Microstructure and Corrosion Properties 0Cr21Mn17Mo2N0.8 High Nitrogen Austenitic Stainless Steel

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Abstract. The high nitrogen stainless steel with solid solution heat treatment after forging was austenitized completely. The microstructure of the alloys were observed by OPM, SEM and EDS. The mechanical properties were analyzed by tensile test and impact test. In addition, the corrosion test of high nitrogen austenitic stainless steel, 304 stainless steel and 316L stainless steel were conducted in the environment of highly purified nitrogen gas in the autoclave, and the deionized water is used to make 10000mg/L sodium chloride solution. The corrosion depth was studied by laser scanning confocal microscope. The experimental results showed that the addition of nitrogen improves greatly the mechanical properties of stainless steel. Otherwise, three kinds of stainless steel caused pitting in sodium chloride solution, because the passive film of stainless steel was destroyed due to the permeation of the chloride ion. Moreover, the corrosion rate of high nitrogen austenitic stainless steel is much lower than that of the 304 and 316L stainless steel. So the corrosion resistance of high nitrogen steel is much better. On account of the chemical interaction between nitrogen and molybdenum, it can prevent the surface from forming high current density and decrease the pitting tendency of stainless steel. The result expanded greatly the application of high nitrogen stainless steel in the field of corrosion.

1. Introduction
In China, the consumption of stainless steel is increasing in recent years. Because of its good mechanical properties and corrosion resistance, it is widely used in marine ships, oil fields, medical industries, buildings and bridges [1-3].

According to the survey, the economic loss caused by corrosion failure of stainless steel is as much as 100 billion yuan in China. Therefore, it is the key to improve the corrosion resistance of high nitrogen steel(HNS). The development of high nitrogen austenitic stainless steel is the breakthrough in the stainless steel field. Nitrogen is present in the form of interstitial atoms in steel. Low-cost and high-performance austenitic stainless steel can be obtained from nitrogen instead of nickel [4, 5]. The addition of nitrogen can improve the strength, toughness and plasticity of austenitic stainless steel and enhance its corrosion resistance [6-8].

In present work, the microstructure, mechanical properties and corrosion properties of solid solution after forging 0Cr21Mn17Mo2N0.8 high nitrogen austenitic stainless steel was investigated. The corrosion mechanism of the alloys were discussed. These work results will expand greatly the application of HNS in the corrosion field.

2. Sample preparation and experimental

2.1 Sample preparation
The ferrochrome, ferromanganese, molybdenum iron, niobium iron and chromium nitride is put into the induction melting furnace. Then the electroslag remelting is used to obtain the uniform density of high nitrogen stainless steel. The chemical composition of high nitrogen austenitic stainless steel is shown in Table 1. Then, after the forging process of HNS, the bar forging with diameter of 168mm and long of 200mm can be obtained. Finally, the bar forging is placed in the energy-saving box-type electric furnace of SX-G07122. The HNS is heated to 1140℃ and cooled in the water after 6h heat preservation, in order to obtain a single austenitic organization.

| element | C    | N    | S    | P    | Mn   |
|---------|------|------|------|------|------|
| content (%) | 0.141 | 0.741 | 0.007 | 0.015 | 18.253 |

| element | Ni   | Cr   | Mo   | Nb   | Fe   |
|---------|------|------|------|------|------|
| content (%) | 0.250 | 21.268 | 2.582 | 0.147 | 56.363 |

2.2 Experimental

Samples are taken directly from the bar forging after solid solution treatment, and sanded with sandpapers. The HNS was polished on the PG-2C metallographic sample polishing machine and corroded in the oxalate electrolyte. Meanwhile the current is 0.2A and the corrosion time is 6 minutes. Then the HNS was placed under the OLYMPUS optical metallographic microscope to observe its microstructure. Finally, the surface hardness of the test specimen was tested by digital display Rockwell hardness tester.

According to GB/T228-2002, the tensile test samples were taken from the bar forging, and the sample size was shown in Fig.1. Then the tensile test was carried out with the WDW-200 electronic universal testing machine. According to GB/T229-2007, the impact samples were taken from the test piece. The sample size was 55mm*10mm*10mm, and the standard charpy impact notch was V. The room temperature impact test was carried out with the 452D-4 pendulum impact tester.

![Figure 1. Shape and size of the tensile specimen.](image)

The corrosion test of HNS, 304 stainless steel and 316L stainless steel were conducted in the environment of highly purified nitrogen gas in the high temperature autoclave, and the deionized water is used to make 10000mg/L sodium chloride solution. And the pressure is 0.63MPa, the test temperature is 52℃, test time is 569h in the autoclave. Then the corrosion morphology of HNS, 304 stainless steel and 316L stainless steel were observed with the JSM-5500LV scanning electron microscope. The pit depth and height difference were observed by the LSM-700 laser confocal microscope observation, and compared with 304 and 316L stainless steel.

3. Results and discussion

3.1 Microstructure and hardness
Nitrogen is a strong element that forms and stabilizes the austenite phase. The addition of nitrogen in the stainless steel can inhibit significantly the formation of ferrite phase. With the increase of nitrogen content, the content of ferrite will decrease. Therefore, the high nitrogen austenitic stainless steel with solid solution after forging is single austenitic tissue. Its grain size is relatively uniform, and it contains a large number of twin crystals, as shown in Fig.2. The Rockwell hardness of HNS is 32.5HRC.

3.2 Tensile properties and impact properties
As shown in Fig.3, the peak strength of HNS is 1099MPa, and the peak strain is 0.44. The tensile strength of HNS is 1099MPa, the yield strength is 959MPa, the elongation percentage is 49.7%, which is higher than the stainless steel with excellent properties, such as 304 and 316L stainless steel [9, 10]. The average value of impact absorbing energy is 189J. According to the tensile test and impact test, the high nitrogen austenitic stainless steel with solid solution after forging has good properties.

Nitrogen is usually insoluble in carbides. Therefore, the nitrogen element delayed the nucleation of carbide, which delayed the precipitation of M23C6. The nitrogen decreases the mismatch between the M23C6 and the austenite, so that the interface energy can be reduced and the precipitate is inhibited. In summary, nitrogen decreases the formation speed of M23C6 in the austenitic stainless steel. In addition, the nitrogen will combine with the niobium element in HNS to produce compounds of niobium and nitrogen, which are dispersed in grain boundaries. And it could improve the creep resistance of HNS. Nitrogen can significantly improve the strength and other mechanical properties of HNS. But it is not added as much as possible, there is an optimal upper limit.

3.3 Corrosion resistance
The microscopic corrosion morphology of stainless steel is shown in Fig.4. In 10000 mg/L sodium chloride solution, the corrosion behavior of HNS, 304 and 316L stainless steel are pitting. But the
The corrosive pit of HNS is smaller than the other two stainless steels. The processing traces are still clearly visible. On the contrary, the corrosion of 304 stainless steel is very serious. Compared the morphology of microstructure with 316L stainless steel, the number of corrosion pit on HNS is less. Therefore the corrosion resistance of HNS is better than 316L stainless steel.

Figure 4. The microscopic corrosion morphology of three types of stainless steels (a) high nitrogen austenitic stainless steel (b) 304 stainless steel (c) 316L stainless steel.
The microstructure of three kinds of stainless steels in the LSM-700 laser scanning confocal microscope is shown in Fig. 5. And the contrastive analysis is conducted on the place where the height difference of the sample surface is the largest. The HNS has the smaller corrosion pit depth and surface height difference than the 304 stainless steel as shown in Table 2. Therefore, the corrosion resistance of HNS is greatly better than 304 and 316L stainless steel.

In sodium chloride solution, there will be a passive film composed of Fe/Cr oxide on the surface of HNS. Meanwhile, there are a lot of local defects on the passive film, and the potential of defect area and defect-free area are different. It can form the battery, the defective part becomes the anode, and the sodium chloride solution is the cathode area. Because the anode area is very small, its current density is very large, it appears corrosive pitting on the surface of stainless steel. Then the dissolved metal ions hydrolyze to generate H\(^+\), which reduces the pH value of the sodium chloride solution. And it can exacerbate the dissolution of the stainless steel, and deepen the pitting. Because the combination of chloride ion and metal ion is strong and the radius of chlorine ion is small, it is strongly adsorbed in the passive film.
Figure 5. The microstructure of three kinds of stainless steels in the LSM-700 laser scanning confocal microscope (a) high nitrogen austenitic stainless steel (b) 304 stainless steel (c) 316L stainless steel.

Table 2. Corrosion surface parameters on laser scanning confocal microscope.

| steel  | depth (μm) | height difference (μm) |
|--------|------------|------------------------|
| HNS    | 5.2        | 5.0                    |
| 304    | 35.1       | 31.0                   |
| 316L   | 13.0       | 12.2                   |

However, the nitrogen and molybdenum in the HNS interact with each other in the vicinity of the passive layer. This improves the protective ability of the passive film, mainly because nitrogen will accumulate in the form of nitride under the passive film during the long period of passivation process. In local acidic environment, the nitrogen compounds form NH3 and NH4+, and consume H+ to raise the pH value of the solution, in order to promote passivation ability and improve corrosion resistance of the stainless steel. Therefore, the corrosion resistance of HNS is much better than 304 and 316L stainless steel, it expanded greatly the application of HNS in the corrosion field.

4. Conclusion

(1) The HNS is single austenitic structure. Its Rockwell hardness is 32.5HRC. The tensile strength of HNS is 1099MPa, the yield strength is 959MPa, the elongation percentage is 49.7%, and the average value of impact absorbing energy is 189J. The properties were higher than the stainless steel with excellent properties, such as 304 and 316L stainless steels. In conclusion, the high nitrogen austenitic stainless steel with solid solution after forging has great properties.

(2) The microscopic corrosion morphology of HNS, 304 and 316L stainless steel are pitting. But the corrosive pit of HNS is smaller than the other two stainless steels. The nitrogen and molybdenum in the HNS interact with each other in the vicinity of the passive layer, therefore, the corrosion resistance of HNS is much better than 304 and 316L stainless steel.

References

[1] M.O. Speidel, Properties and Applications of High Nitrogen Steels. Foct J, Hendry A, eds. High Nitrogen Steels. London: The Institute of Metals, 1989. 92-96
[2] J.W. Simmons, Overview: High-nitrogen alloying of stainless steels. Mater Sci A, 1996, 207 (2)
[3] A.G. SVYAZHIN, J. SIWKA, L.M. KAPUTKINA, High-nitrogen steels: The current state and development trends. Advanced Steels. Heidelberg: Springer Berlin Heidelberg, 2011. 368

[4] M. SUMITA, T. HANAWA, S.H. TEOH, Development of nitrogen-containing nickel-free austenitic stainless steels for metallic biomaterials-Review. Materials Science & Engineering C, 2004, 24 (6/7/8) 753-760

[5] TOPPO, ANITA, M.G. PUJAR, C. MALLIKA, et al, Effect of Nitrogen on Stress Corrosion Behavior of Austenitic Stainless Steels Using Electrochemical Noise Technique. 2015, 3 (3) 1140-1149

[6] A. POONGUZHALI, M.G. PUJAR, U. KAMACHI MUDALI, Effect of Nitrogen and Sensitization on the Microstructure and Pitting Corrosion Behavior of AISI Type 316LN Stainless Steels. 2013, 4 (4) 1170-1178

[7] Wu Hao, Xu Guifang, Yan Yu, et al, Pitting corrosion resistance of a new high nitrogen and low nickel austenitic stainless steel. Heat Treatment Metals, 2015, 40 (12) 11

[8] W.Y. LV, C. PAN, W. SU, et al, A study on atmospheric corrosion of 304 stainless steel in a simulated marine atmosphere. Journal of Materials Engineering and Performance, 2015, 24 (7) 2597-2604

[9] K. DAYAL, N. PARVALHAVARITHINL, BALDAV RAJ, Influence of Metallurgical Variables on Sensitization Kinetics in Austenitic Stainless Steels. International Materials Review, 2006, 50 (03) 129-155

[10] V.S. SRINIVASAN, B.K. CHENDNARY, M.D. MATHEV, et al, Long-term Creep-rupture Strength Prediction for Modified 9Cr−1Mo Ferrite Steel and Type 316L(N) Austenitic Steel. Materials at High Temperatures, 2012, 29 (01) 41-48