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Preparation and Micro-analysis of the 1Cr18Ni9Ti with Different Magnetic and Same Component

Yonghui WEI [1,3]*, Xiuli WANG [1], Yongzhen ZHANG [2], Yue CHEN [2], Zhiqiang JIANG [1], Yongqiang WEI [1]

[1] *School of Mechatronics Engineering, Zhengzhou Institute of Aeronautical Industry Management, Zhengzhou 450015, China*

[2] *School of Materials Science and Engineering, Henan University of Science and Technology, Luoyang 471023, China*

[3] *School of Mechatronics Engineering, Northwestern Polytechnical University, Xi'an 710072, China*

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In some studies, the metal materials with different magnetic permeability and same chemical composition need to be prepared to avoid the interference caused by different compositions and make the parameter of magnetic permeability become the key variable directly. In order to prepare the metal materials with different magnetic and same component, the paper has considered other two commonly schemes, such as the casting method by adding some ferromagnetic elements and the heat-treatment process to increase its phase content of martensite or ferrite. Finally, it has been found that the cold working process was preferable if the austenitic stainless steel 1Cr18Ni9Ti with paramagnetic was selected as a raw material, because it got better control in forging ratio. The method of magnetic balance has been used to measure the relative magnetic permeability of every specimen with different hardness HB 165 (A), HRC 20 (B), HRC 25 (C) and HRC 30 (D). The metallurgical microscope, XRD, TEM and SEM has been put to use to analyse their microstructure before and after forging. The results show, the cold working process improved magnetic properties of 1Cr18Ni9Ti continuously and largely within limits by controlling different forging rate, as well as the process was not complicated. The relative rate of magnetic permeability for 1Cr18Ni9Ti and W18Cr4V (high-speed steel) could be up to 1:2.435 at 0.03 T. The 20.1 % maximum reduction of the austenite phase should be a main reason to improving magnetic permeability of 1Cr18Ni9Ti. The real magneto-crystalline anisotropy should be due to martensite or ferrite phases with strong magnetic property. The 1Cr18Ni9Ti after cold working still maintained high corrosion resistance. Furthermore, this process method was also applicable to other austenitic steels with paramagnetic and strong cold work hardening characteristics.

Keywords: magnetic properties, metals, cold working, magnetic materials, 1Cr18Ni9Ti.

1. INTRODUCTION

Magnetic materials are widely used in electricity, energy, military, telecommunications, medical equipment, high-energy physics, transportation, mechanical engineering, etc., relating with many aspects of a national economy closely [1 – 2]. Different magnetic materials are needed in different fields and working conditions. Furthermore, in a study on the coupling relationship between magnetic permeability of materials and characteristics of Magnetic-environment Dry Tribology (MDT) [3 – 6], whether new materials with different magnetic permeability and same chemical composition being prepared become a bottleneck for MDT research to be in-depth.

Following are several frequently-used ways, which have one or another drawback, to manufacture the materials with different magnetic permeability. The conventional method for changing magnetic permeability is to change the chemical composition, such as references [7-8] by adding some ferromagnetic elements. However, such process methods become involved, long in producing cycle, delicate in controlling precision and high prices. Changing the microstructure (austenitic, martensite, ferrite) of steels by means of heat-treatment process bured to increase its magnetic permeability. However the high-temperature heat treatment processes will also change material component due to producing oxide on the surface. Moreover the content of ferromagnetic phase and magnetic permeability of materials can be changed small.

A simple process method is developed in this paper, which can greatly short the manufacturing cycle and reduce production costs. So, it will have enormous social and economic benefits.

2. MATERIAL AND METHODS

The magnetic permeability of an austenite phase with paramagnetic in steel is very low, and martensite and ferrite with ferromagnetic remain high magnetic permeability. Therefore, in the paper, austenitic stainless steel 1Cr18Ni9Ti (paramagnetic material) is selected as the raw material. Table 1 shows the chemical composition of 1Cr18Ni9Ti stainless steel.

Table 1. The chemical composition of 1Cr18Ni9Ti stainless steel (%, Fe balance)

C	Si	Mn	Cr	Ni	P	Ti
≤ 0.12	≤ 1.0	≤ 2.0	17-19	8-11	≤ 0.035	0.80

Its magnetic properties were changed in the forging process at room temperature by changing the austenite

* Corresponding author. Tel: +86-15838369195; fax: +86-371 60632060. E-mail address: *yangguangyingyu@163.co*m (Y. Wei)

phase content through utilizing its strong work-hardening characteristics. Finally, soft-magnetic materials with different magnetic permeability have been made by controlling different forging rate. The forging process is performed in C41-250 air hammer testing machine at room temperature. The samples after forging need to be annealed at 180 °C for 0.5 h to eliminate their residual stress. Many kinds of soft-magnetic materials with different magnetic permeability can be manufactured in this way to use for different devices or different types of an electromagnetic device.

In order to overcome the inhomogeneity of microstructure, the size of specimens can be processed at φ 7 mm × 15 mm by wire cutting process. In the forging process, the hardness and mechanical properties of materials change with improving the magnetic permeability of 1Cr18Ni9Ti. Moreover numerous kinds of new soft-magnetic materials with different hardness can be obtained if classified in accordance with the hardness.

3. RESULTS AND ANALYSIS

3. 1. Changes of relative magnetic permeability

Based on the forging volume from low to high, the specimens A, B, C, D with hardness HB 165 (A), HRC 20 (B), HRC 25 (C) and HRC 30 (D) are defined, respectively. The relative magnetic permeability of every specimen has been measured by the method of magnetic balance at 0.03 T (Fig. 1 a). The rate of relative magnetic permeability for (A:)(B:)(C:)(D) measured is 1:36:124:93 (as shown in Fig. 1 b). From Fig. 1 b, there is a maximum value for magnetic permeability at specimen C among specimens A-D. While deformation rate of 1Cr18Ni9Ti are larger or less than that of specimen C, the magnetic permeability decreases in a different distinction.

Magnetic permeability of specimen D whose hardness is highest among specimens A – D although, is also less than that of specimen C. This situation may be caused by the excessive deformation. Specimen E is high-speed steel (W18Cr4V) in Fig. 1 b.

The rate of relative magnetic permeability between specimen C and specimen E is 1:2.435, which indicates that the magnetic permeability of 1Cr18Ni9Ti prepared has been improved considerably. Here, 'magnetic permeability' referred to is the initial relative magnetic permeability under a weak magnetic field 0.03 T.

3. 2. Changes of austenite phase content

Fig. 2 shows the change of the content of an austenite phase based on XRD analysis. The results show the austenite phase content decreases with the hardness of materials increasing. The maximum dispersion of austenite phase content is up to 20.1 %.

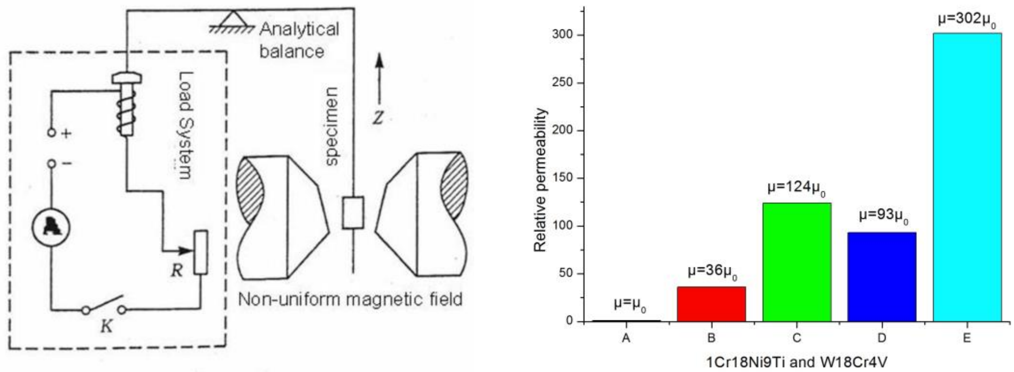
3. 3. Changes of Microstructure

Samples were prepared by mechanical polishing and eroding with aqua fortis (concentrated (HCl:) HNO_3 volume rate of 3:1) for 20 – 30 min. From the eroding process, specimen B, C and D still maintained high corrosion resistance of parent specimen A.

Fig. 3 shows the metallographic morphology of four specimens with different hardness before and after forging (×200). The austenite grains on specimen A appear typical big granular-like (Fig. 3 a). All of B, C and D are the specimens after forging, whose rate of forging are increased continuously. The greater the deformation amount is, the higher the hardness of specimen is. The grain size and austenite content decrease with the hardness are increasing (Fig. 3 b, Fig. 3 c, Fig. 3 d).

Fig. 4 shows the SEM morphology (×1000) of the specimen A and C eroded with aqua fortis. From Fig. 4, the grain size on specimen A is big block-like, while much more twins and tendentious textures appear on specimen C. Deformation twinning becomes fine, uniform, longitudinal growth.

Fig. 5 a and b show the TEM morphology and diffracted patterns of specimen A [9]. Fig.5 a shows that some fine carbide exists. From the diffracted pattern matrix, it can be identified that the matrix structure is austenite mainly ('A' on behalf of austenite in Fig. 5). No obvious grain boundary can be seen due to large grains relatively. Fig. 5 c and Fig. 5 d show the image of bright field and dark field of specimen C under TEM. Fig. 5 c and Fig. 5 d shows that there exists the lath or lamellar twinning microstructures in specimen C. Fig. 5 c and Fig. 5 e and Fig. 5 g show the deformation twinning become thin twin steps, and then growing longitudinally and thickening horizontal. Fig. 5 e – h show TEM morphology and diffracted patterns of the specimen C. Fig. 5 f – h shows that there exists austenite and martensite with twins in the matrix of specimen C ('M' on behalf of martensite in Fig. 5).



a b

Fig. 1. a – experiment setup in magnetic balance method at 0.03 T; b – the relative magnetic permeability of specimens A-E

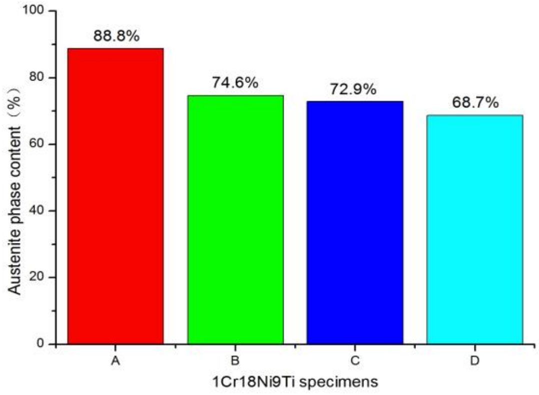


Fig. 2. The content of an austenite phase from XRD

From Fig. 5 e – g, it can be identified there are high density of dislocations, needle and lath martensite, which cause distortion in the austenite lattice, resulting in improvement of hardness and strength of 1Cr18Ni9Ti forged.

4. DISCUSSION

In a macro level, according to Fig. 2 from XRD, it can be understood the macroscopic reasons of magnetic permeability improving of 1Cr18Ni9Ti forged. The content of austenite phase decreases greatly, so that the magnetic permeability improving. The reduction in the austenite phase must generate the martensite or ferrite with ferromagnetic. Perhaps the annealing treatment after cold deformation inducies dynamic recovery and recrystallization, resulting in martensite or ferrite transformation, which improved the permeability of 1Cr18Ni9Ti.

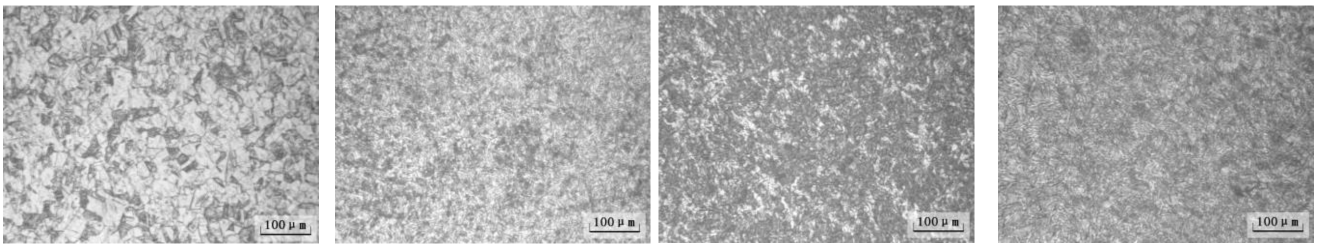
In a micro level, it can be understood combining metallographic morphology (Fig. 3), SEM (Fig. 4) and TEM (Fig. 5). The typical granular phase refines and needles deformation during forging. The lamellar texture appears which generates lath austenite twins, micro-twins, the high density dislocations, as well as lath and needle-like martensite. Therefore, these lath twins, needle and lath martensite raise the magneto-crystalline anisotropy of martensite or ferrite phase [10, 11]. This could be because of the martensite or ferrite phase that have a strong magnetic permeability.

The results were supported by the previous reseaches. researcher had found these changes of macro or micro in related earlier research of the 1Cr18Ni9Ti, but the main aim of this paper is to prepare the materials with same components and different magnetic permeability. We consequenced that the raw material 1Cr18Ni9Ti can be one choose among all of the austenitic steels with paramagnetic and strong work-hardening characteristics, from which in this way could also be prepared the materials with that same components and different magnetic properties.

5. CONCLUSIONS

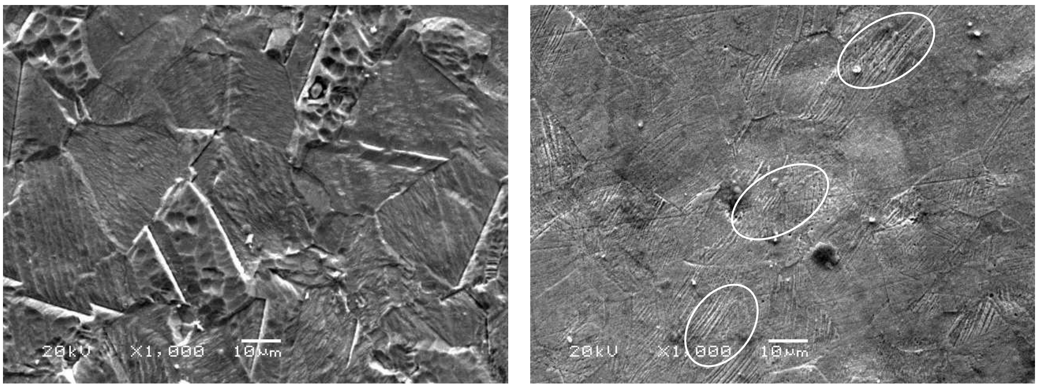
In this paper, the 1Cr18Ni9Ti with different magnetic permeability have been made by forging process. Moreover, the reasons for improving magnetic permeability of 1Cr18Ni9Ti were discussed from the macro and micro aspects according to the XRD and microstructure analysis. The main conclusions are drawn as follows:

1. The cold working process can improve magnetic permeability of 1Cr18Ni9Ti continuously and considerably within a specified range by controlling different forging rate. The rate of relative magnetic permeability for 1Cr18Ni9Ti/high-speed steel (W18Cr4V) can be up to 1:2.435 at 0.03T. The excessive forging deformation can cut down the magnetic permeability of 1Cr18Ni9Ti.



a A HB 165 b B HRC 20 c C HRC 25 d D HRC 30

Fig. 3. Metallographic morphology of four specimens before and after forging (×200)



a Specimen A b Specimen C

Fig. 4. SEM morphology of specimen A and C etching with aqua fortis (×1000)

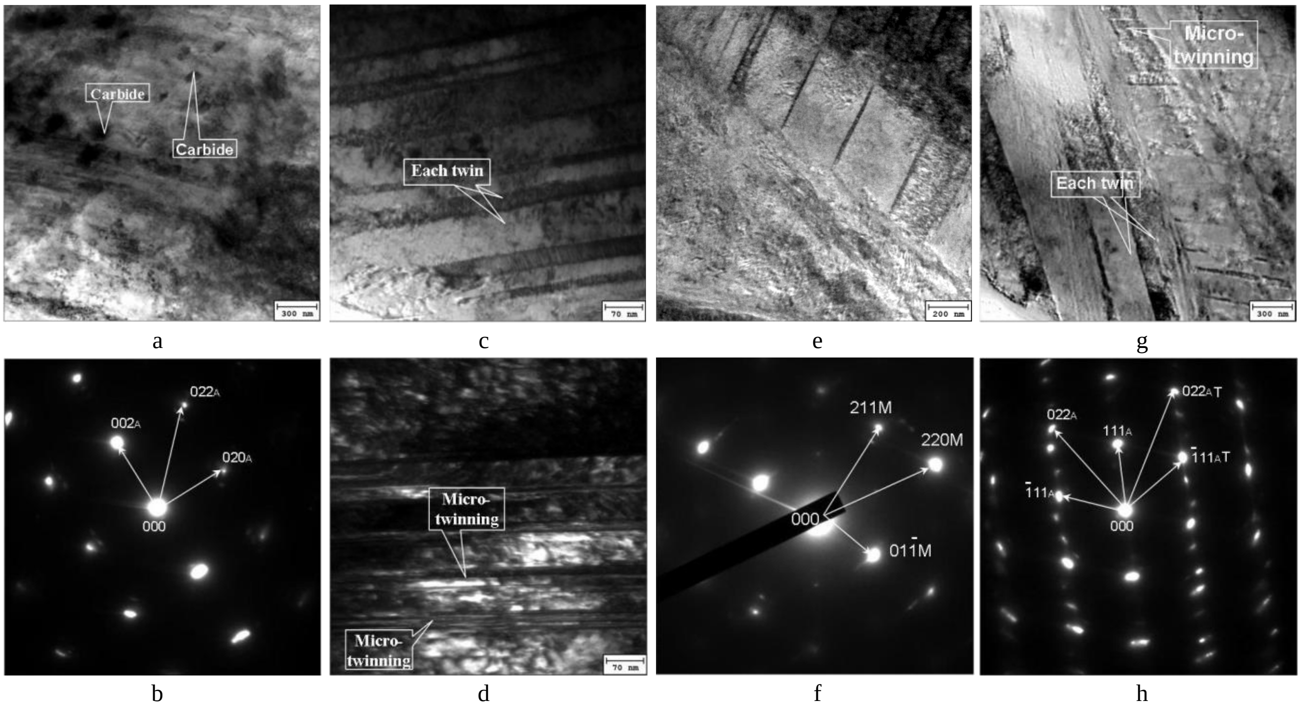


Fig. 5. a – TEM morphology and b – diffracted pattern of the specimen A; c – bright area image and d – dark area of specimen C from TEM; e, g – TEM morphology and f, h – diffracted patterns of specimen C

2. By XRD analysis, the maximum reduction of austenite phase amounts to 20.1 %. By analyzing the metallographic, SEM and TEM morphologies, the grain size and austenite content decrease with the hardness of 1Cr18Ni9Ti increasing; there exists lath austenite and martensite with twins; 3) The main reasons of improving magnetic permeability of 1Cr18Ni9Ti are that the content of austenite phase decreased greatly. The reasons of martensite or ferrite phase having ferromagnetic may be that the magneto-crystalline anisotropy of martensite or ferrite phase is better than that of the austenite phase; 4) The 1Cr18Ni9Ti after forging still maintained high corrosion resistance.

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