastic deformation occurs. The yield point can be easily found in the stress-strain curve, for the yield strength is a fixed value. As for polycrystalline materials, the resolved shear stress on every grain varies with different orientation. Under the external stress, when some of the grains start plastic deformation, some of them are still in elastic zone. Therefore, the yield point is not obvious in the stress-strain curve. It is not until the resolved shear stress are over the yield stress in all the grains that the material enters plastic deformation totally. In practice, the yield point in polycrystalline materials is defined as the deviation over 0.2% of the elastic limit.

In low-carbon steels, the solute atoms in the matrix produces atmosphere, interfering the dislocation slip [7]. As the dislocations are affected by the carbon atmospheres, additional stress is required to attain the yield strength, and the upper yield point appears. After the dislocations freed from the atmospheres, the yield strength decreases, and the lower yield point appears. In this process, because the deformed and undeformed area is not homogeneous, Luders bands emerge at the surface of the material. This phenomenon is more common in the stamping and deep drawing process. For the slips of the dislocations in each grain don't occur at the same time, the slip direction of them are also different. As a result, because of the different orientation of the Luders bands between neighbor grains, the surface of the material is no longer smooth. The rough surface looks like orange peels viewed from eyes, and thus defined as "orange-peel effect" [8]. In this study, several experiment are executed to find the appropriate temperature and time to control the microstructure, avoiding the "orange-peel effect" in the product.

2. Experimental

The material in this study was the SAE1010 hot-rolled coil product, Fe-0.1C-0.45Mn (wt%). Samples were prepared with the size of 5*5cm with the thickness of 4.5mm. The optical micrograph result suggested that although the pearlite was already spheroidized totally, the coarse grains also formed. Therefore, the annealing parameters should be adjusted. The experimental furnace was set with two temperature (680 and 650℃), and several tests with different holding time (12-16 hours) were executed. Afterwards, optical micrograph was observed to confirm the level of spheroidization and the improvement of abnormal grain growth. Besides, the hardness test was also executed to promise that the product would meet the requirement.

3. Result and discussion

The microstructure of optical micrograph of SAE1010 hot-rolled sample, Fe-0.1C-0.45Mn (wt%), is shown in Fig. 1. The microstructure was composed of fine ferrite grains and small amount of pearlite. Because of the contact to the air at the surface, the nearby grains became a little larger. Overall, the whole microstructure was typical and there was nothing abnormal. After enlarging the local area in Fig. 2, the pearlite structures were resolved more clearly. During the cooling process, austenite transformed into ferrite and partitioned the carbon into the parent phase. The carbon content of the parent phase rose and finally transformed into pearlite. Therefore, the pearlite structures were flat and long along the grain boundaries of the ferrite structures.

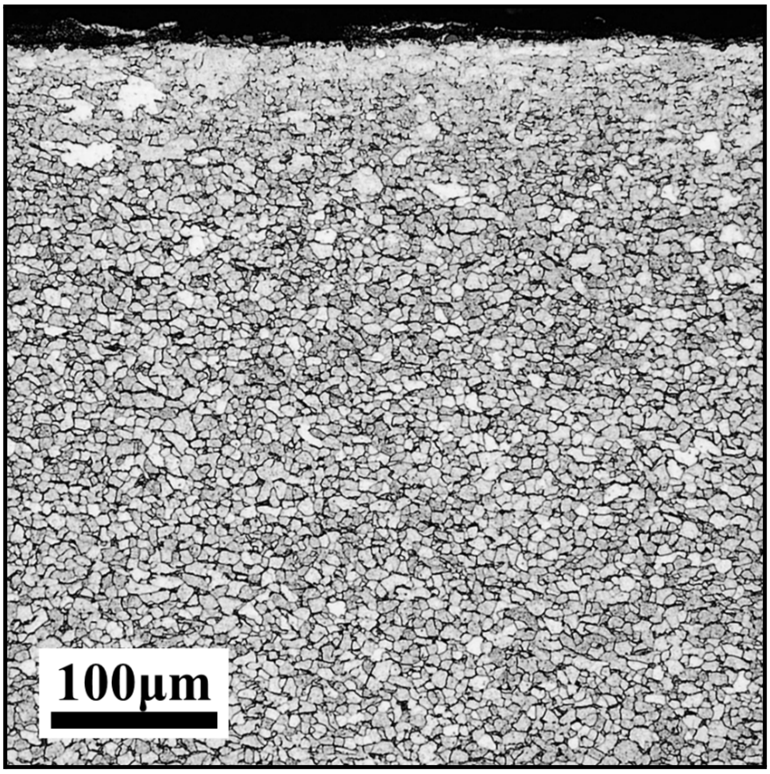

Fig. 1. The microstructure of SAE1010 hot-rolled sample.

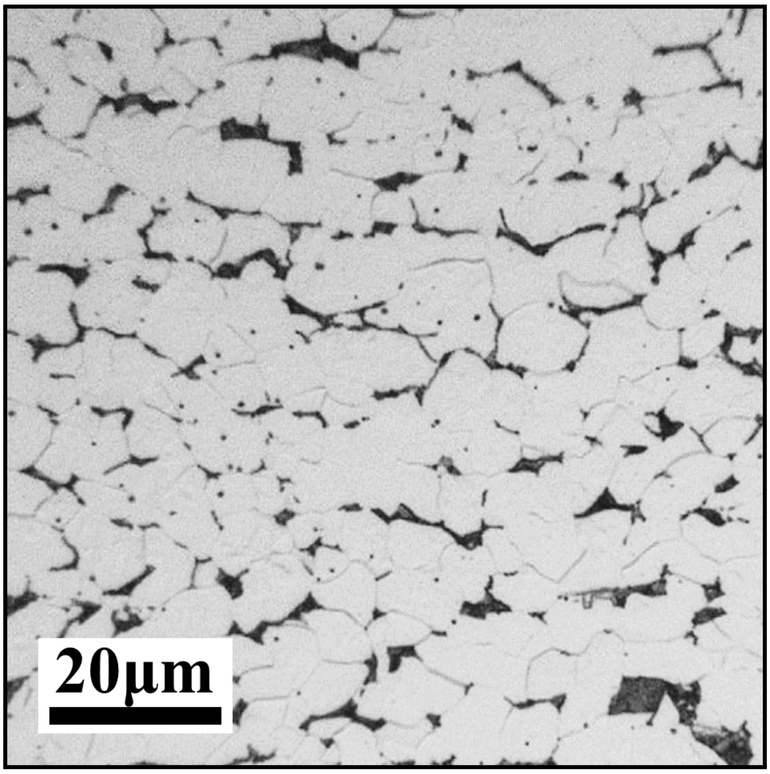

Fig. 2. The pearlite structures in the sample.

In order to enhance the formability of the materials, the pearlite structures should be spheroidized, decreasing the chance of the cracks occurrence. After the annealing process, a high level of the spheroidization attained as shown in Fig. 3. However, abnormal grain growth happened at the same time. At high temperature, the coarse grains grew exaggeratedly with the sacrifice of the fine grains. Besides, as the hot-rolled coil was on the production line, the introduced strain also lead to abnormal grain growth at high temperature. The “strain-induced grain growth” made the coarse grains grew more deeply and make the situation even worse. The abnormal grain growth at the surface is shown in Fig. 4. Although the annealing treatment softened the materials (the hardness was 59HRB), the coarse grains in the microstructure brought about negative effect after the shaping process. The grain size was more than 200μm, which lead to “orange-peel effect” after deformation. To improve this phenomenon, several annealing treatment was executed. The result was analyzed and decent annealing temperature and time was decided.

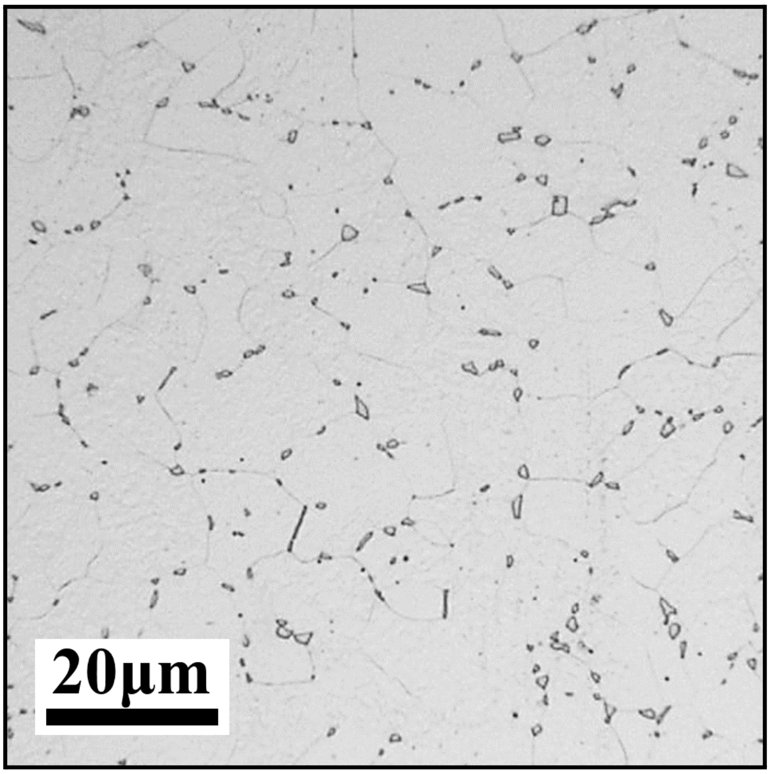

Fig. 3. The spheroidization of the sample after the annealing process.

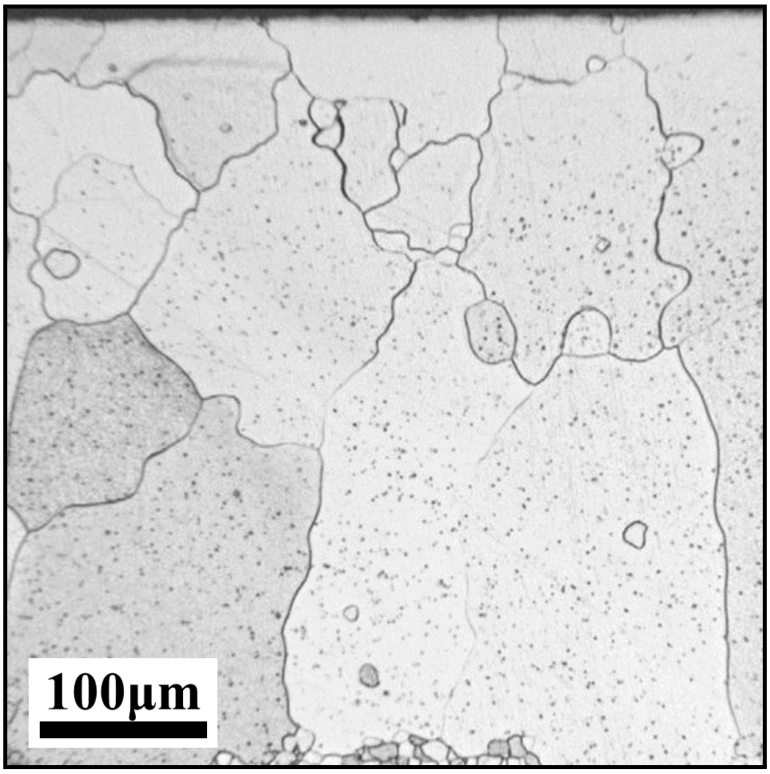

Fig. 4. The abnormal grain growth at the surface.

The annealing treatment in laboratory with 650℃ and 680℃ for 12-14 hours was executed. The results are shown in Fig. 5. At 650℃ as shown in Fig. 5a, b & c, grain growth appeared at the surface. As the holding time increased, the amount of coarse grains only increased a little, and there was no exaggerated large grains. When the temperature increased to 680℃ as shown in Fig. 5d, e & f, abnormal grain growth occurred significantly; in addition, the exaggerated large grains grew along the thickness direction. With the holding time increasing from12 to 16 hours, the coarse grains became much larger. The experimental results suggested that if the temperature was no more than 650℃, the abnormal grain growth could be inhibited.

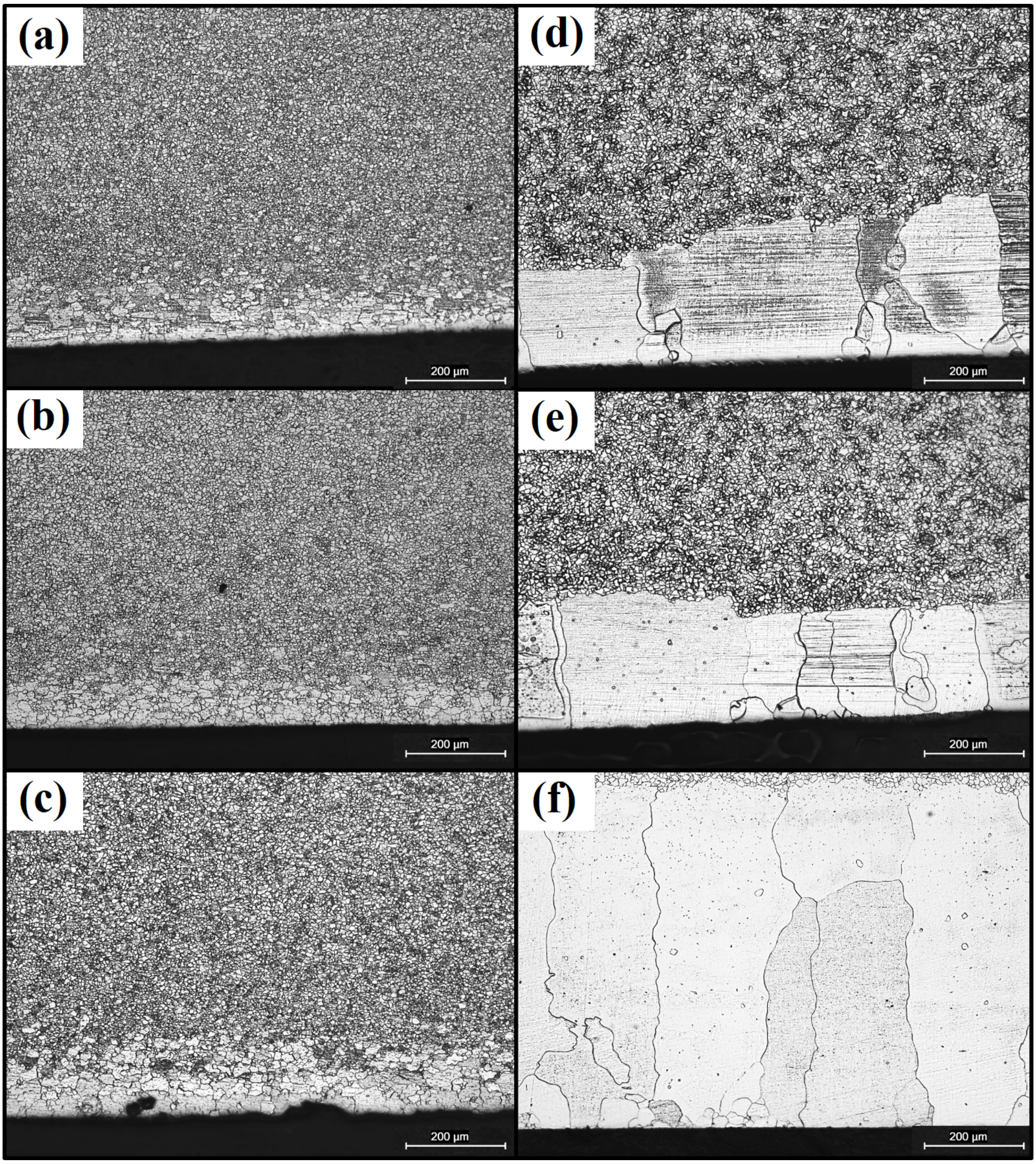

Fig. 5. The optical micrograph of the annealing treatment. (a) 650℃ for 12 hours (b) 650℃ for 14 hours (c) 650℃ for 12 hours (d) 680℃ for 12 hours (e) 680℃ for 14 hours (f) 680℃ for 12 hours

After understanding the influence of the annealing temperature and time on the microstructure, the experimental results were applied on the production line. The microstructure of hot-rolled coil after the revised annealing process is shown in Fig. 6. The microstructure was made up of fine ferrite and spheroidized pearlite. Only the grains nearby the surface was affected by the grain growth process; however, the effect was too slight to cause the “orange-peel effect.” The pearlite structure after the revised annealing process is shown in Fig. 7. Because the annealing temperature was lowered, the spheroidization was also less effective. Nonetheless, despite the lower level of the spheroidization, the hardness of the materials only increased a little, 65HRB by contrast to the original 59HRB. Last but not least, the problem of the abnormal grain growth was solved, and the hot-rolled coil product with revised annealing process met the requirement of the customer.

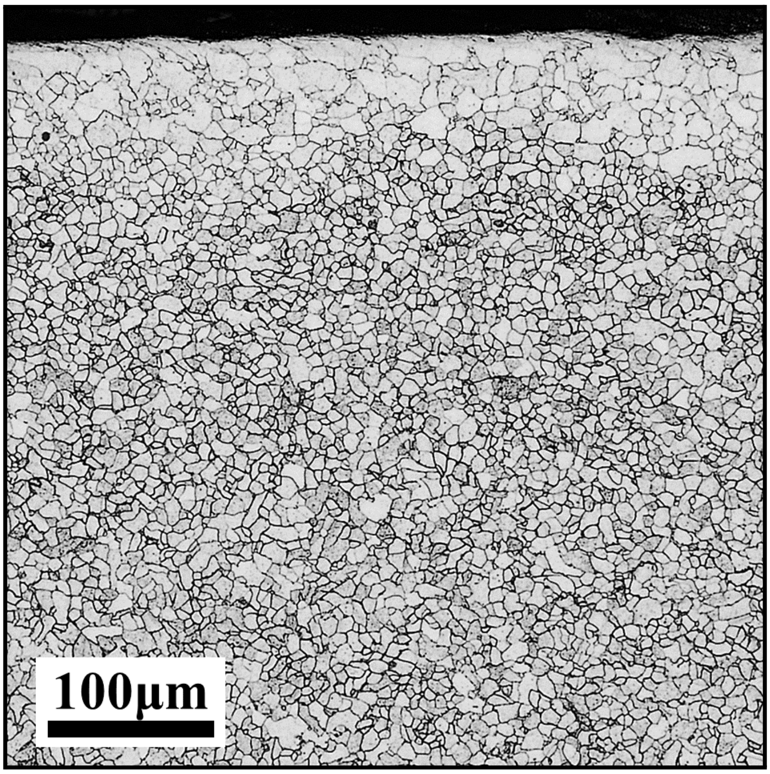

Fig. 6. The microstructure of the hot-rolled coil after the revised annealing process.

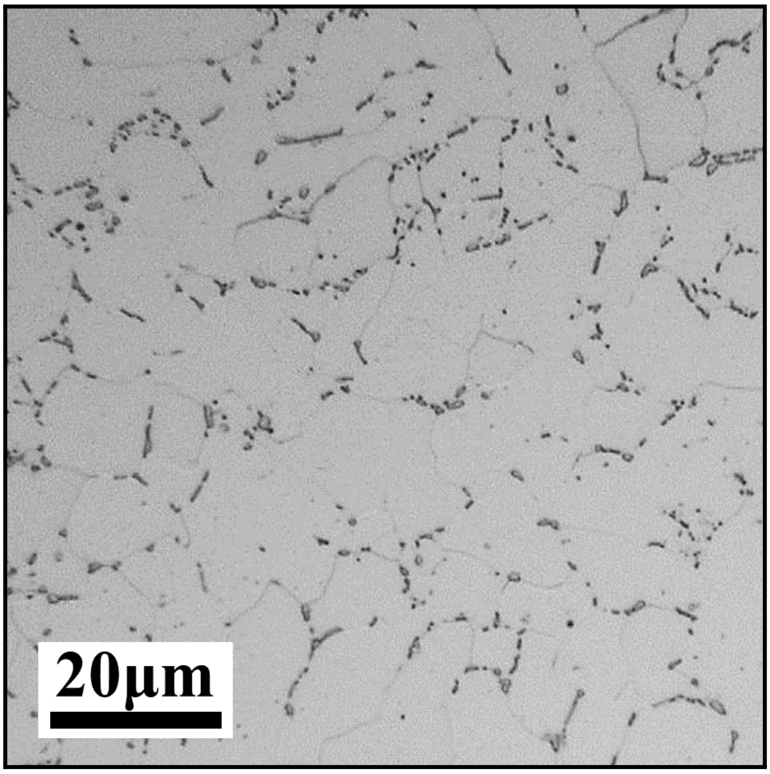

Fig. 7. The pearlite structure after the revised annealing process

4. Conclusions

During the annealing treatment, the pearlite structure was spheroidized, and the material was softened. However, abnormal grain growth occurred at the high temperature process. In this study, several annealing experiments (650℃ & 680℃) were executed, and the effect of temperature and time on the microstructures were also understood. According to the experimental results, with the temperature no more than 650℃, the abnormal grain growth was inhibited. Finally, the annealing parameters were applied on the production line. In spite of the lower level of spheroidization, the coarse grains were suppressed. Above all, after the revised annealing treatment, the microstructure and mechanical properties of the product satisfied the requirement.

5. Reference

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