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Effect of Nb on Microstructure and Mechanical Properties in Non-magnetic High Manganese Steel

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Abstract: Microstructure and mechanical properties of two kinds of non-magnetic high manganese steels with and without Nb addition which experienced the same rolling and heating treatment were investigated by means of scanning electron microscopy, electron back-scattered diffraction, transmission electron microscopy, X-ray diffraction and tensile test. It was found that the microstructure of the high manganese steel was refined by the Nb addition. Moreover, steel with Nb addition has a higher stacking fault energy which favors the deformation twinning. Twinning is the most important deformation mechanism in the Nb-bearing steel. Therefore, steel with Nb addition has much higher strength and higher plasticity. The product of tensile strength and total elongation exceeds 61.8 GPa • %. In addition, steel with Nb addition also has excellent non-magnetic property.

Key words: non-magnetic high manganese steel; Nb addition; rolling; twinning; mechanical property

It has been well known that the non-magnetic steel has been widely used to avoid the energy loss in many fields, such as the strong magnetic products manufacturing and the transport industry. With the development of modern industry, the demand for high hardness, high strength and excellent formability of the non-magnetic steel is highly increasing. Therefore, many researchers focus on the non-magnetic steel these years. Allain et al.[1] investigated the modeling of mechanical twinning in high manganese austenitic steel. Some other researchers analyzed the influence of alloying elements such as Al[2,3], Cr and Cr-N[4] on the hot working of twinning induced plasticity (TWIP) steels. Li et al.[5] designed the 30Mn26Al4V non-magnetic high manganese steel.

Moreover, the mechanical properties of high manganese austenitic TWIP steel result from different deformation mechanisms: crystallographic slip, possible martensitic transformation and twinning effect[6]. Such mechanisms are related to different stacking fault energy (SFE) values[7], which strongly depend on Mn, Al, Si and C contents, as well as temperature[8,9]. The SFE can be decreased by the Si addition and enhanced by the Al addition[10,11]. And alloys with high SFE tend to form mechanical twin instead of phase transformation[11,12]. The twin boundaries act as strong barriers to dislocation motion which leads to the increase of ultimate tensile strength[11,13]. Furthermore, the mechanical twins change the crystallographic orientation and increase the motion probability of some suppressed slip systems accordingly. The increment of plastic deformation mechanism by the strain induced twins plays an important role in the elongation improvement[13]. The twins can produce the deformation more than 40%, and the value will be further enhanced when the secondary twin is formed[14].

However, there is still a problem that the forging processing property of the high manganese austenitic steel is so poor that it is hard to be machined. How to take full advantage of the existing equipments and

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improve the comprehensive mechanical properties of the steel has been more and more important.

In this work, the microstructure and related mechanical properties in the hot rolled high manganese steels with and without addition of niobium (Nb) were investigated. In particular, the effects of Nb on mechanical properties, microstructures and magnetic permeability were discussed.

1 Experimental Scheme

Table 1 shows the chemical composition of the designed steel used in the present work. The steels under investigation were melted in a vacuum induction furnace and cast as ingots. Then the cast ingots were forged to the plate of 40 mm×95 mm×115 mm. The samples were homogenized in an air furnace at 1200 ℃ for 1 h, then hot rolled to 7 mm thick plate at 1100 ℃ by five passes (The finishing temperature was about 900 ℃). After the rolling process, the rolled plate was reheated to 1000 ℃ for 15 min and then rapidly cooled in water which named the water toughening process.

Table 1 Chemical composition of experimental steels

mass%

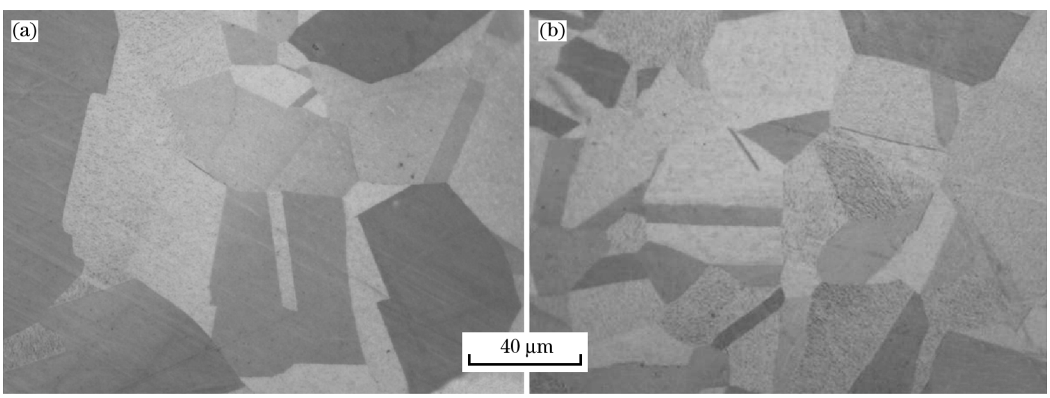
Steel	C	Si	Mn	P	S	Nb
No. 1	0.86	0.42	14.4	0.008	0.0055	—
No. 2	0.95	0.38	14.9	0.007	0.0047	0.012

The tensile samples were cut from the rolled plates of both steels and each group included three samples. Tensile tests were performed by the MTS810 type universal material testing machine at room temperature. At last, the tensile properties could be calculated by averaging the test values of the three samples. The microstructures of the steels and morphology of precipitates were analyzed by using an optical microscope (OM), a ZEISS SUPRA 55 type scanning electron microscope (SEM) and an HITACHI H-800 type transmission electron microscope (TEM). The high angle grain boundary was analyzed by electron backscattered diffraction (EBSD). The magnetic permeability was measured by the PMS-9 system.

2 Results and Discussion

2.1 Microstructures after water toughening

Fig. 1 shows the microstructures of the experimental steels after the water toughening process. Figs. 1(a) and 1(b) show the microstructure of the high manganese steel without and with Nb addition, respectively. It can be seen that both of the two steels have equiaxed austenite grains. Moreover, there are some annealing twins with straight boundary in the austenite grains. In addition, it is obvious that the austenite grains of steel with Nb addition are finer than those without Nb addition. It is considered to be related to the precipitation of the Nb-bearing steel during the hot rolling and heat treatment processes.



(a) No. 1 steel without Nb; (b) No. 2 steel with Nb.

Fig. 1 Microstructure of experimental steels after water toughening

In order to verify the effect of Nb on the steel, TEM analyses of the Nb-bearing high manganese steel is presented in Fig. 2. From Fig. 2(a), the nano-sized precipitate marked by the arrow can be seen clearly, which presents spherality or granulate type. The energy spectrum of the precipitates was also analyzed and its result is shown in Fig. 2(b). Both the Nb and C peaks can be seen in the energy spectrum, which implies that the precipitates of the Nb-bearing high manganese steel are NbC. Therefore, it can be easily understood that the grains of the Nb-bearing steel are much finer because of the retarding effect of precipitates on the grain boundaries.