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Effect of heat treatment temperature on the mechanical properties of low-temperature high strength maraging steel

Hua Hou*, Haifeng Li, Yuchun Jin, Xinran Wang, Zhiqin Wen

College of Materials Science and Engineering, North University of China, Taiyuan 030051, China

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The effect of austenitizing temperature on mechanical properties of 00Cr9Ni9Co5Mo3 corrosion resistant maraging steel has been investigated. The results show that the recrystallization temperature of experimental steel is 850 °C. The austenite formed by non-diffusion reverse $\alpha' \rightarrow \gamma$ transformation inherit high density defects of the forging structure when solution treatment temperature is below recrystallization temperature. High-hardened martensite is formed during the cooling, the strength keeps a high level. Meanwhile, high-hardened austenite improves the resistance of $\gamma \rightarrow \alpha'$ transformation in the cooling process, which leads to more retained austenite in the steel and guarantees good low temperature toughness. The increasing of the pretreatment can further improve the low temperature toughness. When the pretreatment is added, the low temperature toughness is improved further, and the mechanical properties of materials are stable with the fluctuation of pretreatment temperature.

1. Introduction

The most important basic properties of the structure materials of metal are strong toughness. Therefore, materials must be designed to meet the requirements of the component conditions, especially the components are used under the liquid nitrogen temperature (−196 °C). Not only does it ensure sufficient strength, but it also has good low temperature toughness. Traditional low-temperature steel, such as low carbon manganese steel or low nickel steel, was difficult to use under liquid nitrogen temperature [1]. The high-nickel steel, austenitic cryogenic steel, whose strength was lower at very low temperature than that at the room temperature, were difficult to meet some special equipment usage requirements [2–4]. Low temperature maraging steel provided a new direction for the load-bearing parts under the harsh conditions of the low temperature. It not only had a good impact toughness at liquid nitrogen temperature, but also its strength achieved high levels above 1200 MPa. The heat treatment system is the main influencing factors of the mechanical properties of maraging steel. The austenite transforms into different phases though different heat treatment processes. Jones and Bhadeshia [5] described a modification of the Avrami overall transformation kinetics theory as adapted by Cahn, for grain boundary nucleated phases. The modification dealt with the simultaneous occurrence of two or more transformations: the austenite could transform into allotriomorphic ferrite, Widmanst QUOTE tten ferrite and pearlite.

Babu et al. [6] investigated the isothermal transformation of high-carbon austenite-to-bainitic ferrite with the in-situ technique of time-resolved X-ray diffraction using synchrotron radiation. The measurements indicated that prior to transformation, the austenite divided into regions with significantly different lattice parameters. Nambu et al. [7] investigated the martensitic transformation process in lath martensite. The formation process in martensitic transformation at a free surface was divided into two stages. The initial stage involved the partitioning of the austenite grain into several parts, and the remaining austenite then transformed relatively gradually. 00Cr9Ni9Co5Mo3 corrosion resistant maraging steel used for low temperature has been studied in this paper. It mainly explored pretreatment (PT) temperature and solution treatment (ST) which influence the low temperature toughness of the experimental steel. Finally it obtains good comprehensive properties, the room temperature strength is 1330 MPa and the liquid nitrogen temperature impact energy is 67 J, so it ensures that the components are reliable to use.

2. Experimental methods

The raw steel was melted in a vacuum induction furnace. Ingot was forged (final forging temperature was 850 °C) into 40×40 mm^2 forging bars, and its chemical compositions were showed in Table 1. The start and end temperatures when artensite

* Corresponding author. Tel.: +86 15035 172 958; fax: +86 0351 3557 006.
E-mail address: zyh388@sina.com (H. Hou).

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Table 1
Chemical compositions of experimental steel.

C	Cr	Ni	Co	Mo	Al	Si	Mn	P	S
0.024	8.94	9.35	4.94	2.57	0.018	0.29	0.26	0.0054	0.0039

transformed into austenite were 620 °C and 690 °C, respectively. The temperatures were measured by a Formastor-D automatic transformation measuring instrument. The blanks used for stretching and impacting (U-type) and metallographic samples were longitudinally cut from the forging bar. Tarasenko et al. [8] researched cryogenic maraging steel aging temperature, the results indicated that the experiment steel aging treatment (AT) temperature was 500 °C. Sample blanks were solutionized at 750, 800, 850, 900, 950 and 1000 °C, respectively, and holding time was 1 h before water-cooled. Then the simples used for impacting and stretching were aged at 500 °C for 2 h. To explore the influence of pretreatment temperature on mechanical properties, another group of sample blanks were pretreated at 750, 800, 850, 900 and 950 °C, which were compared with samples without pretreatment.

After the heat treatment, test steel was processed into the test bars whose gauge diameters were 5 mm and gauge lengthes were 65 mm and $10 \times 10 \times 55$ mm^3 standard U-notch impact test specimens. The room temperature tensile properties were measured by a MTS-810 tensile testing machine. Considering cryogenic application background of 00Cr9Ni9Co5Mo3 steel, U-shaped notch impact absorbed energy was measured by a JBN 300 impact testing machine at room temperature (20 °C) and liquid nitrogen temperatures (−196 °C), respectively. Microstructure analyses included following aspects: metallographic specimens which were eroded thermally by H_2SO4, $KMnO_4$ solution (2 g $KMnO_4$, 20 ml H_2SO_4, and 80 ml H_2O) showed the original austenite grain boundaries to observe the changes of the austenite grain morphology and size; the impact fracture was analyzed by a S-4300 cold field emission scanning electron microscope; the phase composition of the low-temperature impact simples and metallographic specimens were measured by a Philips APD-10 X-ray diffractometer (Co target, graphite monochromator filter). The austenite volume fraction was calculated according to the diffraction data.

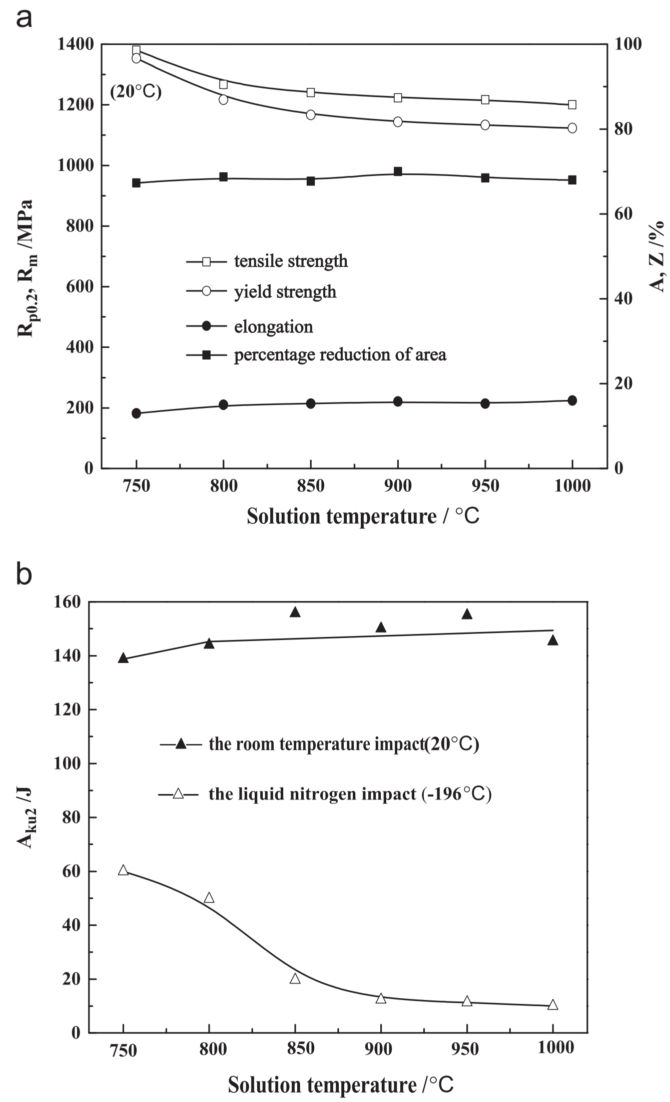

Fig. 1. The effect of solution temperature on mechanical properties.

3. The experimental results and discussion

3.1. Mechanical test results of ST+AT samples

Room temperature tensile test results can be seen in Fig. 1(a). The elongation after fracturing and reduction of area of the experiment steel, which are maintained about 15% and 68% respectively, change little with ST temperature rising. Changes of solution temperature have a greater influence on the tensile strength and yield strength. Tensile strength and yield strength of specimens are the highest by 750 °C solution treatment, which are 1380 MPa and 1353 MPa, respectively. The tensile strength and yield strength of specimens continue to decrease with the increasing of solution temperature. When the solution temperature is 1000 °C, the tensile strength and yield strength of the experimental steels are reduced to 1200 MPa and 1123 MPa, respectively.

Fig. 1(b) shows room temperature (20 °C) and low temperature (−196 °C) impact test results of sample which were treated at different solution temperatures. It can be seen that impact value has a certain anticorrelation to the tensile strength and yield strength at room temperature. The higher strength of sample is, the lower room temperature toughness is. The toughness of sample was tested about 150 J. But the low temperature impact toughness is obviously different. The low-temperature impact value is the highest by 750 °C ST, and impact absorbing energy is up to 60 J. As the solid solution temperature increasing, the low-temperature impact energy continues to reduce. The low-temperature impact absorbing energy is 10 J with 1000 °C solution treatment.

3.2. SEM observation of the ST+AT sample

After different ST+AT, low temperature (−196 °C) impact fracture morphology is shown in Fig. 2. Fig. 2(a) shows low-temperature impact fracture morphology of the specimen at 750 °C by ST. It can be seen that fracture mechanisms is quasi-cleavage fracture combining with dimple. There is a certain width of the ductile tearing zone between dimples, and dimple is relatively uniform and small. It shows that unstable propagation of the sample is predominantly microscopic holes aggregation model. The circular inclusions are at the bottom of dimples. Tiny sleek inclusions, which are sulfide inclusions by energy spectrum analysis, slow down the stress concentration and buffer against crack propagation. It has an effect on increasing toughness. There are no other particles in dimple, to a certain extent, which explains that there are few dissolved phases in 00Cr9Ni9Co5Mo3 steel by ST at 750 °C. It ensures good low-temperature impact toughness of