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Effect of the Thermomechanical Treatment on the Microstructures of CLAM Steel

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***Abstract*—The thermomechanical treatment test of CLAM steel is simulated by the thermal simulated test machine Gleeble3500, by means of constant temperature compression test to study the effect of the thermomechanical treatment processing on microstructure of China Low Activation Martensitic steel(*CLAM steel*). The results show that the thermomechanical treatment processing has a great effect on the microstructure of CLAM steel, which makes a great contribution to refine the martensitic lath, the formation of $M_{23}C_6$ carbide and MX nano-sized carbo-nitride, leading to strengthen the CLAM steel's structure. Thus by means of the thermomechanical treatment processing to refine the microstructure of CLAM steel to improve its property is viable.**

Keywords-thermomechanical treatment processing; CLAM steel; microstructure; MX carbo-nitride

I. INTRODUCTION

The Reduced Activation Ferritic/Martensitic (*RAFM*) steel has been considered as the primary candidate structural material for the future nuclear fusion demonstration reactor and the nuclear fusion power reactor, for its outstanding mechanical property, low irradiation swelling rate, low thermal expansion coefficient and excellent thermal conductivity. Nowadays the majority of countries in the world are actively researching and developing their independent RAFM steels, for example, the Japanese F82H and JLF-1, the European EUROFER97, the American 9Cr-2WVTa, and so on[1-3].

At the same time, China independently designs its own RAFM steel, called the China Low Activation Martensitic(*CLAM steel*), which is in possession of Chinese own intellectual property, with the independent design of constituent and performance optimization [4-5]. At present, the CLAM steel still needs us to make further study to improve its properties in order to satisfy the engineering demand.

The thermomechanical treatment processing is the metallic material intensification method which integrates deformation enhanced transformation with hardening through phase transformation, so we can apply the thermomechanical treatment to CLAM steel to obtain satisfactory mechanical properties, and it is no doubt that researching the effect of thermomechanical treatment on microstructure of CLAM steel is very necessary[2-5]. This article mainly researches the effects of the thermomechanical treatment processing on microstructure of CLAM steel.

II. EXPERIMENTAL PROCESSING

CLAM steel is conducted vacuum induction melting and vacuum electroslag remelting. The sheet is processed full annealing treatment (950℃ 2h). Then we need to cut some columnar specimens from the sheet after full annealing treatment, and the size of the specimens are Φ8mm×12mm. This experiment about the thermomechanical treatment test on CLAM steel is simulated by the thermal simulated test machine Gleeble3500, and the experiment mainly researches the effects of the thermomechanical treatment processing on microstructure of CLAM steel. So we design the thermal treatment parameters as follows: the specimen (*a*) is without any other thermal treatment; the specimen (*b*) is heated to 950 ℃ at the heating rate of 5 ℃/s, which is at the stain rate of 5 s^{-1}, with the deformation quantity of 70%, and the true stain is 1.2, then cooled to room temperature at the cooling speed of 10 ℃/s. For the sake of preferably studying the microscopic structure transformation by thermomechanical treatment, the specimens after thermomechanical treatment are conducted tempering treatment once time, the tempering temperature at 760 ℃, soaking time of 90 min; With the help of Olympus BX41M, Nova Nano SEM 450 Hot Field Emission Scanning Electron Microscope and FEI Tecnai G2 F20 S-TWIN Transmission Electron Microscope to observe the variation of the microstructure.

III. RESULT AND DISCUSSION

Observing Fig.1, we can clearly see the martensitic structure; in contrast to Fig.1a and Fig.1b, the lath martensitic structure morphology exists in great difference. At the same time, we can find out some broken crystal and crystal shape polygonization from the specimen grain diagram by means of thermomechanical treatment processing; the average grain size of thermomechanical treatment processing is about 6um. The average grain size without the thermomechanical treatment processing is about 10um.Thus the thermomechanical treatment processing can refine the size of CLAM steel grain.

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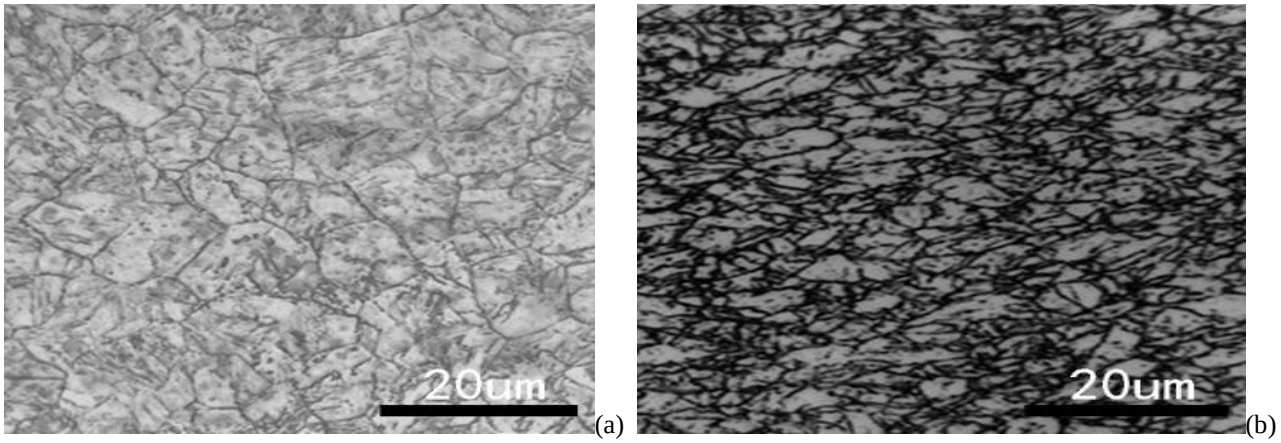
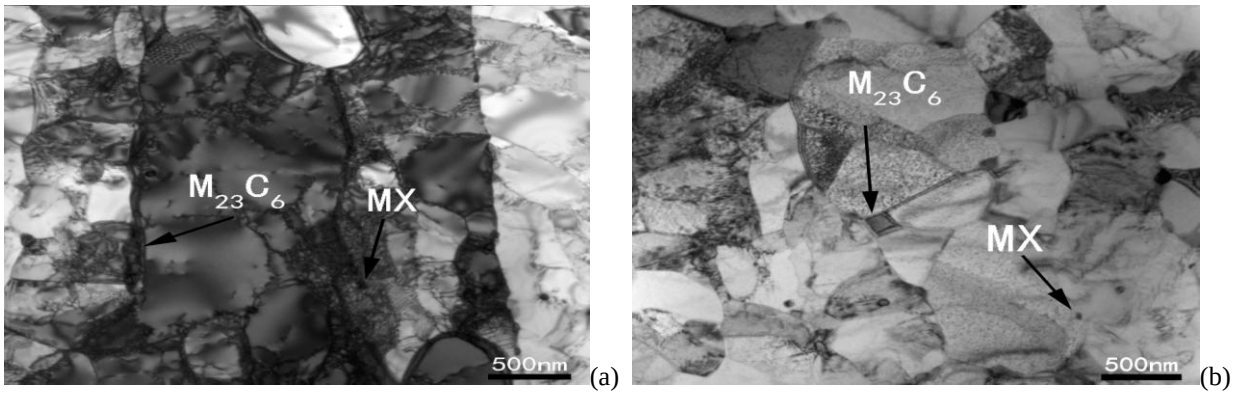


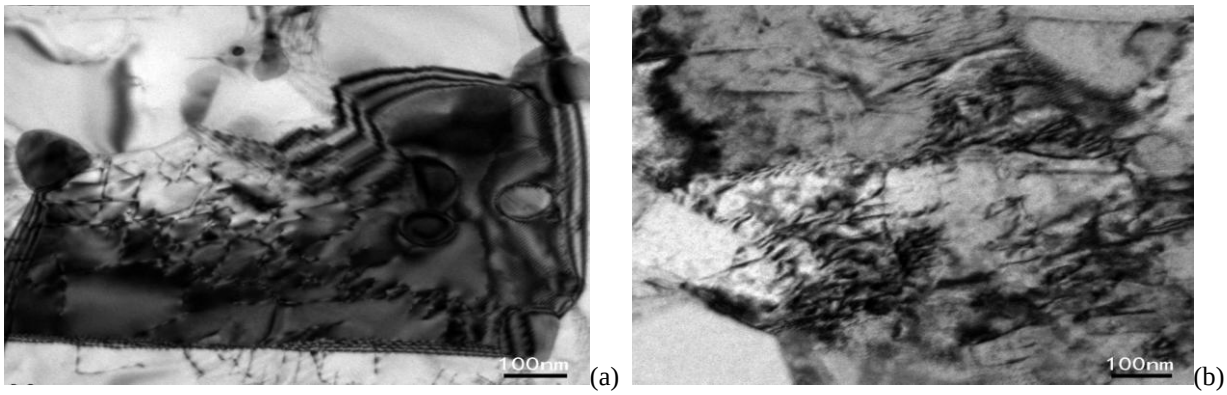
(a) (b)

Figure 1. The grain diagram of the picture (a) of traditional thermal treatment processing, (b) of thermomechanical treatment processing.



(a) (b)

Figure 2. The TEM micrographs showing the change on microstructure of the CLAM steel (a) of traditional thermal treatment processing, (b) of thermomechanical treatment processing.



(a) (b)

Figure 3. High density dislocations generated in the microstructure of the CLAM steel (a) of traditional thermal treatment processing, (b) of thermomechanical treatment processing.

The Fig.2 is the CLAM steel transmission electron microscope microstructure with the thermomechanical treatment processing (*Fig.2b*) and not (*Fig.2a*), and from the Fig.2b we can observe a certain extent break of the martensitic lath, at the same time we are able to find out that the $M_{23}C_6$ carbide distributes in the martensitic lath boundary and the martensitic lath presents parallel arrangement, simultaneously all of the MX carbo-nitride distribute inside of martensitic lath. With the thermomechanical treatment processing (*Fig.2b*) the average martensitic lath breadth is about 170nm, and the average size of $M_{23}C_6$ carbide is about 140nm, simultaneously the average size of MX carbo-nitride is about 8nm. From the Fig.2a, the average martensitic lath breadth is about 350nm, and the average size of $M_{23}C_6$ carbide is about 240nm, simultaneously the average size of MX carbo-nitride is about 12nm.We can find out that the thermomechanical treatment processing is able to refine the

microstructure of martensitic lath breadth, $M_{23}C_6$ carbide and MX carbo-nitride. At the same time, the thermomechanical treatment processing makes contribution to increase the quantity of nano-sized MX carbo-nitride.

By the transmission electron microscope, we can observe that the body of CLAM steel martensitic lath after the thermomechanical treatment appears high density dislocation, as shown in Fig.3b, in comparison with Fig.3a, we will clearly find out that all of the interior on martensitic lath with thermomechanical treatment exists in high density dislocation, and the quantity of high density dislocation is distinctly higher than without thermomechanical treatment. By means of thermomechanical treatment, the body of martensitic lath generates high density dislocation, which could provide some advantageous condition for the nucleation of MX carbo-nitride, at the same time, the high density dislocation will effectively hinder the increase of MX carbo-nitride1 [6-9]. Simultaneously, the solute atoms diffusion rate along these high density dislocation pipeline is higher than else direction, and the atom Ta and V of CLAM steel easily segregates in the defective condition such as the high density dislocation, which could availably accelerate substitutional diffusion of the MX carbo-nitride forming element[8-10]. In the process of thermomechanical treatment, the deformation stress prompts solubility variation of the carbon and nitrogen in the original austenite, the solubility reduces by a large margin, so thermomechanical treatment can be able to induce the MX carbo-nitride to separate out in certain effectiveness [10-11]. When MX carbo-nitride separates out in the condition of high density dislocation, the precipitated MX carbo-nitride takes great effect on pinning for high density dislocation, which results in high density dislocation gains multiplication in development in the process of thermomechanical treatment, and the multiplication dislocation could likewise provide a large amount of conditions for the precipitation of MX carbo-nitride, repeatedly like this, prompting the MX carbo-nitride to separate out in the high density dislocation[9-12], making a contribution to the MX carbo-nitride to separate out inside of martensitic lath.

IV. CONCLUSION

In comparison with the traditional thermal treatment , the thermomechanical treatment processing has obviously refined the microstructure of CLAM steel as fellows:

(1) The average grain size of CLAM steel by thermomechanical treatment is signally less than the traditional thermal treatment.

(2) By the thermomechanical treatment, the martensitic lath, $M_{23}C_6$ carbide and MX carbo-nitride have been refined, at the same time the quantity of $M_{23}C_6$ carbide and MX carbo-nitride has increased, which strengthens the structure of CLAM steel.

(3) High density dislocation has come into being by thermomechanical treatment, which is benefit to refine the size of carbide and increase its quantity, thus the property of CLAM steel will be improved.

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REFERENCES

[1] Klueh R L, Gelles D S, and Jitsukawa S, “Ferritic/martensitic steels overview of recent results,” Journal of Nuclear Materials,vol.307-311, pp.455-465, 2002.

[2] Klueh R L, Alexander D J, and Rieth M, “The effect of tantalum on the mechanical properties of a 9Cr-2W-0.25V- 0.07Ta-0.1C steel 1,” Journal of Nuclear Materials, vol.273, pp.146-154,1999.

[3] Kohno Y, Kohyama A, and Hirose T, “Mechanical property changes of low activation ferritic/martensitic steels after neutron irradiation,” Journal of Nuclear Materials, vol.271, pp.145-150, 1999.

[4] Huang Qunying, Li Chunjing, and Li Yanfen, “R&D status of China low activation martensitic steel,” Chinese Journal of Nuclear Science and Engineering, vol.27, pp.41-50, 2007.

[5] Huang Q, Li C, and Li Y, “Progress in development of China Low Activation Martensitic steel for fusion application,” Journal of Nuclear Materials, vol.367-370, pp.142-146, 2007.

[6] Yvon P and Carr F, “Structural materials challenges for advanced reactor systems,” Journal of Nuclear Materials, vol.385, pp.217-222, 2009.

[7] Huang Q, Li C, and Wu Q, “Progress in development of CLAM steel and fabrication of small TBM in China,” Journal of Nuclear Materials, vol.417, pp.85-88, 2011.

[8] Klueh R L, “Reduced-activation steels: Future development for improved creep strength,” Journal of Nuclear Materials, vol.378, pp.159-166, 2008.

[9] Jitsukawa S, Kimura A, and Kohyama A, “Recent results of the reduced activation ferritic/martensitic steel development,” Journal of Nuclear Materials, vol.329, pp.39-46, 2004.

[10] Kurtz R J, Alamo A, and Lucon E, “Recent progress toward development of reduced activation ferritic/martensitic steels for fusion structural applications,” Journal of Nuclear Materials, vol.386, pp.411-417, 2009.

[11] Kimura A, Sawai T, and Shiba K, “Recent progress in reduced activation ferritic steels R&D in Japan,” Nuclear Fusion, vol.43, pp.1246, 2003.

[12] Bloom E, Conn R, and Davis J, “Low activation materials for fusion applications,” Journal of Nuclear Materials, vol.122, pp.17-26, 1984.