Analysis on Influencing Factors and Control Measures of Metal Materials Heat Treatment Deformation

Yanli Yu*

1Jiangxi Vocational College of Mechanical & Electrical Technology, Jiangxi 330013, China

*1910012008@stu.jci.edu.cn

Abstract—The scientific application of heat treatment technology is aimed at improving the performance of metal materials, which is very important for improving the utilization rate of metal materials. In the process of heat treatment, metals are easily affected by factors and deform, which leads to metal materials can't be used normally. Therefore, it is necessary to deeply analyze the factors affecting heat treatment, and then formulate effective control measures to reduce the probability of metal material deformation and improve the service performance of metal materials. Based on this, this paper explores the influencing factors and control measures of heat treatment deformation of metal materials.

1. Introduction

With the deepening of China's economic system reform, all walks of life are showing a trend of vigorous development, and the level of industrialization is obviously improved. Especially since entering the new era, the application of metal materials is more and more extensive, involving industrial manufacturing, aerospace, fire safety, medical services and many other fields, so the quality requirements of metal materials are becoming more and more strict. In order to meet the use requirements of metal materials in different fields, it is necessary to change the properties of metal materials through heat treatment. However, the heat treatment process will lead to the deformation of metal materials, which will lead to the failure of metal materials to achieve the expected use effect. How to take effective measures to control the deformation of metal materials during heat treatment has become an urgent problem to be solved. In the process of heat treatment, metal materials have extremely high requirements on the treatment environment and technology. It is necessary to comprehensively analyze the causes that may lead to the deformation of metal materials, and optimize the operation process according to actual use requirements, so as to achieve high-quality heat treatment effect.

2. Overview of heat treatment of metal materials

Heat treatment is an important means of metal material processing, which can eliminate the non-uniformity of chemical composition, reduce the internal residual stress, avoid the defects of metal materials, and then promote the change of internal structure and improve the performance of materials. However, if the heat treatment is improper, it will not only make the metal materials unable to meet the use requirements, but also cause waste of manpower and material resources. According to the practice, it is found that the internal structure of metal materials will change during the heating and cooling process, and the high-temperature phase of the quenched metal materials will change into hard phase, which will enhance the hardness of materials [1]. At the same time, in the process of heat
treatment, it can also protect the metal materials, so as to avoid reducing the carbon content of the materials by oxidation. In 1960s, plasma field effect was used for plasma nitrocarburizing and low temperature nitriding. Up to now, there are many kinds of heat treatment processes for metal materials. The commonly used heat treatment process is to heat metal materials to a certain temperature, and then slowly cool down after a certain period of time, or quickly cool down in water or oil after heating to a certain temperature to change the properties of materials [2]. There are three common methods of metal heat treatment: integral heat treatment, surface heat treatment and chemical heat treatment. Surface heat treatment mainly adopts flame heating quenching, induction heating quenching and laser heating treatment, while chemical heat treatment mainly adopts carburizing and nitriding. Heat treatment has a detailed technological process, which can be divided into the following steps:

| Technology name          | Function                                    | Applied range                                                                 |
|--------------------------|---------------------------------------------|-------------------------------------------------------------------------------|
| Anneal                   |                                             |                                                                               |
| Homogenizing annealing   | Component uniformity                        | Steel castings, forged and rolled parts with component segregation           |
| Full annealing           | Tissue refinement, reduce hardness          | Forging, welding and rolling parts of hypoaeutectoid steel                    |
| Isothermal annealing     | Tissue refinement, reduce hardness, and prevent white spots | Carbon steel, alloy steel, high alloy steel, stamping parts, etc             |
| Under annealing          | Tissue refinement, reduce hardness          | Medium and high carbon steel, low alloy steel                                 |
| Relief annealing         | Relieve internal stress                     | Castings, welded parts, forged and rolled parts                              |
| normalizing              |                                             |                                                                               |
| Homogenizing annealing   | Improve performance, increase hardness and reduce surface roughness | Low-carbon steel                                                             |
| Full annealing           | Uniform structure, grain refinement, and preparation for quenching | Medium carbon steel and alloy steel                                           |
| Isothermal annealing     | Elimination of reticular carbide            | High carbon steel, high alloy steel                                          |
| Under annealing          | Eliminate the network carbide in the infiltrated layer | Carburizing steel                                                           |
| Relieve annealing        | Eliminate abnormal structures such as coarse grains | Castings and forgings                                                        |
| Single medium quenching  | Final heat treatment                        | Low-requirement carbon steel                                                 |
| Double medium quenching  |                                             |                                                                               |
| Quench                   | Quench in a single cooling medium such as oil, water and air to improve hardness and strength | The most common method                                                        |
| Step quenching           | Reduce deformation and cracking             | Parts with complex shapes and strict deformation requirements                |
| Bainite isothermal quenching | Reduce deformation and cracking, and obtain good comprehensive performance | High carbon die steel parts                                                  |
3. Analysis of Metal Material Deformation Mechanism

3.1. Internal Stress Shaping
In the process of heat treatment of metal materials, heating, heat preservation and cooling should be carried out. In many cases, the temperature of heating and cooling can't be effectively controlled, and the uniformity of metal materials in solid phase transformation is poor, which easily leads to internal stress and plastic deformation of metal materials [3]. There are many reasons for the formation of internal stress, among which the structural stress is mainly due to phase transformation, while the thermal stress is due to the thermal expansion of metal materials caused by heating and cooling. Different metal parts have different use requirements, different shapes and sizes, and different conditions for hot working plasticity, resulting in various deformations, which easily lead to defects in metal materials.

3.2. Specific Volume Deformation
Because the internal structures of different metal materials are obviously different, the slight changes in size and volume during heat treatment are called specific volume deformation. Although the degree of deformation is slight, it has great influence on the iron content, hardenability and alloy content of the material. Specific volume deformation is more uncertain than internal stress plasticity, and the number of thermal deformation directly affects the deformation form.

3.3. Creep Factor
Creep is mainly caused by the increase of plastic deformation of metal materials in hot state. If effective protection measures are not taken, the continuous influence of gravity will easily cause a large degree of bending deformation. In the process of heat treatment, the creep of metal materials is different from the plastic deformation. Plastic deformation is usually the deformation that occurs when the stress exceeds the elastic limit of metal materials, while creep, even if the stress reaches the material limit, is prone to creep as long as the stress acts for a long time [4]. Generally speaking, metal materials will show creep properties under certain conditions, especially in the process of heat treatment, in order to change the shape of materials, stress needs to be continuously applied, and creep is easy to occur.
4. Influencing Factors of Metal Heat Treatment Deformation

4.1. Stress Factor
For the heat treatment of metal materials, professional technologies and methods are needed to standardize the operation. However, due to the corresponding particularity of each metal material and the influence of various external factors, the temperature distribution in the heat treatment process can not be fully guaranteed, and there is obvious internal imbalance, which will inevitably have some adverse effects on metal materials [5]. During the process of heating and heat preservation of metal, the ambient temperature will also change, which will affect the internal stress of the material and lead to the deformation of the material. In addition, if the stress distribution applied by heat treatment is uneven, the probability of material deformation will increase, which will easily reduce the quality of metal materials.

4.2. Quenchant
During the heat treatment of metal materials, quenchant is one of the important factors that affect the heat treatment effect, and it is also closely related to the deformation of metal materials. If the selected quenchant lacks rationality or has quality problems, it cannot be guaranteed that the quenching process meets the standard. In addition, the lack of effective control of the stirring speed and operation method of the medium will adversely affect the heat treatment of metal materials, resulting in material deformation.

4.3. Pretreatment
Pretreatment process can effectively avoid the deformation of metal materials and should be strictly implemented before heat treatment. However, although pretreatment can achieve the effect of stress relief, due to the influence of environmental factors, it has adverse effects on the reactor cooling effect, and it is difficult to reach the cooling standard, which will also affect the structure of materials [6]. In addition, due to the difference of pretreatment technology, normalizing pretreatment method will increase the probability of material deformation.

5. Deformation Control Principle of Metal Materials Heat Treatment

5.1. Scientficity
In the process of heat treatment of metal materials, in order to effectively avoid deformation, we should pay attention to the application of control methods to ensure that the whole process of heat
treatment is scientific. During the heat treatment, we should strictly abide by the basic principles of science, standardize the treatment process, scientifically apply technology and equipment, scientifically control the deformation factors of heat treatment, make the metal materials reach the standard category, and effectively improve the use effect of metal materials.

5.2. Practicability
As a non-renewable resource, the storage of metal materials is very limited. When using metal materials, practical principles should be strictly followed to avoid wasting materials due to improper processing. In the process of heat treatment of metal materials, it is necessary to scientifically and reasonably control the deformation, establish the idea of saving resources and protecting the environment, and realize the coordinated development of industry and ecology [7]. At the same time, based on the basic principle of practicality, the heat treatment process used should have high efficiency, effectively improve the utilization rate of metal materials, and achieve the expected benefits.

5.3. Convenience
In the process of metal heat treatment, we should reasonably choose the treatment process and site conditions to meet the heat treatment standard. At the same time, we should improve the fault-tolerant rate of deformation control scheme and effectively reduce the adverse effects of environmental factors. In addition, we should scientifically optimize the heat treatment technology, reduce the difficulty of operation, and make the heat treatment orderly, so as to reduce the possibility of metal material deformation.

6. Control Measures for Heat Treatment Deformation of Metal Materials

6.1. Pay Attention to Pretreatment Link
In the process of metal heat treatment, normalizing and annealing will lead to deformation of metal materials. The higher the normalizing temperature, the greater the internal deformation of materials, so it is necessary to control the normalizing temperature scientifically. From the practical application point of view, isothermal quenching method should be selected after normalizing to effectively control material deformation factors. Before heat treatment, we should effectively improve the molecular structure of materials and enhance the internal uniformity [8]. At the same time, we should reasonably select and apply the process according to the specific use function to ensure that the temperature will not affect the heat treatment, effectively reduce the possibility of metal material deformation, and lay a good foundation for material heat treatment.

6.2. Reasonable Selection of Quenchant
Quenching plays an important role in the heat treatment of metal materials, which can control the internal stress of materials and avoid the deformation of metal materials. In order to ensure the standard of quenching operation for heat treatment of metal materials, it is necessary to strictly abide by the treatment principles and processes and improve the treatment effect. In the quenching and cooling process of metal materials, it is necessary to scientifically control the temperature to prevent deformation due to poor cooling uniformity. In the quenching process, water and oil are the main media, and the cooling speed of water can reach 600°C/s (550-650 °C cooling condition), and even at 200-300°C cooling condition, the speed can still reach 270°C/s. When the cooling speed is high, material deformation is easy to occur [9]. In order to reasonably control the deformation factors, we can use saline water, alkaline water and other media. The cooling rate of oil at 200-300°C is about 20°C /s, which can control the quenching deformation within a certain range and avoid serious material cracking. However, at the temperature of 550-650°C, oil cooling not only takes a lot of time, but also can't form martensite, which leads to great limitations in application.
6.3. Select the Applicable Cooling Method
At present, single-liquid quenching, double-liquid quenching and graded quenching are the most commonly used cooling methods. Among them, single-liquid quenching is relatively simple, it uses a single medium such as oil, water and air, and it has a high degree of mechanization, which is the most commonly used cooling method. However, there are some defects in quenching speed, which often can't meet the use requirements of materials, and material deformation defects are easy to occur. At the same time, there are some problems in single oil quenching, such as poor uniformity and low hardness, which can not meet the standard requirements. Double-liquid quenching is mainly cooled by water and oil, water and air, oil and air. First, the material temperature is reduced to 300°C in the medium with fast cooling speed, and then put into another medium, which is suitable for medium and high carbon steel parts and large alloy steel parts, and can effectively control quenching crack and deformation [10]. Graded quenching is to form martensite after salt bath or alkali bath treatment, so that the temperature inside and outside the material is the same, and finally, it is cooled in the air. However, the effect of graded quenching is poor, and its application scope is limited. It is usually only suitable for small-size and high-precision metal materials.

6.4. Use Scientific Clamping Method
In order to ensure the deformation of metal materials to be well controlled, we should carry out heating and cooling according to the standard to ensure the uniform stress of the material structure. In the specific operation process, we should adopt appropriate clamping methods, give full play to the function of the fixture, meet the verticality standard for the disc workpiece, and adopt the vertical mounting method reasonably. In addition, we can properly apply gasket components, optimize the operating conditions of heat treatment by overlapping gaskets and supporting gaskets, and effectively control the influence of deformation.

6.5. Improve Machining Technology
For metal materials, there are obvious fixing characteristics in the heat treatment process, but due to the differences in material properties, the corresponding heat treatment processes will be different. Heat treatment is the key process of metal material processing, but due to the particularity of some metal materials, it is often impossible to achieve the expected heat treatment effect. This requires us to reasonably improve the machining technology, reduce the influence of residual stress inside the material, and control the deformation within a reasonable range. If the material after heat treatment exceeds the deformation range, it is necessary to comprehensively analyze the specific factors causing the deformation, ensure the scientificity of mechanical processing and effectively solve the material deformation problem.

Fig. 2 Mechanical heat treatment
6.6. Eliminate Heat Treatment Residual Stress
During the heat treatment of metal materials, it is particularly necessary to control the residual stress to ensure the shape, size and properties of the materials. Therefore, we should pay attention to the method of eliminating residual stress in heat treatment. According to the characteristics of metal materials, we can improve the stress resistance of materials by adding alloy elements, which can not only effectively control the deformation problem, but also improve the service performance of metal materials, so that they can meet the actual use requirements. In addition, before heat treatment of metal materials, we must carefully check the surface cracks, scratches and roughness of metal materials, and deal with the defects of metal materials themselves, usually by welding, high-temperature plastic deformation and other methods to lay the foundation for the heat treatment process [11].

6.7. Scientifically Configure Part Structure
During the initial heating of metals, we should pay attention to the scientific configuration of parts and control the thickness of materials according to production standards. In the production process, we should ensure the smooth surface of the material and avoid stress concentration to avoid structural deformation. In addition, in order to control the influence of cooling rate on metal materials, we should formulate corresponding heat treatment scheme according to the test data to further optimize the properties of metal materials. In this process, we should formulate perfect process indicators and operation procedures, and assign special personnel to supervise and guide the operation process to effectively control the influence of human factors.

7. Conclusion
To sum up, in the process of heat treatment of metal materials, we should pay attention to the influence of deformation factors, choose appropriate control methods, and improve the performance of metal materials, so as to ensure that the heat treatment deformation does not exceed the specified requirements to meet the use requirements of metal materials. Therefore, it is necessary to strengthen the analysis of deformation mechanism of metal materials, scientifically control internal stress, reasonably select quenchant and improve the standardization of heat treatment to achieve the expected heat treatment effect.

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