Study on the effect of grain refinement of deformable heat treatment on steel properties

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Abstract: Iron and steel is the foundation and symbol of a country's industrial strength, which plays an important role in the process of industrial modernization. Because of its high strength and good mechanical properties, it is widely used in all fields of society. Therefore, how to improve steel performance, mass production, reduce steel energy consumption and cost is very important. In this paper, the grain refinement principle of steel deformation-heat treatment and its influence on steel properties are expounded and analyzed. Meanwhile, the experimental data show that grain refinement of deformation-heat treatment has obvious effect and simple method to improve steel properties, which is conducive to the large-scale production of high-performance steel and plays an important role in the industrial development of China.

1. Introduction
With the rapid development of steel technology in the world, China's low-end steel overcapacity, high-end just short of supply, the demand is increasing. In addition, higher requirements are put forward for environmental protection and energy saving, high strength, high plasticity, easy weldability, long life, machinability, mass production and low cost of steel. For example, China's production of advanced excavator equipment, the need for yield strength of 600MP class of high-performance steel; The container manufacturing industry needs hot and cold steel plates with yield strength of 550-700MP; Aircraft carriers need high performance steel with yield strength of 1100MP and high temperature and corrosion resistance. Strategic nuclear submarine to descend to 900 meters, need yield strength of 2000MP super steel; Many other industries, such as high-speed railway and its track, machine tool manufacturing, oil pipelines, bridge skeleton and so on, have put forward very high requirements for steel performance.

2. Method of grain refinement
The properties of steel are not only related to its constituent elements, but also closely related to the grain refinement structure. There are many ways to refine grain. It includes deformation heat treatment refinement, metallurgical treatment refinement, magnetic or electric field treatment refinement, mechanical ball milling refinement, amorphous crystallization refinement, strong plastic deformation refinement, etc. Researchers from all over the world have put forward many constructive and practical measures and Suggestion for these grain refinement methods. These methods of grain refinement have both advantages and disadvantages. However, at present, one of the most widely used methods to effectively improve the properties of steel in industrial production is the deforming heat treatment grain.
superrefinement method, which solves the worldwide problems such as limited grain refinement technology, low degree, complex process, high cost and inability to achieve continuous large-scale industrial production.

3. Ultrafine grain of deformation heat treatment
Deformable heat treatment refining is a combination of heat treatment of solid phase change or recrystallization and mechanical deformation technology, which can effectively refine austenite grains and obtain ferrite with fine grains. Deformation heat treatment can eliminate stress, prevent deformation, restore plasticity, refine grain, improve microstructure, and obtain high performance steel with higher strength and better toughness.

3.1. Methods of deformation heat treatment
Deformable heat treatment is generally divided into high temperature deformable heat treatment and low temperature deformable heat treatment. High temperature deformable heat treatment means that the steel is heated to a temperature of 30-50 degrees Celsius above AC3, stay for a period of time, make the grain structure of steel to achieve complete austenitizing. Then, the austenite is subjected to intense deformation, which is more than 70% in general. Under constant temperature, the austenite is initially recrystallized and quenched before the grain grows to increase the number of nucleation so as to obtain the fine grain quenching structure. Low temperature deformable heat treatment means to heat the steel to austenite state for a certain period of time. Then, it is cooled to 30-50 °C below AC3 rapidly and deformed. Finally, it is quickly quenched and cooled to room temperature.

3.2. Features of deformation heat treatment refinement
Deformation heat treatment refining process is simple, using mechanical deformation, heat treatment and other conventional technology, do not need special preparation process, cheap materials, are commonly used alloy elements, there is no precious metal, such as: manganese, carbon, vanadium. Supersteel with fine structure, higher strength, stronger hardness and better plasticity can be obtained even without the addition of alloying elements such as copper and nickel. In 2017, China produced super steel. It was tested and measured that the cost of this super steel was less than 60 yuan per kilogram, only one fifth of that of martensite aging steel. Its performance was similar to that of titanium alloy, and its hardness was harder than diamond. The grain diameter of this steel is very small, with grain diameter up to 0.5-1 micron, yield strength up to nearly 2200MP, elongation up to about 6%, and section shrinkage up to 25%. In addition, test measured, under 750 degrees Celsius, the conventional pressure for this kind of steel is five times the reduction of the particle deformation, steel organization and oblique slide, can let two particles on the surface of the steel plate into each other, together, form a smooth polished, gap less than 0.1 mm, almost no welding mark, there will be no strength degradation phenomenon, and high plasticity, can be up to 2 times of ordinary steel, which can realize large-scale industrialized production, environmental performance and high security, low carbon emissions, use convenient, price cheap, can be used for construction, aerospace, shipbuilding, war industry and other fields, it is of great significance to improve the production level of high-end steel products in China.

3.3. Influence of grain refinement of deformable heat treatment on properties of steel
The relationship between steel strength and grain diameter can be determined by the Hall-Petch formula \( \sigma_s = \sigma_i + Kyd^{-0.5} \). \( \sigma_s \) refers to the yield strength of steel at room temperature. \( \sigma_i \) and \( Ky \) are constants associated with steel; \( D \) is the diameter of grain. This formula applies to grains of 0.3 to 400 microns in size. The relation between grain size \( D \) and toughness is: \( \beta_{T_c} = \ln B - \ln C + 0.5 \ln d \). Where \( \beta \), \( B \), \( C \) are constants, and \( T_c \) is the brittle transition temperature. It can be concluded from the formula that the finer the grain is, the higher the strength and hardness are. Because the smaller the grain size of the steel, the larger the total grain boundary area, the more dislocation barriers, resulting in the need for coordination of different orientation of the grain grains, the higher the resistance of the steel to plastic
deformation; The finer the grain of the steel is, the lower the brittle transition temperature is, indicating that the higher the resistance to cold and brittle is, the higher the plasticity and toughness are. The smaller the grain size of steel is, the more grains are contained in the unit volume. When impacted by huge external force, the more uniform the grain deformation is, and the larger the plastic deformation occurs before fracture, resulting in the simultaneous increase of the strength and plasticity of the steel. The greater the work consumed by the steel before fracture is, the better its toughness is.

4. Analysis of deformation heat treatment data

4.1. Take 09MnNb steel as the test material

Table 1. 0.09MnNb Steel Content of domestic components (mass fraction, %)

|     | C  | Mn  | Si  | Nb  | S  | P  |
|-----|----|-----|-----|-----|----|----|
| 0.15| 0.87| 0.41| 0.05| 0.02| 0.03|

The experimental materials were heated to 890℃ and fully austenitized. Normal rolling of the first steel; The second section of steel is controlled rolling, known as deformation heat treatment. After tensile performance test and notch impact test, the strength and impact value data are paired as shown in Table 2.

Table 2. Yield strength and impact value

| Method            | Yield strength (σb, MPa) | Impact value (aK, J/cm²) |
|-------------------|--------------------------|--------------------------|
| Normal rolling    | 380                      | 6.5                      |
| Controlled rolling| 520                      | 90                       |

4.1.1 Analysis of results

According to the data in Table 2, the yield strength of the steel after deformation heat treatment is 140MPa higher than that of the normal rolled steel, and the impact value is 83.5j/cm². It can be concluded that deformation heat treatment can significantly improve the strength and toughness of the steel.

4.2 Take 20Mn2 steel as the test material

Table 3. Chemical composition of test steel (mass fraction, %)

| Materials | C  | Mn  | Si  | Nb  | ZrC Volume percentage |
|-----------|----|-----|-----|-----|-----------------------|
| S1 Steel  | 0.23| 2.40| 0.64| 0.05| 0.2                  |
| 20Mn2     | 0.17-0.24| 1.4-1.8| 0.17-0.37| -  | -                    |

Taking 20Mn2 steel as the experimental material, after deoxidizing steel in the melting furnace, 0.05% Nb and 0.20% ZrC particles are added to obtain steel S1. The chemical composition is shown in Table 3. Then, the rolling deformation, shape variable up to 85%, the final rolling temperature is controlled at 890℃, steel S1 is cooled by water quenching after rolling, and then heated to 200℃.

The specimen structure was observed and analyzed by tensile property test, metallographic microscope and scanning electron microscope, as shown in Table 4.

Table 4. Mechanical properties and grain size of test steel

| Heal treatment condition | Tensil properties of tested steel | | d/μm |
|-------------------------|----------------------------------|----|------|
|                         | σ₀.2/MPa                          | σb/MPa | δ(%) |
4.2.1 Analysis of results

Table 4 shows that after deformational heat treatment, there is an increase of 163% (982.5 mpa) for S1 and 110% (884.9 mpa) for B, an increase of 4.1% in elongation, and a refinement of grain size from 12 m to 2 m for 20Mn2. Deformation heat treatment can be very good grain refinement, enhance the performance of steel, the method is simple, can achieve high performance steel mass production. The Nb and Zr elements can improve the performance of steel.

5. Suggestions on grain refinement of deformable heat treatment

The properties of steel are closely related to the structure of steel, which is not only related to its chemical composition, but also related to the process of steel heating and cooling.

(1) In the process of deformation heat treatment, continue to do a good job of austenite initial recrystallization research, master its law, form a theoretical system, for the acquisition of high performance steel to lay a theoretical foundation.

(2) Diction in order to get more austenitic recrystallization nucleation number and improve the high temperature deformation cold deformation induced ferrite recrystallization nucleation number, can add just the right amount of Nb, Ti, V, Zr elements, such as they are in the process of hot rolled precipitation diffuse or particle carbide nitride, its concentration at the grain boundary, can rise to refine grain and improve the uniformity of microstructure, enhance the effect of plasticity, improving strength and diffraction rate.

(3) The development of new technology, the development of new technology. If the composite heat treatment can be used, the combination of deformation heat treatment and rapid cooling and rapid heat can better refine grain structure and improve the performance of steel.

(4) In order to get fine grains, in the process of grain refinement of deformation heat treatment, you can explore the process of refinement of repeated deformation heat treatment, through the experiment measured the best times, in order to simplify the process, reduce the cost.

(5) Explore the new medium needed for quenching and tempering, using big data and artificial intelligence and other high-tech wood to control the temperature of austenite transformation, accurately adjust the interval between the sheets, improve the performance of the steel.

6. Conclusion

As a strategic supporting material for national industrial production, steel has brought social and economic benefits to China's development, and is of great significance to national economic construction, national defense modernization, and aerospace development. Therefore, how to improve the performance of steel is very important. The grain refinement of deformable heat treatment is a very effective method to improve the performance of steel. It is suitable for all kinds of carbon steel and alloy steel. It is of great significance to the large-scale production of steel, the simplification of process and the reduction of cost, and plays an immeasurable role in the modern process of industrialization.

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