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A review of cooling in the industry

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Abstract. In modern society, metal products are needed in various industries. The annealing process is commonly employed in manufacturing. Based on the specifications of the product, the purpose of annealing is different, the annealing process specification has a variety of commonly used complete annealing, spheroidal annealing, and stress relief annealing. This paper investigates and compares the characteristics of different annealing processes in the production process through the literature research method. This paper describes seven annealing methods, mainly detailing two annealing processes, spheroidizing annealing, and recrystallization annealing, and gives examples of the advantages and disadvantages of these two processes. Annealing is primarily used to improve machinability and reduce hardness. It also stabilizes size, lowers residual stress, and lessens the tendency for deformation and cracking. Cut down on grain, reorganize, and get rid of organizational flaws, even material composition and organization can enhance a material's qualities or prepare it for upcoming heat treatments.

Keywords: Cooling, annealing, steel, spheroidizing annealing, recrystallization annealing.

1. Introduction

Cooling is the transfer of heat that lowers the temperature of an object, sometimes accompanied by a change of state. In life, cooling can inhibit the life activities of microorganisms and the biochemical action of enzymes, thereby prolonging the shelf life of food. In industry, cooling is a very important process that is often included. For example, circulating cooling water systems have been widely used in various industries, such as petrochemicals, electric power, metallurgy, medicine, textiles, machinery, electronics, etc. Generally speaking, in industrial production, the way of industrial cooling is determined by the temperature required for the production process, the cooling rate, and the material of the product. Common cooling methods include water cooling, air cooling, and coolant circulation. For example, convection cooling is a kind of air cooling, divided into natural convection cooling and forced convection cooling. Forced convection cooling refers to using the airflow formed by fans or specially designed devices to accelerate the airflow to achieve the purpose of cooling. Natural convection cooling uses the spontaneous flow of air during the heating process to achieve the cooling goal, and the cooling is relatively slow. The difference between the two the difference is the speed of airflow. In the metallurgical industry, the circulating cooling water system is an important auxiliary system for the main process production, and it is also a subsystem with high energy consumption [1]. For example, in the steelmaking industry, the annealing cooling method is usually used. During the process of processing metal, the metal sometimes deforms due to high temperature. The annealing cooling method can maintain the stable structure and performance of the metal during the cooling process, making the

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product more durable. Obtain good performance and process performance, and prepare for its further quenching. This article will delve into the importance of cooling in industry and its wide application in various fields. This paper can familiarize the reader with the advancements and challenges of related research in the field of annealing by organizing and summarizing the significance and function of common annealing processes. It can also give future researchers some food for thought regarding whether or not more research can yield more meaningful results.

2. An introduction to annealing

The process of annealing involves gradually raising the metal's temperature to a predetermined point, maintaining it there for a suitable amount of time, and then allowing it to cool at the proper rate. Complete annealing, spheroidizing annealing, isothermal annealing, recrystallization annealing, graphitization annealing, diffusion annealing, and stress relief annealing are a few of the different heat treatments available for annealing.

2.1. The purpose of annealing

Annealing is an important part of the steelmaking industry. Its goal is to stop the product from deforming and cracking by reducing or eliminating the different microstructural changes and residual stress brought on by steel during casting, forging, rolling, etc. The product might be made softer at the same time in preparation for further processing. Additionally, annealing can prepare the steel for the ultimate heat treatment, improve the internal structure of the steel to increase the mechanical properties of the product and refine the grains.

2.2. Commonly used annealing processes

After casting, forging, and welding, complete annealing is utilized to improve the medium and low-carbon steel's weak mechanical qualities. The product is heated to a temperature that is 30 to 50 °C over the point at which ferrite turns into austenite. It is then allowed to remain warm for a while before being gradually cooled using a furnace. The austenite changes once more while cooling, allowing the product to be created. Steel's structure gets more refined.

After forging, spheroidizing annealing is used to lower the high hardness of the tool and bearing steel. The product must be heated to a temperature that is 20 to 40 °C above the point at which the steel starts to generate austenite during the annealing process. After heat preservation, the product must be cooled gradually. The lamellar cementite in the pearlite becomes spherical during the cooling process, which lowers the hardness.

To make subsequent cutting processes easier, isothermal annealing is used to lessen the high hardness of certain alloy structural steels with high nickel and chromium content. In the annealing process, the material is typically cooled quickly to the austenite's most unstable temperature and held there for the proper amount of time. Hardness can decrease as austenite changes into troostite or sorbite.

The hardening of metal wires and thin plates during cold drawing is prevented by recrystallization annealing. It must be heated to a temperature that is 50 to 150°C lower than the point at which austenite formation occurs in steel. The metal can only be softened and the hardening effect removed in this manner.

Iron with a high cementite content can be made pliable and plastically strong through graphitization annealing. The casting is heated to around 950°C, left warm for a predetermined amount of time, and then suitably cooled to allow the cementite to break down and form a cluster of flocculent graphite.

Diffusion annealing can increase the performance of the cast alloy by uniformizing its composition. Raise the temperature of the casting to its maximum and maintain it there for an extended period. Once the alloy's constituent elements have uniformly distributed and diffused, allow it to cool down gradually.

Steel castings with internal stress can be made stress-free by annealing them. To reduce internal stress, the steel must be heated to a temperature that is 100 to 200°C below the melting point and then let to cool in the air for a while.

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3. Application of two annealing methods

3.1. Spheroidizing annealing

Through spheroidizing annealing, the carbides in the steel can be spheroidized, so that the structure of spherical or granular carbides is evenly distributed on the ferrite matrix. Spheroidizing annealing is mainly used for eutectoid steel and hypereutectoid steel to obtain a spheroidized structure similar to granular pearlite, thereby reducing the hardness, enabling better processing, and preparing for quenching. These steels are rolled and forged and then cooled, and the resulting structure is lamellar pearlite and reticular. This structure is hard and brittle, which is not only difficult to cut, but is also prone to deformation and cracking during the subsequent quenching process. Spheroidized tissue not only has better plasticity and toughness than flaky tissue but also has slightly lower hardness. When cutting products with spheroidized structures, the tool can avoid cutting hard and brittle cementite and pass through the soft ferrite, thereby extending the service life of the tool and improving the cutting processability of steel [2]. After spheroidizing annealing, cementite is distributed throughout the ferrite matrix as spherical particles to form a spherical pearlite structure. Compared with flaky pearlite, it not only has lower hardness and is easier to process, and during quenching and heating, the austenite grains are not easy to grow, and the product has little tendency to deform and crack during cooling. The heating temperature for spheroidizing annealing is Ac1+(20~40) ℃ or Acm-(20~30) ℃. After a period of heat preservation, it is cooled isothermally or directly cooled slowly. Because austenization is not complete during spheroidizing annealing, the flaky pearlite is only transformed into austenite, and a small amount of carbide is dissolved at the same time. Therefore, spheroidizing annealing cannot eliminate network carbides. If there are network carbides in hypereutectoid steel, they need to be normalized first and then spheroidized annealing to eliminate the carbides to ensure normal spheroidizing annealing.

Studies reveal that when the spheroidization time (t2) is short, the number of carbides and the fraction of fine carbides diminish and subsequently grow as the austenitization time (t1) increases, while the number of flaky carbides keeps rising. The number of carbides and the percentage of fine carbides both fall with extended spheroidization times, while the number of flaky carbides does not rise. As the austenitization period increases, steel's hardness initially drops and subsequently increases. The carbide size and hardness of steel follow the same trend as the spheroidizing time under varying austenitizing conditions. The size of the spheroidized carbides grows and the steel's hardness diminishes with increasing spheroidization time. The longer the austenitizing holding time, the higher the early spheroidization rate. However, in the later stage of spheroidization, the [3] spheroidization rate and the time of austenitization show an opposite trend. As the cooling rate increases, the size of the carbides becomes smaller and the number of flaky carbides increases. Through spheroidizing annealing, the carbon in 8Cr13MoV high-carbon martensitic stainless steel precipitates in the form of spherical carbides and is evenly distributed in the ferrite matrix. Spheroidizing annealing reduces the hardness of stainless steel, improves plasticity, and prevents edge cracks and fractures of the steel during cold rolling [4].

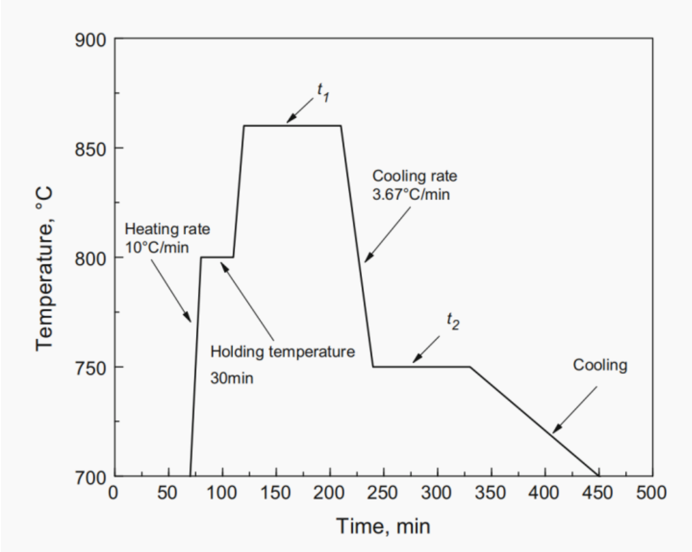

Figure 1. Schematic diagram of thermomechanical test profile of spheroidizing annealing [5].

3.2. Recrystallization annealing

Recrystallization annealing is the process of raising a product that has undergone cold plastic deformation to a temperature above the recrystallization temperature and holding it there for the necessary amount of time. The homogeneous grains are reformed to reduce distortion and the crystallographic flaws produced during the cold plastic deformation process are eliminated through recrystallization. Process of annealing to remove residual stress and strengthen. This kind of annealing generally only needs to set the maximum heating temperature and holding time, and the heating and cooling speed can be ignored. The characteristic of this kind of annealing is that the structure and properties are unidirectional and irreversible changes, and can only change in the direction of equilibrium. As the deformation of steel and other metals increases during the cold working process, after cold working, the crystal lattice will be distorted, the grains will be damaged, broken, or elongated, relative slippage will occur between the grains, and work hardening will occur at the same time, making steel, etc. The metal becomes stronger and harder, but its ductility and fluidity diminish over time, making processing more challenging. These qualities must be removed by recrystallization during the annealing process. During the recrystallization annealing process, due to the results of recovery and recrystallization, cold work hardening is eliminated, and the microstructure is transformed from a fibrous structure into a granular structure. Therefore, the strength of the metal is reduced and the plasticity is improved, thereby restoring the deformation ability to facilitate further processing [6]. The recrystallization temperature and process performance requirements are the primary determinants of the recrystallization annealing temperature. If annealing occurs below the recrystallization temperature, only the recovery process can occur. In addition to eliminating part of the internal stress, most of the cold work hardening effect is retained, the strength of the metal decreases very little, and the plastic recovery is not large. This kind of annealing is suitable for the production of semi-hard products and is called "the first type of low-temperature annealing". If the annealing temperature is higher, the recrystallization process can be fully carried out, the strength of the metal is significantly reduced, and the plasticity is significantly improved. This kind of annealing is suitable for the production of soft products, and is called "the first type of high-temperature annealing". With the first kind of annealing, temperature control is comparatively easy. The maximum heating temperature and holding duration are all that is required to be stated; the heating and cooling rates are not very important. The purpose of homogenization annealing of ingots or castings is to eliminate the inhomogeneity of composition and structure. It is a one-way irreversible change. According to its characteristics, it belongs to the first type of annealing [7]. As an illustration, consider researching the mechanical characteristics of cold-rolled steel and how they vary with annealing temperature. Recrystallization was placed over ten minutes, starting at 600 °C and ending at 700 °C. Good agreement is found with the equilibrium dissolving temperature of M3C carbides, as evidenced by the dramatic fall in Rockwell hardness between 800 and 900 °C and the increase in coarsening ratio of recrystallized grains above approximately 840 °C . The carbides harden by precipitation at 700–800 °C, which is when tensile strength recovers. A precipitation time-temperature plot from a dilution test shows a nose temperature of 800 °C . The dent size decreases to 700 °C and then increases again with increasing annealing temperature, strongly proportional to the austenite grain size [8].

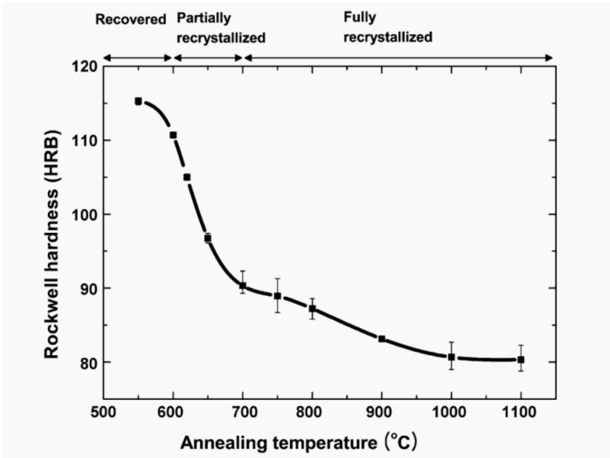

Figure 2. Change in Rockwell hardness with annealing temperature in Fe-18Mn-0.6C-1.5Al TWIP steel. The annealing annealing time at each temperature was 10 min [9].

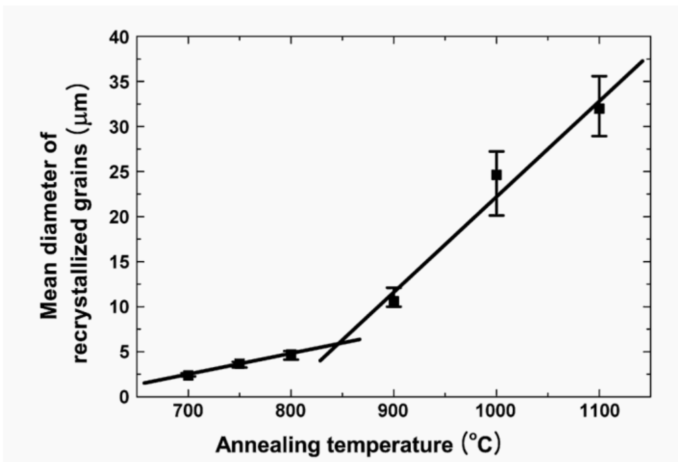

Figure 3. Variation of the mean diameter of recrystallized grains with annealing temperature in Fe-18Mn-0.6C-1.5Al TWIP steel. The annealing time at each temperature was 10 min [10].

4. Conclusion

Through in-depth explanations and examples of spheroidizing annealing and recrystallization annealing processes, this article demonstrates that spheroidizing annealing can transform lamellar cementite in steel into spherical cementite. It is suitable for high-carbon steel parts with a carbon content of more than 0.6%. Bearing steel, carbon tool steel some alloy tool steels, and part of spring steel all belong to this type of steel. Spheroidizing annealing is usually applied after blank forging, before cutting, and after final heat treatment. The functions and purposes of spheroidizing annealing are: to improve the plasticity and toughness of steel, improve cutting performance, reduce the tendency of overheating and deformation, and cracking during quenching and heating so that steel parts have sufficient strength, hardness, wear resistance, and contact fatigue resistance. properties and fracture toughness. For recrystallization to take place, the material needs to be heated above a specific temperature and undergo a specific quantity of cold plastic deformation. The lowest recrystallization temperature is the lowest temperature at which recrystallization takes place. For typical metal materials, the minimum recrystallization temperature is 0.4T melting. The recrystallization annealing heating temperature should be 100–200°C higher than the lowest recrystallization temperature (steel recrystallization temperature is around 450°C), and after appropriate heat preservation, it should be cooled gradually. Recrystallization annealing can significantly reduce the strength and hardness of steel, improve plasticity, eliminate work hardening, release stored energy, and restore properties to the level before deformation.

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