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Technical Innovation of Stainless Steel Wire Rods for Cold Forging in China

“冷顶锻用不锈钢盘条“技术创新内容

1. Overview

Bolt connection is one of the most common connection methods in automobiles. As the basic component of a connection node, a bolt is usually subjected to damaging loads such as acceleration, speed change and alternating load, which is crucial to the load-bearing safety of the structure. For this reason, a technical overview of the main applications of stainless steel materials in automobiles is given, and the crafting characteristics and technical elements of the four most widely used stainless steel materials, namely austenitic, ferritic, martensitic and austenitic-ferritic duplex stainless steel, are analyzed and explained, with the aim of providing a strong reference and theoretical basis for the selection of stainless steel materials for applications in automobiles and the formulation of the best connection.

With the rapid development of modern equipment industry, the demand for high strength and high performance is forcing equipment parts to go lightweight and high-strength. As a connection component, a bolt plays a pivotal role in the safe operation of equipment, and the performance level will become higher and higher with the improvement of the overall performance of equipment. However, stainless steel bolts can be made from various stainless alloys, and their ultimate strength can reach 480 to 1500 MPa. **Although high-strength carbon steel and alloy steel bolts are widely used for their higher strength and new design methods, their performance decreases faster in specific occasions, and the sensitivity of high-strength bolts to stress corrosion increases, and failure as well as rupture occur from time to time, bringing safety risks to the operation of the equipment. For this reason, the performance of stainless steel bolts is gradually improved, which has attracted attention.**

2. Stainless Steel Coil for Cold Top Forging

Stainless steel wire rods for cold forging are used to manufacture various kinds of cold forged products like bolts, screws, nuts, rivets, pins, etc. Most of China's current low-end cold forged products use Chinese materials, and high-end cold forged products still rely on imported materials. Therefore, it is necessary to vigorously promote the research and development of stainless steel wire rods for cold forging, formulate industry standards accordingly, take the lead in technology, improve the quality of Chinese cold forged products, provide reference and guidance for the development of Chinese cold forged products, and realize total domestication of high-end cold forged products in China.

At present, there is no standard for stainless steel wire rods for cold forging at home and abroad. Meanwhile, because the quality of stainless steel wire rods for cold forging in China is still unstable, these wire rods usually use the American or Japanese standards. Based on the current state of the industry, the standard is compatible with the existing standards of China, Japan and the United States for stainless steel wire rods for cold forging, so that the standard is operable.

The industry standard of these wire rods mainly refers to the following standards: Steel wire standard: GB/T 4232 stainless steel wires for cold forging, ASTM A493 stainless and heat resistant steel wires for cold heading and cold forging, JIS G4315 stainless steel wires for cold heading and cold forging. Standard for wire rods: GB/T 4356 Stainless steel wire rods.

The purpose of the standard is to form the technical requirements of stainless steel wire rods for cold forging and to provide direction and basis for the technical and quality progress of the forging stainless steel manufacturing firms in China. At the same time, in order to enable customers to purchase materials based on this standard, they can produce stainless steel wires for cold forging that meet the requirements of different standards at home and abroad. The standard is determined mainly according to GB/T 4232, ASTM A493, JIS G4315, GB/T 4356, GB/T 4356, GB/T 4232, GB/T 4232, GB/T 4232, GB/T 4232, GB/T 4232, GB/T 4232, GB/T 4232, ASTM A493, JIS G4315, GB/T 4356, GB/T 4237 and other relevant domestic and international standards, relevant sample analysis data, various performance data during the development process, and laboratory testing data on product-related indicators.

3. Introduction of Technical Innovation

In the standard of stainless steel wire rods for cold forging, the range of steel types and chemical composition covers the technical requirements for these wire rods specified in various standards, and the relevant requirements for stainless steel wire rods in China's standard are referenced.

3.1 Chemical Composition

According to the application of stainless steel wire rods for cold forging at home and abroad and with reference to the Chinese standard for these wire rods, 24 steel grades are identified to fully cover the requirements on austenitic, ferritic, martensitic and austenitic-ferritic duplex stainless steel series.

These wire rods are recommended as an industry standard. The technical indexes of this standard are more stringent than the American standard ASTM A493 for "Cold heading, forging and heat resistant stainless steel wire rods" as well as the Chinese standard GB/T 4356 for "Stainless steel wire rods". The harmful sulfur content is reduced by more than 0.005%, which means this technical standard is on par with international advanced standards.

Carbon is a strong austenite forming element, which can significantly improve the strength of steel, but the higher the carbon content in stainless steel, the worse the plasticity, and carbon also has a negative effect on corrosion resistance. Chromium is the main ferrite forming element, and the combination of chromium and oxygen can produce the corrosion-resistant Cr203 passivated film, which is one of the basic elements to maintain the corrosion resistance of stainless steel. Nickel is the main austenite-forming element, which can reduce the corrosion phenomenon of steel and the growth of grains when heated. The application of nickel in stainless steel is mainly in combination with chromium in order to play a better role and change the structure of stainless steel, thus improving the mechanical properties, processing properties and corrosion resistance of stainless steel in certain corrosion media. In contrast, the tensile test reflects the overall macroscopic mechanical properties of wire rods, so the presence of decarburization and sulfide causes the actual strength of Chinese stainless steel wire rods to be lower than the theoretical strength, which must be noted.

In ferritic stainless steels, the increase of Si and Mn elements improves the solid solution strengthening of ferrites, while C and N have a great influence on toughness. Impurities in ferritic stainless steels, including oxygen, aluminum, phosphorus, silicon and manganese, reduce toughness, but their effect is small compared to that of carbon and nitrogen, and sulfur has almost no effect. Niobium and titanium are the main stabilizing elements in ferritic steels, and Niobium and titanium have opposite effects on toughness and plasticity, so the metallurgical design can be adjusted to the desired product shape.

In martensitic stainless steels, the mechanical properties are strongly influenced by the chemical composition; higher Cr content and lower Ni content result in higher ferritic content and lower strength properties in a quenched and tempered condition. On the contrary, when the Cr content is lower and the Ni content is higher, the ferrite content in the steel is lower and the strength of the steel is higher.

The results of austenitic, ferritic, martensitic and austenitic-ferritic duplex stainless steel bolts were studied in the temperature range of 20-600°C. At temperatures ≤450°C, the austenitic and martensitic stainless steel bolts can maintain the elastic modulus, yield strength and ultimate strength better than carbon steel and alloy structural steel bolts.

3.2 Surface Defects

Surface defects is an important factor that causes cold forging cracking. According to statistics on customer use, each year scrapped cold forging parts take up about 50% of all the scraps. Stainless steel wire rods used for cold forging must first go through cold-drawing. If surface defect is not eliminated after cold-drawing, there will likely be head cracking in the subsequent cold forging, resulting in scrapped parts. Therefore, it is necessary to restrict the allowable depth of defect on the surface of wire rods, and control the depth while comparing to the said standard and China's national standard GB / T 4356, where when the allowable wire rod diameter is ≥ 4.5 ~ 14mm, the allowable defects depth is from ≤ 0.15mm to ≤ 0.08mm; when the wire rod diameter is > 14 ~ 20.0mm, the allowable defects depth is from ≤ 0.20mm to ≤ 0.15mm; when the wire rod diameter is >20～40mm, allow the depth of defects according to mutual agreement.

3.3 Process and Mechanical Properties

The hardness of the ferritic and martensitic stainless steel wire rods for cold forging affects customers success rate in the cold forging. Ferritic stainless steel wire rods are usually annealed to improve plasticity and toughness, ensure corrosion resistance and eliminate stress. Generally, the annealing temperature of ferritic stainless steel is 750-850°C, and the annealing temperature of martensitic stainless steel is 800-900°C. After sufficient heat preservation, a homogeneous ferrite and carbide equilibrium state is obtained. After a small amount of drawing and cold forging, if the original hardness of the wire riods is too high, the hardness will be too high after drawing, and the cold forged portion will be likely to crack up. For ferritic and martensitic stainless steel wire rods for cold forging, the maximum hardness limit is specified.

Stainless steel wire rods need to undergo limited drawing deformation before going through cold forging. To ensure a smooth wire drawing process, the wire rods need to have a certain degree of plasticity. The original strength of the wire rods should not be too high, so the mechanical properties of the austenitic stainless steel wire rods for cold forging are limited. Austenitic-ferritic duplex stainless steel is heat treated and solution treated at 950-1120°C. The reason why high-temperature solution can be used is that the carbon content of duplex stainless steel is much lower than that of ferritic stainless steel. Considering the effect of solution temperature on microstructure, mechanical properties and corrosion resistance, the solution heating temperature of duplex stainless steel generally takes the middle limit value in the specification. To prevent the precipitation of σ phase, it should be cooled rapidly after the solution temperature is kept warm. The σ phase is distributed along the grain boundary. The plasticity of the steel is significantly reduced, and the dispersion is less likely to affect toughness, and has a certain strengthening effect. The σ phase increases the notch sensitivity of the steel, has little effect on strength and hardness, and has a significant effect on toughness. The σ phase significantly reduces the plasticity, toughness, oxidation resistance, and intergranular corrosion resistance of steel, and increases the occurrence of thermal fatigue. After the σ phase is formed, the matrix is depleted of chromium (or molybdenum, tungsten), thus reducing the corrosion resistance of the matrix and weakening the effect of solid solution strengthening. In short, the σ phase is more harmful, and the appearance of this phase should be avoided as much as possible.

4. Metallographic Examination of Stainless Steel

4.1 Preparation of Samples

The preparation process for the metallographic samples of stainless steel is basically the same as that of high alloy steel. Among them, the matrix structure of austenitic stainless steel is relatively soft, the toughness is high, and it is easy to cause work hardening. It is difficult to prepare the sample, and it is easy to produce mechanical slippage and disturb the metal layer structure during the polishing process, which will affect the normal metallography. analysis and inspection. Improper sample preparation of semi-martensitic steel will cause austenite to transform into martensite, so the preparation of the sample should not cause the sample to generate high heat. The polishing force should not be too large, and the polishing time should not be too long.

4.2 Chemical Corrosion

Stainless steel has high corrosion resistance, so the etchant that shows its microstructure must be strongly erosive to make the structure clearly visible. The appropriate etchant should be selected according to the steel composition and heat treatment state. Commonly used etchants are:

1. Ferric chloride 5g + hydrochloric acid 50ml + water 10ml (applicable to A stainless steel and F-A stainless steel);
2. Hydrochloric acid 10ml + nitric acid 10ml + alcohol 100ml;
3. Picric acid 4g + hydrochloric acid 5ml + alcohol 100ml (harder to corrode samples can be heated in a water bath);
4. Hydrofluoric acid (5%) 1ml + nitric acid (5%) 4ml + water 45ml.

In addition, ferrite, austenite, carbide, δ ferrite, and σ may also appear in stainless steel at the same time, which can be distinguished by chemical erosion. In terms of morphology, austenite has twin grains, and ferrite is often band-like or dendritic; the ferrite becomes rose-colored after being corroded with red salt potassium hydroxide solution (red salt 10g-15g+NaOH 10g-30g+water 100mL, boiled at 60-90°C). The austenite body is bright, and after being corroded with alkaline potassium permanganate, the carbide is light brown, and the σ phase is orange-red.

4.3 Examples of Metallographic Structure

For ferritic stainless steel annealing, the metallographic structure is ferrite + M7C3 (carbide). If heated above 900 °C, the grains will expand and cannot be refined, so the temperature needs to be controlled. The structure of 1Cr17 steel heated to 850°C and air-cooled is ferrite + carbides distributed along the rolling direction, as shown in **Figure 1**.

After the annealing of martensitic stainless steel is fully maintained, a uniform ferrite and equilibrium structure of carbide is obtained. **Figure 2** shows the annealed state of 30Cr13 steel raw materials, corroded by ferric chloride hydrochloric acid aqueous solution; the structure is point-like and spherical pearlite, as well as secondary carbides distributed intermittently along the grain boundaries.

Solution treatment of austenitic stainless steel, heats up to 1000 ℃ - 1100 ℃, so that all carbides are dissolved in austenite, and then quickly cooled to room temperature to obtain a uniform austenite structure. **Figure 3** shows that the structure of 06Cr17Mn7Ni5CuN steel is austenite; **Figure 4** shows that the structure of 0Cr19Ni10 steel is austenite + a small amount of ferrite.

In austenitic-ferritic duplex stainless steel heat treatment solution treatment (950℃ ~ 1140℃), the metallographic structure is ferrite + austenite, corroded by potassium ferricyanide and potassium hydroxide aqueous solution; the structure is white austenite and gray-black (brown) ferrite. δ phase (δ ferrite) is a phase formed in the high temperature region, generally called high-temperature ferrite, to distinguish from low-temperature α-ferrite. δ ferrite is a body-centered cubic lattice, but the lattice constant is different from that of α ferrite, and exhibits higher brittleness. The ferrite content should be inspected according to GB/T 13305-2008 "Metallographic Determination of α-phase Area Content in Stainless Steel". After negotiation between the supplier and the buyer, other inspection methods can also be used. The ferrite content must be controlled at 40% ~60%. **Figure 5** shows that the structure of 022Cr23Ni5Mo3N steel after solid solution is austenite + ferrite.

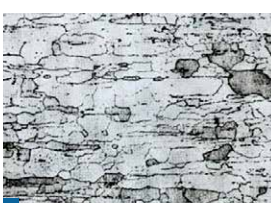

Fig. 1
10Cr17 steel structure is ferrite + carbide

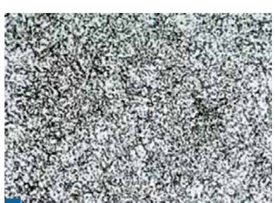

Fig. 2
30Cr13: pearlite + carbide

Fig. 3
06Cr17Mn7Ni5CuN structure is austenite

Fig. 4
0Cr19Ni10 structure is austenite + a small amount of ferrite

Fig. 5
022Cr23Ni5Mo3N structure is austenite + ferrite

5. Conclusion

In recent years, with the continuous improvement of automotive lightweighting, long service life and user-perceived quality requirements, coupled with the current stricter requirements for automobile emission regulations, stainless steel materials have been developed and applied relatively rapidly in China's automobile industry. In order to track the rapid development and application of high-performance stainless steel materials in automobiles, it is necessary and urgent to increase the development and accumulation of advanced stainless steel material connection technologies for automobiles in the next step.