Experimental Research on The Microcosmic Mechanism of Stress-magnetic Effect For Magnetic Memory Testing

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Abstract

Influenced by the earth magnetic field, there will exist the irreversible reorientation of domain organization with the characteristic of magnetostriction in internal organization of the loaded ferromagnetic material. The different compressed loads are exerted onto the 20 steel and 40 steel specimens after annealling ,which are then made into the metallographic observation test specimens. The magnetic domain structure is observed by the Bitter Method. Then compare the magnetic domain structure pictures of specimens with the same material and under different loads, and analyze different affections of different loads. The experimental results shows that in the occasion of no stress or less stress ,the lamellar domains appear in the area，and the domain walls are parallel to the same crystalline grain. The labyrinthian domains appear in company with the concentrated stress increasing，and the harder stress loads, the more labyrinthian domains appear. Meanwhile，the length and the distance between the domain walls change accordingly.

Keywords :Metal magnetic memory ;Magnetic domain ;Labyrinthian domain ;Lamellar domain

Metal magnetic memory testing is a new nondestructive testing method which judging the dangerous zone in the light of stress concentration in ferromagnetic items[1,2]. Consequently, so far it is deemed to be the only nondestructive technique to diagnose the early damage in

ferromagnetic items effectively. The basic principle is that because the material exists a variety of internal friction effects (such as viscoelastic internal friction, dislocation internal friction, etc.), which makes internal stress concentration region retained after the dynamic load eliminated. According to the theory of the Ferromagnetism, concentrated stress will lead to the magnetic characters change in the area nearby, and the external magnetic field (such as the geomagnetic field) will bring the magnetic field distortion into existence. At present, metal magnetic memory testing(MMMT) research is mostly focusing on loading test, scene application and theoretical analysis etc., while MMMT technique microcosmic mechanism is still at junior step. In view of what mentioned above, in this paper the Bitter Method[3] is adopted to carry out experimental research on the magnetic domain structures of ferromagnetic material. Through observing magnetic domains of specimens under different loads, it is found that, due to the existence of internal stress inside the specimen, the internal magnetic domains will change orientation in different extent which is a valuable reference for validating MMMT technique microcosmic mechanism.

1、Principle of MMMT

Because of the spontaneious magnetization occurring in ferromagnetic material , all the atom magnetic moment in a certain area of ferromagnetic material will queue to a same orientation which will engender magnetic domains. When the ferromagnetic specimen is exerted with outer stress, there will exist stress energy inside the ferromagetic specimen in the stress concentration part. According to the Principle of Minimum Energy, magnetostriction transmogrification will happen to the ferromagnetic items, which will lead to the displacement of internal magnetic domain walls under the geomagnetic field and even the irreversible reorientation of magnetic domains[4], so as to counteract the increase of stress energy. With internal friction effects, stress concentration field remain in the loaded ferromagnetic items, and the realignment tropism of magnetic domain will also remain.

On the basis of theory above, through the observation of the magnetic domains in specimens before and after loading, we can summarize the corresponding connection between magnetic domain structures in ferromagnetic microcosmic field and stress transformation, which is caused by remnant stress concentration. It is proved that MMMT is based on stress-magnetization effect of ferromagnetic material from microcosmic perspective.

2、MMMT Method

Bitter Method is taken to observe the magnetic domains in specimen[5,6]. The whole equipment consists of a metallographic microscope and polishing equipment. Besides requesting a higher surface finishing of the specimens, the key step is the preparation of magnetic particle suspension. That is to say, suspending capability of the magnetic particle suspension must be so good that can easily agglomerate at the verge of the magnetic domains. Preparing suspension with a suitable size of Fe_3O_4 granule is the key step of the testing process.

The suitable size of Fe_3O_4 powder for eligible Magnetic particle suspension must be prepared.

First of all, liquefy suitable proportion of $FeCl_2.4H_2O$ and $FeCl_3.6H_2O$ in determinate volume of distilled water to crank out the first liquor. Second, liquefy suitable proportion of NaOH in determinate volume of distilled water，then drip the NaOH liquor into the first liquor in a determinate temperature condition, and the chemical reaction will happen as follows:

$$FeCl_2+2\ FeCl_3+8NaOH \longrightarrow Fe_3O_4+8NaCl+4H_2O$$

In this way, Fe_3O_4 powder will deposit, and the temperature must be controlled in a range strictly. Higher temperature will produce the thicker powder. At the same time, we must rave about the liquor after deposit subsided, and plus hot water and stir the liquor , then filtrate it with filter paper. Repeat several times to remove sodium chloride which produced in the reaction and the Na hydronium and CI hydronium deep-dyed in the deposit. Finally, suitable Fe_3O_4 powder has been finished.

Finally, we make Fe_3O_4 powder into magnetic particle suspension. Add a determinate cocoanut oil amine into 1N of hydrochloric acid and let the pH value equal to 7. Then dilute it with distilled water, and add Fe_3O_4 powder into it. After commixing sufficiently, drip a little hydrochloric acid to keep pH value equal to 7(if needed) and dilute with distilled water, then the eligible magnetic particle suspension preparation is finished.

After that, in order to observe the magnetic domains, we must treat the specimens with incise, anneal, burnishing and polishing etc. Then drip the magnetic particle suspension on the surface of the specimens and wait for the moisture vaporized naturally. As stray magnetic field existing along the boundary of the magnetic domains on the surface of the specimens, the iron magnetic powder would be absorbed on the boundary by stray magnetic field and domain walls will appear, which is easy for us to observe the appearance of the domain walls.

20 steel and 45 steel is taken as the study objects. And the first step is to machine material as cuboid in Figure-1, then anneal it to eliminate residual stress inside, and exert different loads on specimens by Universal Testing Machine as what the arrows indicate to produce residual stress inside, then treat the specimens Metallographic tested with steps such as burnishing, polishing etc. Drip the confected magnetic particle suspension in the observation field on the specimens and analyze stress effect to the domain framework by the appearance of the magnetic domains after the moisture be vapored in the magnetic particle suspension.

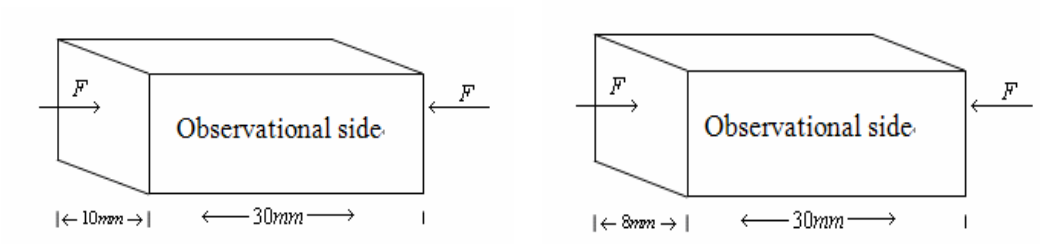
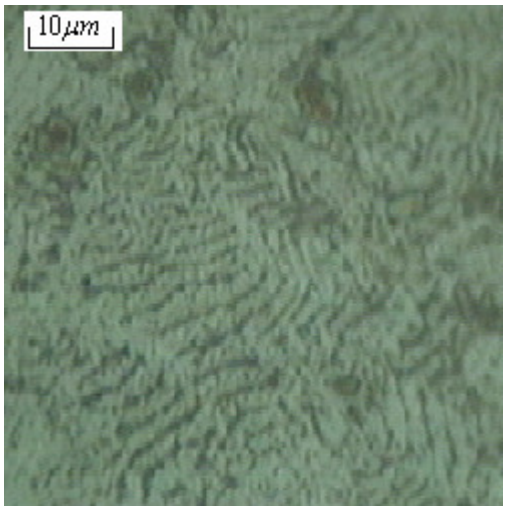


Figure-1 The sketch of loads exerted on 20steel and 45steel

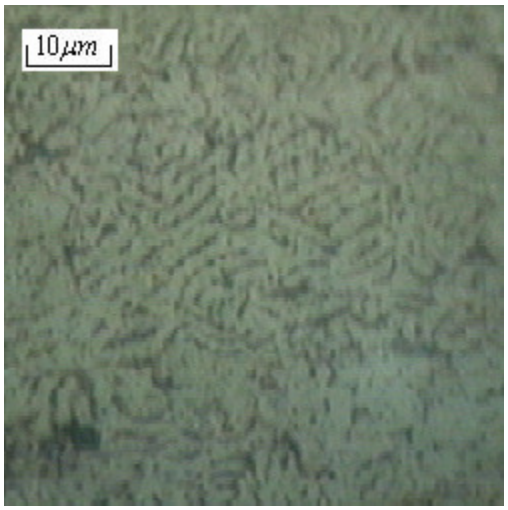
3、Testing result and discussion

3.1 Stress effect to the appearance of magnetic domains in 20 steel

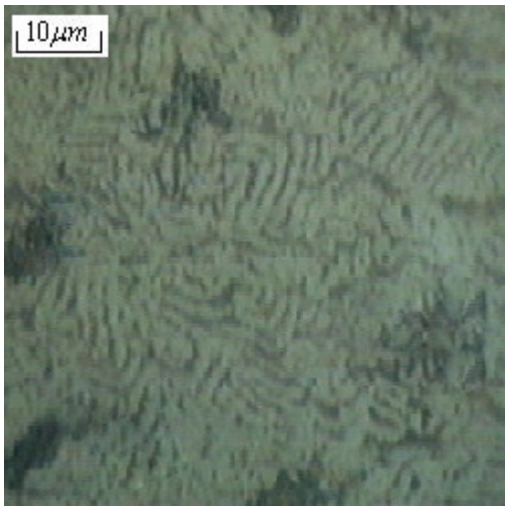
Exert different loads separately onto four pieces of 20 steels specimens by 0kN, 50kN, 90kN, 120kN and observe and compare structure of the magnetic domains by 600 times microscope as Figure-2 (a, b, c, d). Demonstrated by the pictures , as the 20 steel belongs to polycrystal with small grains, the orientation of magnetic domains is desultory among the grains without any internal stress, but the lamellar domains inside the polycrystal appear 180^{o}, and the direction presents regional unanimity. See Figure 2(a).With the increasing of internal stress , the internal material presents regional magnetic anisotropic while more and more domains' structure turns to labyrinthian . Magnetic domains in perpendicular to the stress orientation increase gradually while the domain wall turns from 180°to 90° in company with the length being shorter and shorter , and the width of magnetic domains change as the result of the difference of the internal stress concentration of specimens.

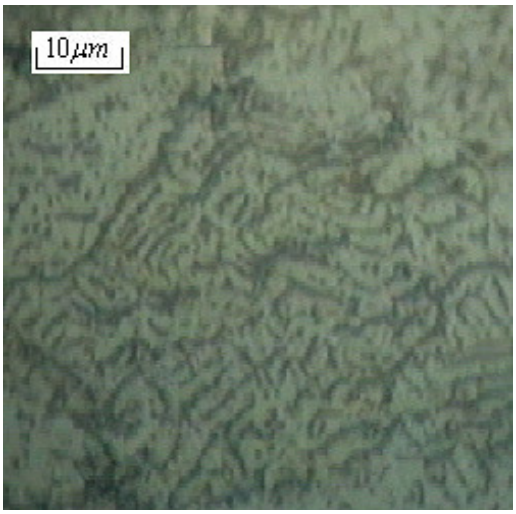


(a) magnetic domains of 20steel specimen without load after annealed



(b) magnetic domains of 20steel specimen exerted by 50kN load after annealed





(c) magnetic domains of 20steel specimen exerted by 90kN load after annealed

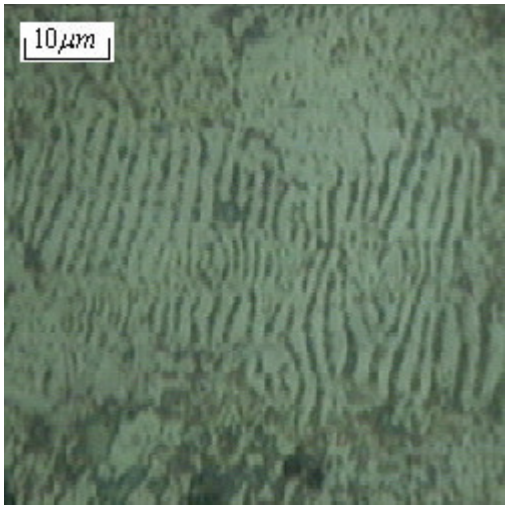
(d) magnetic domains of 20steel specimen exerted by 120kN load after annealed

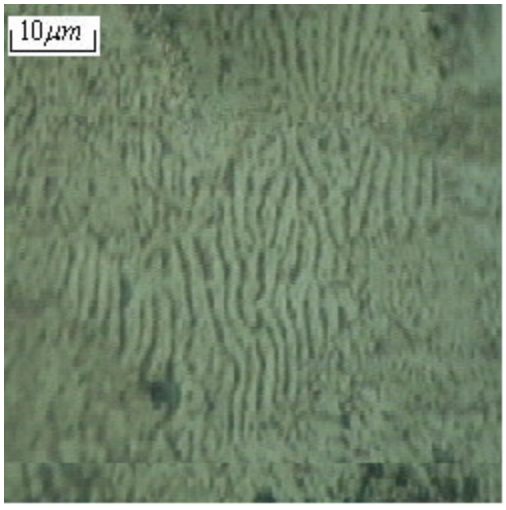
Figure-2 magnetic domains of 20steel specimens exerted by different loads after annealed

3.2 Stress effect to the appearance of magnetic domains in 45 steel

Exert different loads separately onto four pieces of 45 steels specimens by 0kN, 10kN, 50kN, 60kN and observe the magnetic domain by Bitter method. The magnetic structure of 45 steel is shown as Figure-3 (a,b,c,d), the transformation mode is basically the same as 20 ones. The orientation of magnetic domains is desultory among the grains without any internal stress, but the lamellar domains inside the polycrystal appear 180^{o}, and the direction presents regional unanimity. With the increasing of internal stress , the internal material presents regional magnetic anisotropic while more and more domains' structure turns to labyrinthian . Magnetic domains in perpendicular to the stress orientation increase gradually while the domain wall turns from 180°to 90° in company with the length being shorter and shorter ,and the width of magnetic domains change as the result of the difference of the internal stress concentration of specimens. But there're also some differences between 45steel and 20steel.

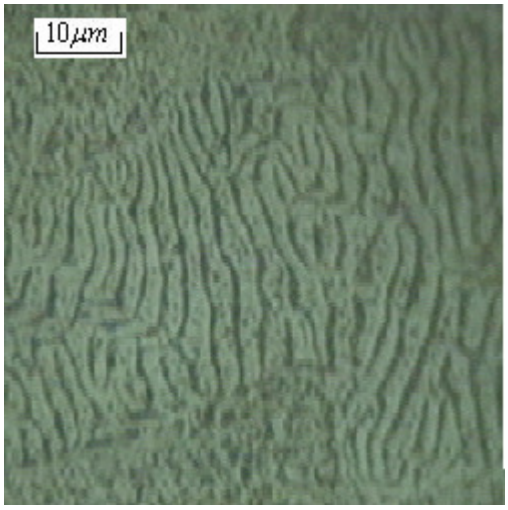
1. Magnetic domains in 45 steel are narrower and shorter than 20 steel's. That's because grains in 45 steel are smaller than the ones in 20 steel，the grain boundary stop the magnetic domains to cross the grain boundary.
2. Observe the magnetic domains with the same loads and it is found the labyrinthian domains in 20 steel is more than the one in 45 ones because permeabilitys in different material are different.

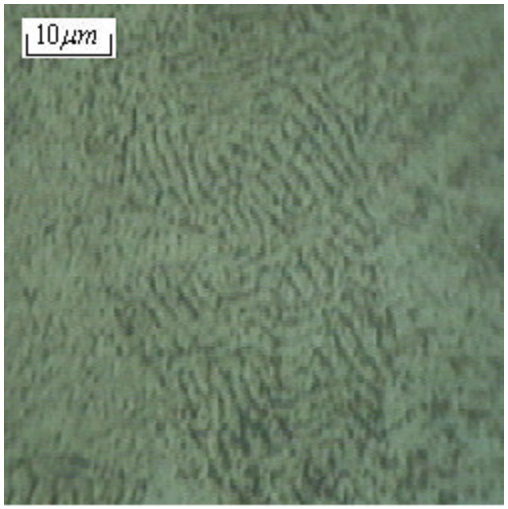




(a) magnetic domains of 45steel specimen without load after annealed

(b) magnetic domains of 45steel specimen exerted by 10kN load after annealed





(c) magnetic domains of 45steel specimen exerted by 50kN load after annealed

(d) magnetic domains of 45steel specimen exerted by 60kN load after annealed

Figure-3 magnetic domains of 20steel specimens exerted by different loads after annealed

4、Conclusions.

The experimental results show that lamellar domains will transform to labyrinthian domains and the domain walls will transform from 180^o to 90^o; the width and length of the magnetic domain also transform accordingly. The result indicates the existence of stress- magnetization effect in the loaded ferromagnetic material will lead to the displacement of internal magnetic domain walls under the geomagnetic field and even the irreversible reorientation of magnetic domains, so as to counteract the increase of stress energy. With the internal friction effects, stress concentration field will remain in the loaded ferromagnetic material in order to counteract the remnants of stress energy, and the realignment tropism of magnetic domains will also remain, then engender leakage magnetic field on the surface. It is proved that MMMT is based on force-magnetic effect in ferromagnetic items from microcosmic perspective, which is a valuable reference to further discuss MMMT's microcosmic mechanism.

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