Microstructure Observation and Mechanism Analysis of High Carbon Steel Decarburization at High Temperature under Electric Field

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Abstract. Electric Field Heat treatment has a significant effect on the superplasticity, recrystallization and phase transformation of metals, and can also improve the superplasticity and mechanical properties of materials. The effect of electric field on high temperature decarburization of high carbon steel was studied by comparing the decarburization degree of high carbon steel under electric field and non-electric field. The mechanism of the electric field is analyzed. The Electric Field promotes the migration of vacancy or vacancy + solute atoms to the grain boundary, dislocation or sample surface to realize the diffusion process.

1. Introduction
With the rapid development of science and technology, all walks of life put forward higher requirements for the performance of materials, which prompted people to continuously develop new materials and new technology research of traditional materials. In recent years, the research of electromagnetic treatment of materials has aroused great interest of metallurgical and materials science workers at home and abroad. The so-called electromagnetic treatment of materials (EPM) is the application of electric field to the preparation and processing of materials, so as to control the process of materials and improve the structure and properties of materials [1, 2]. Electric Field is one of the most important physical fields in nature, because of its unique properties, such as the induction heat of alternating electric field can be used as an efficient and clean heat source. The electromagnetic force produced by alternating electric field in molten metal and the electromagnetic force produced by the interaction of Balanced Electric Field and direct current can be applied to the surface and interior of the material as an external force and is easy to operate and control. It has become an important means to improve the properties of metal materials in melting furnace, purification of melt, refinement of microstructure, control of solidification and forming of melt, and preparation of materials [3, 4]. The application of electric field in material processing has also become a research hotspot.

It has been shown that the superplasticity, recrystallization, phase transformation and atom diffusion of metal treated by electric field have significant effects. Electric field treatment can also improve the superplasticity and mechanical properties of materials. But the mechanism of the electric field is still not very clear one of the most accepted theories is the mechanism of electric field vacancy (electric field promotes the migration of vacancy or vacancy + solute atoms to grain boundaries,
dislocations or sample surfaces, i.e. the process of diffusion) [5, 6]. The effect of electric field on high temperature decarburization of high carbon steel was studied by comparing the decarburization degree of high carbon steel under electric field and non-electric field [7].

2. Experimental material and high temperature decarbonization process

The material used in the experiment is cast by the experimental plant of Wuhan Iron and Steel Group Technology Center. The INGOT is cylindrical. Its chemical composition is shown in Table 1.

| Table 1. Chemical composition of experimental materials (W1%). |
|---------------------------------------------------------------|
| C | Si | Mn | P  | S  | Cu | Fe |
|---|----|----|----|----|----|----|
| T8A | 0.81 | 0.30 | 0.18 | 0.003 | 0.015 | 0.030 | BaL |
| T9A | 0.89 | 0.23 | 0.19 | 0.004 | 0.013 | 0.036 | BaL |

The thin plate specimens were cut by wire cutting on the cuboid after forging treatment, and the upper and lower surfaces of the specimens were polished by water sanding paper before electric field annealing. The burr edges and corners of the sample are removed to prevent the discharge phenomenon during electric field annealing. In the electric field annealing experiment, the sample and the stainless steel electrode plate are placed in parallel and connected with the positive and negative poles of the high voltage DC power supply respectively. The heat treatment process is as follows: The sample is heated to 930°C for 6 hours, then cooled to 400°C in the furnace and then air cooled to room temperature. No protective gas is passed throughout the heat treatment process. When the electric field is applied, the electric field intensity is set to 4kV/cm. Both Electric Field and non-electric field heat treatment experiments were carried out in a self-made electric field heat treatment furnace. In addition to the zero electric field strength, the same process parameters as electric field annealing were used to ensure the comparability of the experimental results.

3. Tissue observation

The metallographic specimen is grinded, then rough and fine polished with diamond grinding paste and water. After finishing, the sample is corroded by 4% nitric acid alcohol solution at room temperature. The microstructure of the samples was observed under Olympus / BX61 metalloscope.

Figures 1 and 2 show the microstructure of T9A steel after holding at 930°C for 6 hours. The average thickness of the decarburized layer heated by electric field is 553μm with only one field of view. Ten thickness values are measured and the boundary line between the decarburized layer and the decarburized layer is circular arc the average thickness of the decarburized layer is 216μm with only one field of view, and 10 thickness values are measured and taken as the average value.

Figure 1. Microstructure of the two ends after holding at 930°C for 6 hours, E=4kV/cm.
Figure 2. Microstructure of the two ends after holding at 930°C for 6 hours, E=0kV/cm.

The microstructure of T9A steel after decarbonization and oxidation at 930°C for 6 H is shown in Fig. 3. The white microstructure is ferrite and the black microstructure is flake pearlite as shown in Fig. 4. By comparing the microstructure of the samples heated by electric field with that heated by non-electric field, it can be found that the decarburized layer of the samples heated by electric field is obviously thicker than that of the samples heated by non-electric field. The total decarburized layer heated by electric field is 377μm, and the total decarburized layer heated by electric field is chosen as two view fields, and 50 thickness values are measured, and the average value is taken.

Figure 3. Microstructure of specimen edge after holding at 930°C for 6 hours.

Figure 4. Microstructures of pearlite of T9A steel heated at 930°C for 6h.

Figures 5 and 6 show the microstructure of the central part of the side surface of T9a steel after holding at 930°C for 6 hours. It can be found that the percentage of ferrite in the core of the sample
heated by electric field is higher than that of the sample heated by non-electric field. The shape of the core structure of the sample heated by electric field is different from that heated by non-electric field. The edge of ferrite grain in the core structure of the sample heated by electric field is slightly round, with few edges and corners. However, the ferrite grains in the core of the sample heated by non-electric field have many edges and corners, showing a slight strip shape.

Figure 5. Microstructure of the sample center of T9A steel after holding at 930℃ for 6 hours, E=4kV/cm.

Figure 6. Microstructure of the sample center of T9A steel after holding at 930℃ for 6 hours, E=0kV/cm.

4. Analysis and discussion
Decarburization of steel surface includes two processes: diffusion of carbon atoms from the metal to the surface and oxidation reaction of carbon atoms on the metal surface with oxygen in the atmosphere of furnace. At a certain temperature, when the surface of the steel is in contact with the atmosphere or furnace atmosphere, the carbon on the surface of the steel will react with oxygen to form a gas, which leads to the formation of a carbon concentration gradient between the interior and the surface the driving force for carbon diffusion has increased significantly. The thickness of decarburized layer of decarburized sample heated by electric field is thicker than that of decarburized sample heated by non-electric field the percentage of ferrite in the core tissue of the sample heated by electric field increased obviously. Therefore, it is certain that the total carbon content of the sample heated by electric field is less than that heated by non-electric field.

The electric field can affect the diffusion process mainly by the vacancy mechanism. When a metal conductor is placed in an applied electric field, the free electrons in the conductor will move in the direction of the electric field under the action of the electric field force, thus causing the electric charge in the conductor to redistribute. If the sample is connected to the positive electrode of the power source, a large amount of positive charge will accumulate on the surface of the sample after
electrification. In the process of vacancy migration, the energy barrier of vacancy jump will be reduced due to the interaction of positive and negative charges. Thus, the vacancy complex composed of carbon atoms and vacancies is diffused to the grain boundary or surface, thus accelerating the process of carbon atoms diffusing to the surface of sample.

The morphology of PROEUTECTOID ferrite in the core of the samples heated by electric field is different from that heated by non-electric field. The edge of the PROEUTECTOID ferrite grains in the core of the samples heated by electric field is slightly round, with few edges and corners. The PROEUTECTOID ferrite grains in the core of non-electric-field-heated samples have a slight strip-like edge with multiple correction angles. It can be explained as follows: In the decarburization process, part of carbon in the sample has been diffused into the atmosphere and lost. The typical microstructure (Secondary Cementite) of eutectoid steel has not been found in the microstructure after decarburization and cooling slowly on the contrary, a large amount of typical structure (EUTECTOID ferrite) of hypoeutectoid steel was found. That is to say, the core of the decarburized T9a steel is no longer hypereutectoid steel, but becomes hypoeutectoid steel. According to the phase diagram of iron and carbon, during the cooling process, the hypoeutectoid steel precipitates ferrite along the austenite grain boundary between AR3 and AR1. After adding electric field, the decarburization is more obvious and the carbon content is lower, so the time of pre-precipitation ferrite is more sufficient, and the volume content of pre-eutectoid ferrite is more. The precipitated ferrite grains grow not only along the austenite grain boundary, but also inside the austenite grain boundary, so the morphology of pre-eutectoid ferrite is relatively rich and round, and the outline of the original austenite grain boundary is almost indistinguishable. The carbon content of decarburized samples under non-electric field is higher than that after electric field treatment. The proeutectoid ferrite precipitates along the austenite grain boundary. As the precipitation time is relatively short, the proeutectoid ferrite grains grow along the austenite grain boundary. However, there is not enough time to grow into the austenite grain, so the morphology of EUTECTOID ferrite is long and angular, and the outline of the original austenite grain boundary can be clearly seen.

5. Conclusion
The samples of T9a steel were annealed at 930°C by electric field and non-electric Field Air, and the decarburization degree was tested. The results show that the thickness of the decarburized layer and the percentage of ferrite in the core of the sample increased obviously compared with the non-electric field annealed sample. When the sample is heated in air, the surface of the sample oxidizes, which results in the depletion of the carbon atoms on the surface. The decarburization of the sample surface heated by electric field increased, which indicated that electric field accelerated the diffusion of carbon atoms to the sample surface and promoted the decarburization process.

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