Application of Forged N6

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Abstract. N6 has excellent performance and obvious advantage in forging. Through mechanical test and metallographic analysis, the process parameters are verified, and the life and safety of the machine are greatly improved.

1. Introduction
Nickel is the most widely used as a major alloying element in stainless and heat-resistant steels. Compared with stainless steel and other non-ferrous metals, pure nickel materials have better impact and corrosion resistance. The solubility of a few elements such as Cr, Mo, Cu in nickel is much higher than that of ordinary materials, which can improve the passivation performance of nickel. When the solution PH is > 7, it also belongs to the passivation range of pure nickel, which is not available in general metal materials. However, the element content that can form carbides in other components is very low, and intercrystalline corrosion will not occur \cite{1}, so it is mostly used in metal materials that are resistant to alkali corrosion.

In pressure equipment, there are three kinds of N5 (corresponding to UNS N02201), N6 and N7 (corresponding to UNS N02200) in common use \cite{2}. N5 belongs to low carbon nickel, the upper limit of allowable temperature is 650; N6 and N7 tend to graphitize at high temperatures, so the upper allowable temperature limit in the standard is 300. Compared with N7, the content of nickel in N6 is the highest (99.5%), and the alloy and impurity elements are more strictly controlled. In some cases where the temperature is not high but the corrosion is serious, the corrosion tendency of N6 is lower, which plays an irreplaceable role.

2. Processing performance of N6

2.1. Turning ability
N6 medium hardness, the hardness after annealing is very low, easy to stick the knife makes the tool local temperature is too high and wear, affect the workpiece precision. Medium and low speed turning is recommended. The tool is preferably made of cubic boron nitride or coated carbide inserts and equipped with shock absorbing shank and fully cooled. The radius of the tool tip should not be too large, R = 0.2-0.4mm is recommended, and the feed amount should not exceed 0.4mm. The feed speed can be lower according to the workpiece diameter and processing requirements.
2.2. High and low temperature performance
As a corrosion resistant component, N6 has a lower allowable temperature of -268, higher strength at low temperature than room temperature, and good plasticity and toughness. The lower limit of elongation of N6 at room temperature is 40%-50% (figure 1)[3], which is more than that of ordinary solid solution austenitic stainless steel and suitable for most cold forming methods, but the cold work hardening phenomenon is more obvious, need to cooperate with intermediate annealing to eliminate stress and restore plasticity and stable size. At high temperature, the elongation is better, the malleable performance is excellent.

![Fig. 1 Mechanical properties of N02200(N6 N7) at different temperatures](image)

3. N6 forging process

3.1. Preparation for forging
The raw material of N6 is mainly electrolytic nickel, which is processed into nickel after vacuum melting. N6, other pure nickel brands and nickel alloys are sensitive to some elements, such as oxygen, sulfur, lead, tin, zinc and bismuth, etc. Over 500℃ in contact with air can oxidize to form NiO, which can be easily retained in the material through cracks, folds, cracks, slag inclusion and other forging defects, which cannot be eliminated through heat treatment. However, under certain temperature and medium conditions, sulfur and nickel can form NiS with low melting point to produce hot brittleness and lead to poor corrosion resistance, which indirectly affects the allowable temperature of the material under specific medium conditions. Therefore, before forging, it is necessary to prepare detailed operating procedures and precautions to guide the production. If using fuel oil or gas, limit or screening should be made for sulfur content[3].

3.2. Forging temperature
It was given in JB/t 4756-2006 that the hot forming temperature of N6 was 650-1260℃, because processing below 650℃ would lead to sharp hardening of the material, resulting in defects. In actual processing, a slightly higher final forging temperature should be selected for control, and it is recommended to be 870-1260℃

3.3. Post-forging heat treatment
Before and after forging, N6 is presented as a face-centered cubic crystal structure, without isomerism transformation or phase transition, and adopts annealing for heat treatment. The first reason is to eliminate the hardened tissue and make the tissue uniform, and the second reason is that the mechanical properties under annealing state are relatively stable (There are two heat treatment states of N6, annealing and stress relief. Only a few heat exchange tubes are used in a stress-relieved state after rolling. As the use temperature changes, the curve strength ratio shows a non-linear trend, the tensile strength becomes the determining factor of the allowable stress, and the value becomes higher, which
is not conducive to ensuring sufficient safety margin, so an annealing operation is used. The approximate melting range of N6 is 1435-1446 ℃, the initial temperature of recrystallization is about 595-650 ℃, which has a wide annealing range. Annealing at a lower temperature will result in fine crystal structure and higher mechanical properties; annealing at a higher temperature will result in coarse crystal structure and low hardness, which is conducive to deformation processing and more suitable for strong corrosion environment. Fig. 2 shows the approximate relationship between annealing grain size of N02200 (N6, N7) and temperature and time [3]. It should be noted that when annealing at high temperature, the growth rate of the crystal nucleus increases sharply, which is easy to cause the grain to be too coarse. The recommended annealing temperature after forging is 760-870 ℃.

![Fig. 2 Annealing time temperature grain size relationship of N02200 (N6, N7)](image)

3.4. Cooling
The thermal conductivity of nickel is about 91W / (m · K). The coefficient of thermal expansion from room temperature to 760 ℃ is 16.02 × 10-6 / ℃, which is between ordinary carbon steel and austenitic stainless steel. Because there is no phase transformation, no large lattice distortion and dislocation during heating, the risk of cracking is very low. Therefore, a higher heating rate can be selected in the heating zone, and the furnace temperature can be raised before entering the workpiece. The heat preservation is generally 30 minutes, not more than 3 hours.

4. Metallography of N6 forgings

4.1. Preparation of metallographic sample
The sample is N6 in forged state, and the chemical composition is shown in Table 1. After forging, the sample is annealed at 780 ℃ and processed to a cylinder of φ 15 × 23mm. After finishing turning the end face, use sand paper of different particle sizes to fine grind step by step, and then use golden velvet and 3.5 μm golden phase polishing paste to finish grinding until the mirror surface (Figure 3). The samples were chemically etched with high iron chloride (3G) + analytical alcohol (100ml). After 12-15s of etching, the samples were cleaned and observed under nim-100 metallographic microscope.

| Table 1 Composition of N6 forgings (mass fraction /%) |
|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Element       | Measured value | Measured value | Measured value | Measured value | Measured value | Measured value | Measured value | Measured value |
| Ni+Co         | 99.81          | 0.0035         | 0.0297         | <0.005         | 0.0652         | 0.0083         | <0.001         | 0.002          |
| Cu            | 0.0035         | 0.0005         | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         |
| Si            | 0.0297         | 0.0005         | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         |
| Mn            | <0.005         | 0.0005         | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         |
| C             | 0.0652         | 0.0083         | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         |
| Mg            | 0.0083         | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         |
| S             | <0.001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         |
| P             | 0.002          | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         | 0.0001         |

Test method: NACIS/C h011:2013 GB/t20123-2006 NACIS/C h048:2013
4.2. Microstructure

Fig. 4 for hot rolled N6 plate through high iron chloride after etching the phase diagram of alcohol solution [4] for materials containing high sulfur, oxygen in the grain boundary to be partial to gather a lot of NiO, NiS, which resulted in increased material brittleness, plasticity and ductility sharply reduce, bad between pitting corrosion and corrosion resistance, has no use value, can only be recycled.

By contrast, the strict control of the forging process of N6, get after annealing organization into a single austenitic organization (figure 5), thin uniform grain boundary in a closed continuous without inclusion, grain boundary is also not found visible oxide, sulfide, or carbide insoluble phase, such as physical properties of the macro performance is very soft and good plasticity. According to the comparison method in GB / T6394-2017 for calculation and comparison, the grain size in the coarse grain area is about 2 grades, which meets the requirements of "Grade 5 or coarser grain size grade" in JB / T4756-2006.
Figure 5 Note: The actual measured average hardness after forging N6 annealing is HBS 53. Forging N6 is extremely soft, which makes the metallographic sample more difficult during lapping. The crisscross “penetration lines” in the phase diagram are micro-textures generated during polishing and lapping; the small black dots with "tails" are caused by foreign matter embedding during lapping. They are prominent after etching and oxidation, and they all exist on the surface of the crystal grains (amorphous boundaries, which are different from the inclusions of oxygen and sulfide in the crystal grains), these interference factors should be excluded when metallographic observation.

5. Tensile specimen and mechanical properties of N6 forgings
The tensile sample is made by referring to the grade forgings in NB/t48028-2012 nickel and nickel alloy forgings, as shown in the figure below.

Fig. 6 N6 forging tensile sample (after stretching)

Fig. 7 Fracture of tensile specimen

Fig. 6 and Fig. 7 show the fracture morphology of N6 forging in tensile test. After the fracture, the overall contraction is smooth and the distribution of fish scales is even. The shrinkage of the fracture site is obviously cup-cone-shaped, and the fracture is gray fiber-like, without any crystalline fracture,
which is a typical ductile fracture. Table 2 shows the average values of 5 groups randomly selected after sampling of N6 forgings one by one. All the data can ensure the lower limit of room temperature mechanical properties of JB/t 4756-2006 plate.

**Table 2 mechanical properties of N6 forging tensile specimens**

| Name             | Test temperature ℃ | Strength of extension Rm/MPa | Condition strength Rp0.2/Mpa | Percentage elongation after fracture A/% | Reduction of area Z/% |
|------------------|---------------------|------------------------------|-----------------------------|------------------------------------------|-----------------------|
| Tensile sample   | 23                  | 424                          | 125                         | 49.0                                     | 84                    |

6. Conclusion

From the perspective of manufacturing, N6 has high raw material cost, limited product shape, and obvious advantages in forging processing. Through reasonable control, uniform organization, stable size, energy saving and consumption reduction.

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References

[1] JB/T4756-2006, Pressure vessels of nickel and nickel alloy[S]. Beijing: Xinhua publishing house,2006.

[2] National technical committee for the standardization of boilers and pressure vessels. Nickel and nickel alloy pressure vessels - standard definition[M]. Xinhua publishing house: Beijing, 2006:138.

[3] Nickel200[EB/OL]. www.specialmetals.com,2018.

[4] Li Jionghui, Lin Chengde. Metallography of metallic materials[M]. Mechanical industry press: Beijing,2006:1929.