New Type of Quenching Medium—Aerosol Quenching
Research Summary

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Abstract. Heat treatment has a significant effect on the mechanical properties of steel. In the heat treatment process of steel, the quenching process is particularly important. The quenching process largely determines the final quality and performance of the material. Compared with the traditional quenching process, the aerosol quenching process has many advantages. Adjusting the pressure of air and water, the cooling rate of the gas mist is between static air cooling and flowing water cooling, and the cooling rate is controllable, which can realize the ideal quenching cooling process. The components of the aerosol are water and gas in the air, with low energy consumption and no pollution. This article summarizes the research status of aerosol quenching based on traditional quenching process and new quenching process.

1. Overview of traditional quenching process

The traditional quenching process mostly refers to the quenching process of steel objects, which is the most important and most versatile process in the heat treatment process. The essence of the quenching of steel objects is that the austenite structure generated by heating and holding is rapidly cooled to below the austenite critical temperature. The difference in Gibbs free energy between the austenite parent phase and the new phase is used as the driving force to promote the composition of the parent phase towards a phase organization of different shapes and properties.

In the process of steel quenching, the greater the cooling capacity of the quenching medium, the easier it is to harden the object and the thicker the hardened layer. However, it is also easier to produce a higher quenching stress, so that the quenched object may be deformed or cracked. When the cooling capacity of the quenching medium is insufficient, it is difficult to obtain the desired organizational state. In the traditional quenching process, different quenching media are generally selected according to the composition of the metal object. According to the different types of quenching media used, the traditional quenching process can be divided into water quenching, salt or alkali aqueous solution quenching, oil quenching and molten salt quenching. For different quenching specimens and different quenching purposes, in addition to the selection of quenching medium, it is sometimes necessary to adopt appropriate quenching methods. These quenching methods include: single-liquid quenching, dual-liquid quenching, staged quenching, austempering, pre-cooling quenching, and partial quenching and cold treatment, etc.
2. Research on new quenching medium
According to the ideal quenching cooling curve of the steel in Figure 1, the high-temperature zone cools slowly; the next is rapid cooling, so as to smoothly pass through the undercooled austenite unstable zone; the low-temperature zone before and after reaching the Ms point can be considered slow cooling, which can reduce cooling. The thermal stress added by the temperature difference between the inside and outside of the workpiece during cooling and the structural stress generated during the transformation of martensite. Under ideal cooling conditions, the martensite structure can be obtained on the premise of reducing the stress generated in the workpiece during quenching and avoiding deformation or cracking of the workpiece.

In view of the advantages and disadvantages of the quenching medium used in the traditional quenching process, the cooling characteristics do not meet the description of the ideal quenching cooling curve. Therefore, seeking a new quenching medium with a cooling capacity between water and oil and a cooling characteristic curve close to ideal conditions has become the goal of the quenching research field. In order to solve this problem, at present, there are mainly the following research directions.

2.1. Organic aqueous solution quenching process
In view of the fact that water is a cheap quenching medium with strong cooling capacity, countries around the world are developing the use of organic aqueous solutions as quenching medium. The method is to improve the cooling characteristics of water as a quenching medium by adding organic matter.

Common organic aqueous solutions for quenching include: polyvinyl alcohol (PVA) aqueous solution, polyether (PAG) aqueous solution, and sodium polyacrylate aqueous solution (SPA). Among them, polyvinyl alcohol aqueous solutions have attracted the most attention. The use of organic aqueous solution as the quenching medium is a new type of quenching process that is widely used in my country. From a trend point of view, organic polymer quenching agents have developed rapidly and are currently the mainstream of water-based quenching media.

2.2. Gas quenching process
High-pressure gas quenching equipment is used for gas quenching. This solution can obtain different quenching cooling effects by selecting different gases, adjusting gas pressure or adjusting gas flow rate.

Compared with the traditional quenching medium quenching, the high-pressure gas quenching process has many advantages, such as: uniform quenching, no quenching spots, reduced distortion, avoiding quenching cracks, low environmental pollution, and controllable process parameters.
At present, the gases used in high-pressure gas quenching technology mainly include hydrogen, helium, nitrogen, argon and other gases. Figure 2 shows the relative cooling rates of different gases under the same gas pressure and other working conditions. Although hydrogen has the best heat exchange and cooling capacity, steel is easily decarburized under hydrogen atmosphere, and hydrogen is easy to explode. Considering the quenching effect and safety, hydrogen is generally not used as a quenching medium. Helium quenching and cooling capacity is also good, but it is a rare gas, the preparation cost is expensive, and it is rarely used as the quenching medium. The cooling capacity of nitrogen is relatively poor, but the cooling capacity can be enhanced by increasing the nitrogen pressure to increase the flow field speed. Because of the low cost of nitrogen preparation, nitrogen quenching has been extensively researched and promoted. When quenching titanium alloy steel and high chromium alloy steel, considering the nitriding factor, other gases must be considered as the quenching medium at this time.

The flow rate of high-pressure gas passing through a certain section per unit time is closely related to the heat transfer coefficient of the quenching interface during quenching. Under the same flow rate conditions, the relative cooling rate increases with the increase of gas pressure, as shown in Figure 3. In addition, the incident angle and turbulence of the gas flow affect the quenching and cooling capacity of the gas flow field. For the quenching process of high-pressure gas quenching, the turbulent flow perpendicular to the surface of the workpiece is more conducive to cooling and heat exchange than the laminar flow parallel to the surface of the workpiece.

Research on quenching shows that the cooling effect of gas mixed in a certain proportion is better than that of single gas quenching. At present, the mixed gas used for quenching is mainly mixed with hydrogen, helium, nitrogen, argon and other gases in a certain proportion. Because of the high cost of some of these precious gases, it is necessary to use cheap ones in order to meet the actual application needs in engineering gas.

As far as the high-pressure gas quenching process has been put into use, although it has many advantages and satisfies the production needs of the industry to a certain extent, it also has many drawbacks that limit the promotion of high-pressure gas quenching.

2.3. Gas atomization quenching process

High-pressure gas quenching cannot be widely promoted due to cost and other reasons, and cannot meet social production needs. In today's era where economic benefits are emphasized, a new type of low-cost, high-efficiency quenching process is urgently sought, and the gas atomization quenching process has emerged.

The atmospheric and high-speed gas quenching device independently developed by Cheng Heming of Kunming University of Science and Technology and other scholars can achieve the same effect as vacuum quenching technology, and also laid a certain foundation for the development of atomization quenching equipment. The gas atomization quenching process is a new type of medium injection quenching process scheme that adds atomized quenching liquid on the basis of gas quenching to
enhance the quenching cooling capacity. This solution not only has great economic advantages, but also has a wide range of adjustable quenching cooling capacity. The current research status of this quenching process will be detailed in the next section.

3. Research status of gas atomization quenching

The gas atomization quenching process is developed on the basis of the gas quenching process. The water stream is broken into mist by high-speed gas to form a mixed mist medium, which is then sprayed on the surface of the specimen for quenching and cooling. It is different from the above-mentioned quenching process. The quenching is carried out in a normal pressure environment without a vacuum furnace, which reduces the cost of equipment investment. At the same time, high-speed gas and atomized water are sprayed to the surface of the workpiece for cooling, which greatly improves the quenching cooling capacity. By controlling the amount of gas injection and water flow, the quenching cooling capacity can be controlled.

Atomized cooling technology has many applications in the chemical, environmental engineering and aerospace fields. Liu Zhenhua conducted an experimental study on the boiling critical heat flux of a water-compressed air mixed spray flow of small-size water droplets when cooling a high-temperature horizontal heat transfer surface, and determined the influence and quantitative relationship of the spray conditions on the critical heat flux. Gao Shan et al. conducted a numerical simulation study on the impact of a single droplet on a constant temperature heating surface, and concluded that the smaller the diameter of the droplet, the greater its flow velocity, and the better the cooling effect. Scholars such as Zhang Hongxing studied the steady-state operation and heat transfer performance characteristics of the spray cooling system, and analyzed the influence of factors such as flow rate, pressure drop, heat flux and spray height on the system characteristics and heat transfer performance through experiments.

At present, domestic research on aerosol quenching is mostly concentrated in universities and research institutes, and it is still in the initial stage of experiments.

Guan E and others analyzed the cooling characteristics of the liquid-gas atomization medium, studied the development of aerosol quenching equipment and the factors that affect the aerosol quenching, and pointed out that the structure of the atomizer is important for simplifying the entire quenching equipment and obtaining an ideal The mist "moment" of hydraulic and thermodynamic characteristics is of decisive significance. The quenching cooling process is suitable for the quenching of large and heavy shafts and plate parts, and can ensure the hardness increase without distortion and quenching cracks.

Li Qitang and others tested the temperature field changes during the aerosol quenching process of the 34CrMo4 petroleum drill pipe welds. Using the finite element program, the temperature field during the quenching cooling process was numerically calculated, and the relationship between the heat exchange coefficient and the spray time was analyzed. The phase change enthalpy is processed by the equivalent specific heat capacity method, and the analysis result meets the actual production needs.

Du Fengshan et al. established a non-linear finite element model of the three-field coupling of structure, temperature and stress to numerically simulate and analyze the cooling process of spray cooling. The model includes continuous subcooled boiling heat transfer boundary and variable physical properties, etc. Conclusion: For large non-hardenable parts, under the same cooling conditions, the maximum surface tensile stress increases as the size of the workpiece increases. During the cooling process, the maximum tensile stress position on the interface moves to the surface.

Zhu Dongmei et al. used a convective heat transfer model to determine the influence of the volume fraction of gas and water, mixed incidence velocity, gas and water incidence velocity ratio, and spray distance on the heat transfer characteristics of aerosol quenching for aerosols with a discrete volume fraction less than 12%. Conclusion: The heat transfer coefficient decreases with the increase of the gas fraction, and increases with the increase of the spray flow velocity. The larger the water and gas velocity ratio, the lower the heat transfer capacity and the smaller the spray height. The heat transfer coefficient Bigger.
Shanghai Jiaotong University invented a gas mist circulating high-pressure gas quenching cooling device, which uses high-pressure mixed gas mist as the quenching medium. This solution solves the problem of insufficient cooling capacity of high-pressure gas quenching equipment, reduces the cost of gas use and relatively low equipment cost.

The quenching experimental research team of Kunming University of Science and Technology has improved on the basis of the research of the atmospheric pressure high-speed gas quenching box, and conducted a research on the quenching scheme with the atmospheric pressure high-speed aerosol two-phase flow as the quenching medium. The quenching cooling capacity is relative to the gas quenching. Significantly improved. In addition, a normal-pressure high-speed aerosol spray device has been developed, and the quenching uniformity has been significantly improved.

Ding Dongfang, Shao Baodong and others used a quenching box aerosol quenching device to conduct experimental research on the aerosol quenching of the low-alloy cutting tool steel 9SiCr under different initial pressures and different water-vapor ratios. They concluded that: When the mixing ratio is the same, the greater the initial pressure, the greater the cooling rate of the mixed aerosol medium, which makes the temperature difference between the surface and the center of the test piece larger. When the initial pressure is the same, the greater the water-gas mixture ratio, the greater the temperature difference between the surface and the center of the quenched specimen.

Teng Hui of Dalian University of Technology used aerosol as the quenching medium to conduct a quenching experiment on boron steel 22MnB5. First, the influence of aerosol spraying process parameters on the properties of boron steel 22MnB5 is studied, and response surface analysis is carried out. Through the range analysis and variance analysis of the orthogonal test results, it is known that the initial quenching temperature has the greatest impact on the hardness of the quenched parts, and it is more significant. Although the quenching height and the gas-water pressure ratio also affect the hardness of the quenched parts, the effect is not significant.

4. Advantages of gas atomization quenching
Experiments under specific working conditions show that atmospheric high-speed aerosol quenching has the effects of both gas quenching and water quenching. It not only has a good cooling effect, but also reduces residual stress and deformation. It is an ideal quenching medium. The research results also show that under the condition that the mixing ratio of water and nitrogen remains unchanged, as the gas pressure increases, the quenching cooling rate increases; under the same nitrogen pressure, increasing the mixing amount of water will increase the quenching cooling rate.

Experimental research shows that the atmospheric high-speed aerosol quenching process has obvious advantages compared with other quenching processes:
- Inheriting the advantages of gas quenching, after quenching, the specimen has small distortion, small residual stress, and no oxidation or carbon increase on the surface.
- Compared with gas quenching, the quenching cooling capacity is improved, and the quenching experiment cost is reduced. In addition, the cooling capacity can be controlled by adjusting the water flow, air flow and ratio during quenching.
- Compared with traditional oil quenching, atmospheric high-speed aerosol quenching has no pollution to the environment and improves the operating environment.

At present, the use of aerosol as a medium to quench this new quenching process is not convenient for large-scale promotion, and a large research investment is needed to better reflect its process advantages.

5. Significance of research on gas atomization quenching
Due to the defects of the cooling characteristics of the traditional quenching cooling medium, a new quenching medium whose quenching cooling capacity can be adjusted in a larger range is urgently sought. Although the high-pressure gas quenching process can be controlled within a certain range, the equipment cost is high, and the gas cost is high. At present, it can only replace the traditional oil quenching and salt bath quenching. Atmospheric high-speed aerosol quenching can not only reduce
the equipment cost, but also greatly reduce the gas cost. The cooling water used can be recycled, and
the cooling capacity is greatly improved, which can be controlled within a larger cooling capacity
range. However, there are still many problems to be solved in the practical application of the
atmospheric high-speed aerosol quenching process, which restricts the promotion of the process.

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References
[1] Ding D., (2011) Numerical simulation and experimental study of atmospheric pressure aerosol
quenching process. Department of Engineering Mechanics, School of Civil Engineering,
Kunming University of Science and Technology.
[2] Shao B., Ding D., Wang L., etc. (2011) Research on the Cooling Capacity of Atmospheric High
Speed Water Spray Quenching. Journal of Kunming University of Science and Technology
(Natural Science Edition).
[3] Teti T., Fried Z., Felde I., (2001) Computer simulation of steel quenching progress using a
multi-phase transformation model. Computational Material.
[4] Teng H., (2018) Research on Mechanical Performance Prediction of High Strength Boron Steel
by Spray Quenching. Dalian University of Technology.