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Effect of Grain Size on Mechanical Properties of Nickel-Free High Nitrogen Austenitic Stainless Steel

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Abstract: The fine grained structures of nickel-free high nitrogen austenitic stainless steels had been obtained by means of cold rolling and subsequent annealing. The relationship between microstructure and mechanical properties and gain size of nickel-free high nitrogen austenitic stainless steels was examined. High strength and good ductility of the steel were found. In the grain size range, the Hall-Petch dependency for yield stress, tensile strength, and hardness was valid for grain size ranges for the nickel-free high nitrogen austenitic stainless steel. In the present study, the ductility of cold rolled nickel-free high nitrogen austenitic stainless steel decreased with annealing time when the grain size was refined. The fracture surfaces of the tensile specimens in the grain size range were covered with dimples as usually seen in a ductile fracture mode.

Key words: grain refinement strengthening; nitrogen; nickel-free high nitrogen austenitic stainless steel; Hall-Petch equation

On account of high strength and ductility and good corrosion resistance, high nitrogen steels have been researched intensively in recent years[1-3]. At present, high nitrogen stainless steels, especially, high nitrogen austenitic stainless steels have been the focus of attention[3-5]. Due to the cost of nickel and the prospected possibility of allergic reactions in the human body, nickel-free high nitrogen austenitic stainless steels appear to be more attractive.

Although there have been many studies on finely grained ferritic steels, only a few research reports are available on refined austenitic stainless steels, especially, high nitrogen austenitic stainless steels. The grain size of ferritic steels can be easily refined by phase transformation, whereas, the only way to promote grain refining of high nitrogen austenitic stainless steels seems to be dynamic recrystallization during hot working or static recrystallization after cold rolling and subsequent annealing. Recrystallization after hot rolling is reported to have the effect of grain refining, but the method seems to be limited[6].

In the present study, the fine grained structures of nickel-free high nitrogen austenitic stainless steels have been obtained by means of cold rolling and subsequent annealing. The relationship between the microstructure and mechanical properties and the gain size of nickel-free high nitrogen austenitic stainless steels was examined.

1 Experimental

Nickel-free high nitrogen austenitic stainless steels were manufactured using a vacuum induction furnace by adding nitrided ferroalloy under nitrogen atmosphere, and using the eletroslag furnace for remelting under nitrogen atmosphere[7]. The chemical composition of nickel-free high nitrogen austenitic stainless steel is shown in Table 1.

The hot rolled steel was given solution treatment at 1 100 ℃ for 1 h and quenched to avoid Cr_2N formation. Subsequently the steel was cold rolled with 70% cold reduction to 1. 4 mm. and annealed at 1 100 ℃ for different time. The microstructure and gain size of the annealed specimens were observed through an optical microscope, and the hardness was measured using an FM-700 Vickers hardness tester.

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Table 1 Chemical composition of nickel-free high nitrogen austenitic stainless steel %

C	Si	Cr	Mn	Mo	Ni	S	P	Al	O	N
0.049	0.4	19.56	19.4	2.29	—	0.003	0.02	0.04	0.005	0.82

Tensile tests were carried out on an Instron-type testing machine with a tensile rate of 3 mm/s at room temperature. The scheme of the tensile specimen is shown in Fig. 1. The fractures of the tensile specimens were observed with the help of scanning electron microscopy (SEM).

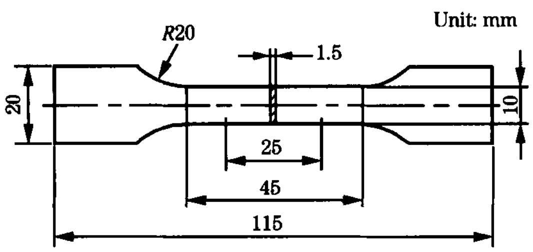
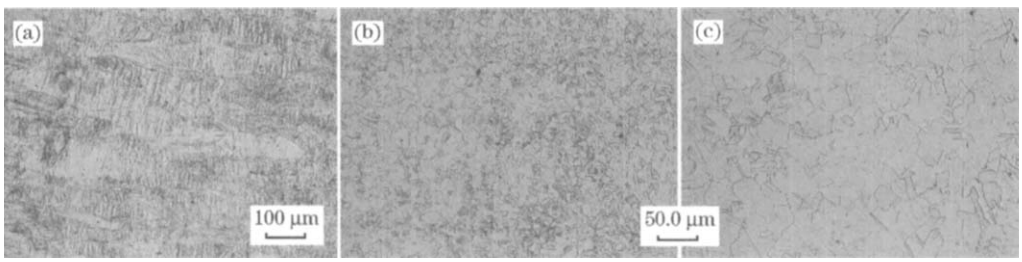


Fig. 1 Scheme of tensile specimen

2 Results and Discussion

The microstructure of the cold rolled plate with 70% cold reduction of nickel-free high nitrogen austenitic stainless steel is shown in Fig. 2. The deformed grains, with slipping trace, can be observed as shown in Fig. 2 (a). After 40 s annealing time, the deformed structure is basically eliminated as shown in Fig. 2 (b), and the recrystallization grains exist mainly in the microstructure. On prolonging the annealing time to 5 min, the recrystallization grains grow remarkably and the twins can be obviously observed in the microstructure as shown in Fig. 2 (c). The gain size of the nickel-free high nitrogen austenitic stainless steel samples with different annealing time at 1 100 ℃ are shown in Fig. 3.



(a) Cold rolled plate; (b) Annealed at 1 100 ℃ for 40 s; (c) Annealed at 1 100 ℃ for 5 min

Fig. 2 Microstructure of cold rolled plate with 70% cold reduction of nickel-free high nitrogen austenitic stainless steel

Grain refinement is commonly known to increase the hardness and the strength of polycrystalline materials. It is well recognized that the yield stress $R_{p0.2}$ and the hardness HV of a metallic material increase with decreasing grain size d. In particular, the Hall-Petch equation expresses the grain-size dependence of strength and hardness[8,9]. In terms of strength and hardness, the Hall-Petch equations are shown as Eqn. (1) and Eqn. (2).

$$R_{p0.2}=R_{p0.2}^{0}+kd^{-1/2} \quad (1)$$

$$H=H_0+k'd^{-1/2} \quad (2)$$

The superscript 0 relates to the material of infinite grain size. k and k' are constants representing the grain boundary as an obstacle to the propagation of deformation.

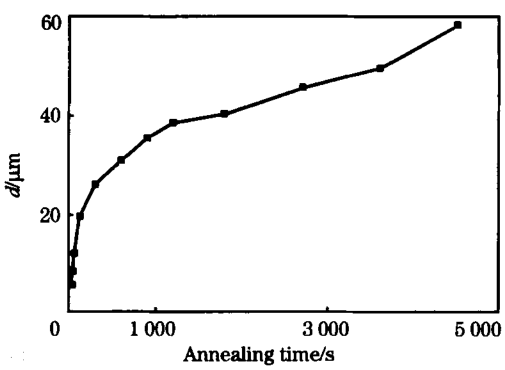


Fig. 3 Variation of recrystallized grain size of high nitrogen stainless steel with annealing time at 1 100 ℃

In the present study, the effect of grain size on the yield strength and tensile strength is shown in Fig. 4. The yield strength and tensile strength increase when there is a decrease in the grain size. Furthermore, the Hall-Petch dependency for both yield strength and the tensile strength R_m is found to be valid for grain size ranges in nickel-free high nitrogen austenitic stainless steel. The same trend is

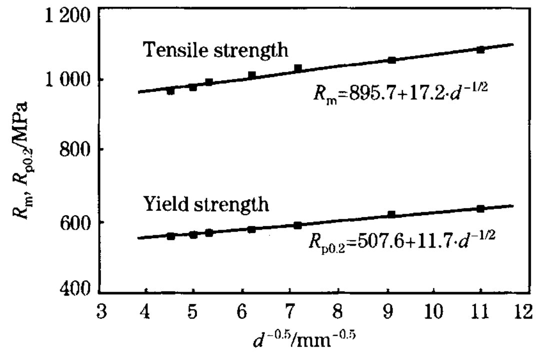


Fig. 4 Effect of grain size on the yield strength and tensile strength of nickel-free high nitrogen austenitic stainless steel

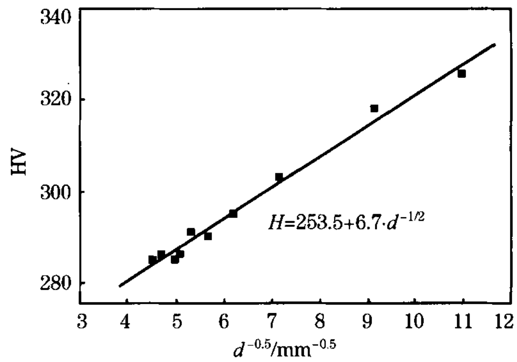


Fig. 5 Effect of grain size on hardness of nickel-free high nitrogen austenitic stainless steel

shown in Fig. 5, where the hardness of the nickel-free high nitrogen austenitic stainless steel increases with a decrease in grain size, according to the Hall-Petch equation.

Ductility is defined as fracture elongation in the tensile test. The effect of grain size on the tensile ductility of nickel-free high nitrogen austenitic stainless steel is shown in Fig. 6. Good tensile ductility of steel has been found, and it is reduced when the grain size is refined in the present study.

The tensile specimens in the grain size range are characteristically ductile with a dimple rupture fracture, and the typical fractographs with 40 s and 1 800 s annealing time are shown in Fig. 7. The relation between fracture elongation and grain size meets the following equation under certain conditions. Of late all the three equations have been used with austenitic stainless steels[9].

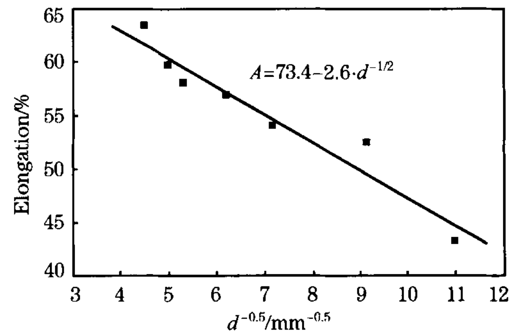
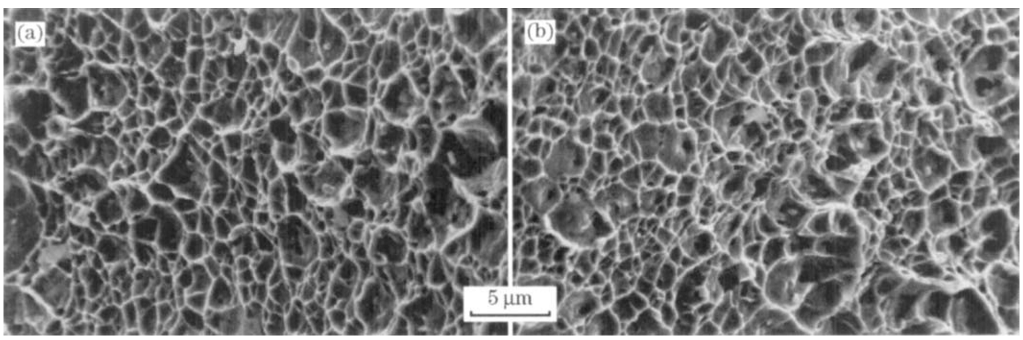


Fig. 6 Effect of grain size on the tensile ductility of nickel-free high nitrogen austenitic stainless steel

$$A = A_0 + k_A \cdot d^{-1/2} \quad (3)$$

From the experiment results, a conclusion has been obtained that nickel free high nitrogen austenitic stainless steel with a different grain size exhibits good ductility and high yield strength and tensile strength.



(a) 40 s; (b) 1 800 s

Fig. 7 SEM micrographs of fracture surfaces of tensile specimens for different annealing time

3 Conclusions

(1) The fine grained structures of nickel-free high nitrogen austenitic stainless steels with high strength and good ductility have been obtained by means of cold rolling and subsequent annealing.

(2) The Hall-Petch dependency for both yield strength and tensile strength is valid for the grain

size range in the nickel-free high nitrogen austenitic stainless steel.

(3) The hardness of the nickel-free high nitrogen austenitic stainless steel increases with a decrease in grain size, according to the Hall-Petch equation.

(4) The fracture surfaces of tensile specimens in the grain size range are covered with dimples as usually seen in a ductile fracture mode. In the present study, the ductility of cold rolled nickel-free high nitrogen austenitic stainless steel decreased with annealing time when the grain size was refined.

References:

[1] Stein G, Huchlenbroich I. Manufacturing and Application of High Nitrogen Steels [J]. Materials and Manufacturing Processes, 2004, 19(1): 7.

[2] Rashev T. Development of Laboratory and Industrial Installations for One Stage Production of HNS [J]. Materials and Manufacturing Processes, 2004, 19(1): 31.

[3] Katada Y, Sagara M, Kobayashi Y, et al. Fabrication of High Strength High Nitrogen Stainless Steel With Excellent Corrosion Resistance and Its Mechanical Properties [J]. Materials and Manufacturing Processes, 2004, 19(1): 19.

[4] Uggowitzer P J, Magdowski R, Speidel M O. Nickel Free High Nitrogen Austenitic Steels [J]. ISIJ International, 1996, 36(7): 901.

[5] Schino D A, Kenny J M. Development of High Nitrogen, Low Nickel, 18%Cr Austenitic Stainless Steel [J]. Journal of Materials Science, 2000, 35(19): 4803.

[6] Schino D A, Kenny J M. Grain Refinement Strengthening of a Micro-Crystalline High Nitrogen Austenitic Stainless Steel [J]. Materials Letters, 2003, 57(12): 1830.

[7] JIANG Zhou-hua, LI Hua-bing, SHEN Ming-hui. Manufacture of Nickel Free High Nitrogen Austenitic Stainless Steels [A]. DONG Han eds. Proceedings of International Conference on High Nitrogen Steels 2006 [C]. Beijing: Metallurgical Industry Pess, 2006. 372.

[8] Petch J N. The Cleavage Strength of Polycrystals [J]. Journal of the Iron and Steel Institute, 1953, 5: 25.

[9] Speidel M O. Nanograin Size, High-Nitrogen Austenitic Stainless Steels [J]. Z Metallkd, 2003, 94(6): 719.

(Continued From Page 31) learning model is also fine, and the deviation is less than 7%. Thus, the precision of the exit gauge of plate is well controlled, and the deviation of the plate gauge is less than 0. 2 mm.

4 Conclusions

(1) Based on the high precision spring model, the soft-measuring method can calculate the exit gauge of the rolling within a certain error, and combined with the target value locked method, the actual value of passes of the rolling can be confirmed.

(2) Using the actual value of exit gauge and other processing data, the actual value of β can be calculated in the rolling process, and combining with the methods of gauge layer division and exponential smoothing, a short-term self-learning model can be carried out.

(3) Based on the short-term self-learning model, a long-term self-learning model can be carried out by disposing the short-term self-learning data with the method of exponential smoothing.

(4) The application of long- and short-term self-learning models indicates that the models are quite practical for the rolling of plate.

References:

[1] HU Xian-lei, ZHAO Zhong, JIAO Zhi-jie, et al. On-Line Soft-Mearsuring Method of Plate Thickness [J]. Journal of Iron and Steel Research, 2006, 18(7): 55 (in Chinese).

[2] HU Xian-lei, QIU Hong-lei, LIU Xiang-hua, et al. Influence of Zero Wave for Spring Curve on Rolling Force Adaption in Plate Rolling [J]. Journal of Iron and Steel Research, 2003, 15 (1): 24 (in Chinese).