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Stress induced magnetic field abnormality ①

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Abstract: Residual stresses in ferromagnetic material affect the direction and structure of domains and generate magnetic field abnormality on the surface. In the formation of stress induced magnetic field, the influence of geomagnetic field is unclear. Residual stress specimen was produced by tight matching of a round ring and a peg. The magnetic fields of contrast specimens, which were produced in geomagnetic field or in shielding geomagnetic field, were inspected with 8 mm lift-off. The results show that mean amplitude of magnetic field of the specimen produced in geomagnetic field is 0.85% larger than that of specimen produced in shielding geomagnetic field. So the formation of stress induced magnetic field abnormality above the surface of inspected ferromagnetic material geomagnetic field gives little contribution.

Key words: magnetic field abnormality; residual stress; geomagnetic field

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1 INTRODUCTION

The effects of stress on susceptibility, coercivity, power loss and remanence, under uniaxial or biaxial even stresses were studied[1-9]. The effect of stress on hysteresis has also been modeled both by a microscopic model which distinguishes magnetization directions within domains and by a model which considers only macroscopic variables for polycrystalline materials without examining behavior inside individual domains[10]. Naturally, such studies require the co-application of magnetic fields.

The domain structures and magnetic properties of polycrystalline ferromagnetic materials under stresses, especially uneven stresses, without co-applied field, have not been studied. For the first time, the spontaneous magnetization phenomena in production were noticed in 1970's by ZHONG[11]. He found that demagnetized ferromagnetic materials are intensely magnetized by cutting or operation, and named the first "magnetization by machining" and the second "magnetization through operation". The same phenomenon was observed in Russia at the beginning of 1980's when strong magnetization was detected in the areas of boiler pipe destruction. Doubov called this phenomenon metal magnetic memory(MMM)[12]. He investigated the level and distribution of residual magnetization and accordingly scattering magnetic field on the surface of the tested equipment, the influence of magnetoelastic and magnetomechanical effects. In the formation of MMM, the influence of geomagnetic field was unclear. A simple two-domain model was created to illustrate stress induced bulk moments by Garshelis[13]. The condition under which stress can alone establish net magnetic moments in the absence of applied field was discussed. However, there were no test data for the model validation.

The distributions of two-dimensional stress and corresponding three-dimensional magnetic field were tested[14, 15]. In these studies, the relationship of residual stress and magnetic field abnormality on the surface of ferromagnetic materials was also discussed. However, these experiments were processed under the circumstance of geomagnetic field. So the action of geomagnetic field was still not resolved in the formation of stress induced magnetic field abnormality.

In this paper, residual stress specimens are produced by tight matching of round rings and pegs in geomagnetic field or in shielding geomagnetic field as contrast. The influence of geomagnetic field is studied in the formation of stress induced magnetic field abnormality above the surface of inspected ferromagnetic material.

2 EXPERIMENTAL

2.1 Specimen

The initial specimens, made of mild steel, are pairs of round rings and pegs. The ring is a circular board with a round hole in its center. The peg is a short column, which has a tight matching with the hole of the ring. Fig. 1 shows the dimensions of the specimen. The external di-

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ameter of the ring is 160 mm, its internal diameter is 40 mm, which has a tolerance of 0 mm to + 0.021 mm. The external diameter of peg is 40 mm, which has a tolerance of + 0.043 mm to + 0.059 mm. The thickness of the specimens is 6 mm.

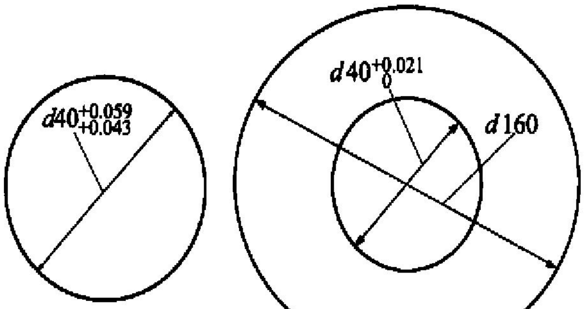

Fig. 1 Dimensions of ring and peg specimen (unit: mm)

The rings and pegs have strongly remanence (exceeding one Gauss on certain place) because of residual stress produced by manufacturing. So the rings and pegs were annealed to reduce residual stress and remanence by heating them at 800 ℃ (just exceeding Curie point) for 1 h, and then allowing them to cool naturally in the furnace. After that, their remanence decreased to less than 0.02 Gauss under shielded environment.

Chemical composition of the mild steel specimen is listed in Table 1.

Table 1 Chemical compositions of mild steel (%)

C	Mn	Si	S	P
≤0.20	1.20 − 1.60	0.20 − 0.55	< 0.030	< 0.035

2.2 Experimental equipment

2.2.1 Hydraulic pressure system

The peg and the ring in § 2.1 should be assembled together to form a specimen which has residual stress. To determine the influence of geomagnetic field on the formation of residual magnetization induced by stress, the pegs were pressed into the rings by hydraulic pressure machine in the environment of geomagnetic field and in the environment of geomagnetic field removal. Fig. 2 illustrates the schematic hydraulic equipment and a specimen is pressed on the condition of geomagnetic field removal. The maximum pressure of the hydraulic pressure machine is 150 kN.

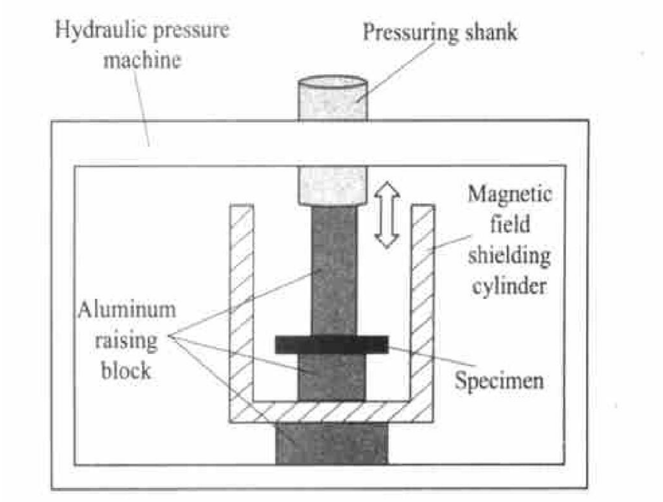

Fig. 2 Sketch map of hydraulic pressure system

Three aluminum columns block the specimen from contacting to ferromagnetic components of the hydraulic pressure machine, which can avoid the magnetization of specimens by the remanence of ferromagnetic components. A cylinder made of 78Ni permalloy was used to shield environment geomagnetic field. The diameter of the cylinder is 200 mm and its height is 400 mm. Two specimens were made in the magnetic field shielding cylinder. The other two specimens were made under geomagnetic field environment for contrast.

2.2.2 Weak magnetic field testing system

Fig. 3 shows a weak magnetic field testing system based on Honeywell's HMC-1001. The magnetic probe in the system is a magnetic resistance device (MRD), whose sensitivity is 10^{-8} T. The

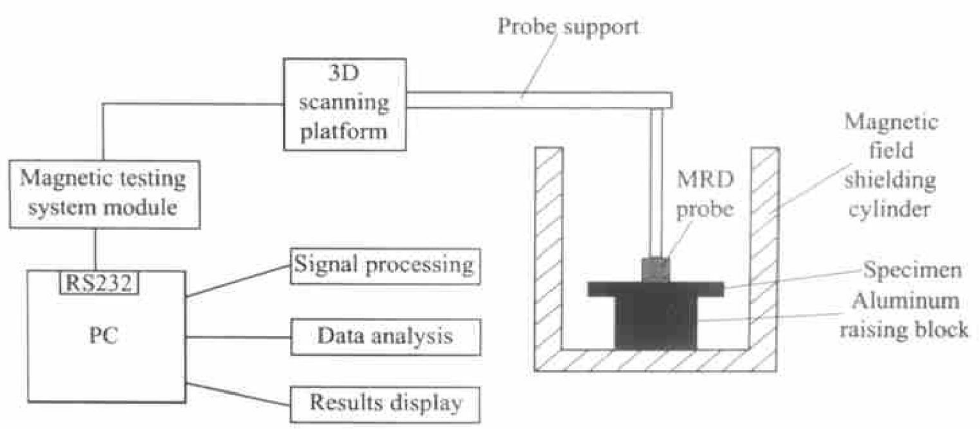

Fig. 3 Schematic of experiment testing system

magnetic testing system module carries out the probe driving, amplifying and filtering of the magnetic signals, A/D transforming and RS232 communicating functions. Those magnetic field signals on the surface of specimen are gotten using the scanning of a 3 D platform. The scanning platform is produced by aluminum alloy to avoid disturbance to test magnetic field. The imaging of magnetic field distribution can be presented in computer screen on real-time. Magnetic field values can be stored in computer automatically and used for following analyzing and data processing.

2.3 Magnetic field abnormality testing

To evaluate the influence of geomagnetic field on the formation of stress induced magnetization, two contrast specimen series were made using the equipment shown in Fig. 2. Specimen No. 1 was made in the magnetic field shielding cylinder and specimen No. 2 was made under geomagnetic field environment. And then magnetic field abnormality testing was processed as shown in Fig. 3. The specimen was placed horizontally and tested in magnetic field shielding cylinder. Testing lift-off (the distance between probe and the specimen surface) was 8 mm. Testing area was a square zone of 100 mm × 100 mm. The center point of the testing area was the center of the specimen. Fig. 4 and Fig. 5 show the magnetic field distributions of specimen No. 1 and specimen No. 2, respectively. The horizontal coordinates represent the distances between the measured points and the left bottom corner of the testing area. The vertical coordinates show the amplitudes of magnetic field.

To contrast the tested magnetic fields of specimens, corresponding central line and column are plotted in Fig. 6 and Fig. 7.

3 ANALYSES

Residual stress in tight assembled specimen affects

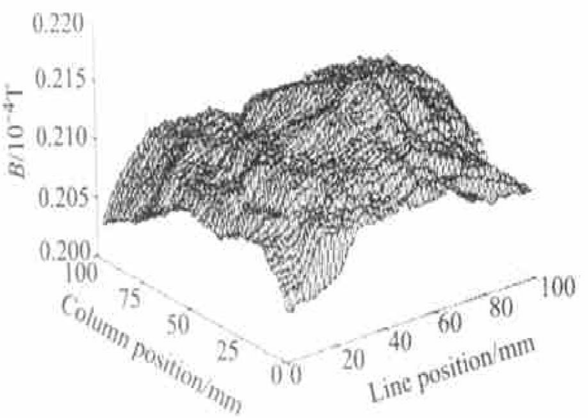

Fig. 4 Magnetic field distribution of specimen No. 1

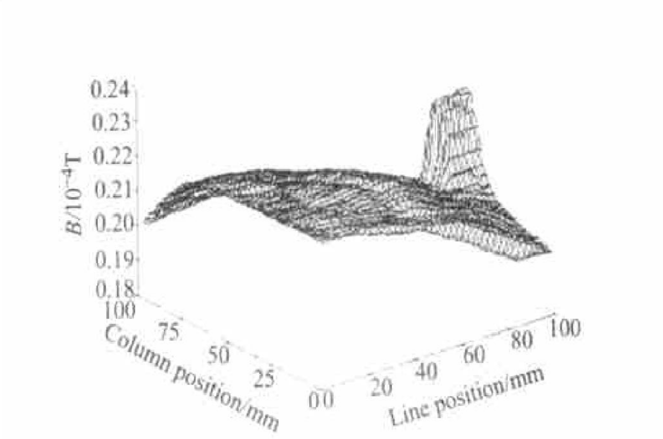

Fig. 5 Magnetic field distribution of specimen No. 2

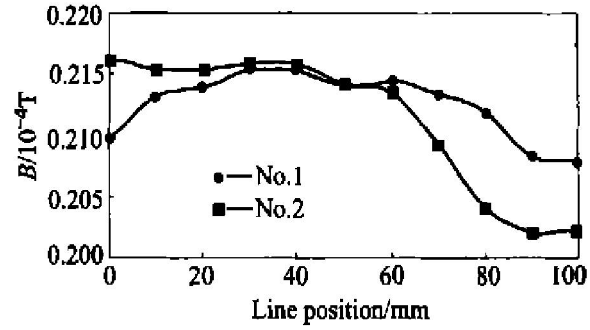

Fig. 6 Contrast of central column magnetic field distribution of specimens

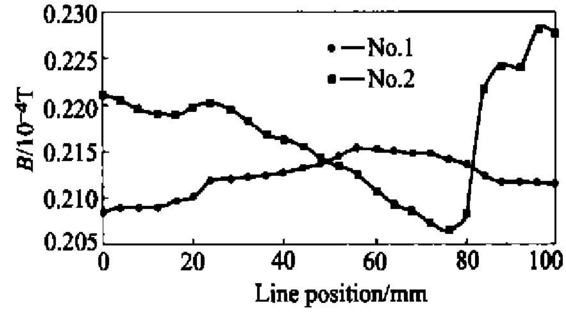

Fig. 7 Contrast of central line magnetic field distributions of specimens

the direction of ferromagnetic material domains and thus varies the magnetic field above the surface of specimen. From the magnetic field distribution shown in Fig. 4, it can be seen that the area near the center has larger amplitudes of magnetic field. But the fluctuation of magnetic field amplitudes is very less, about 3.4%. The result indicates that the area of specimen matching zone has slightly larger stress. There is a slight abnormality at the right in Fig. 5. This abnormality maybe caused by local stress concentration. And the fluctuation of magnetic field amplitudes in Fig. 5 is also very low.

From the contrast curves in Fig. 6 and Fig. 7, it can be seen that specimens No. 1 and No. 2 have approximately equal amplitude of magnetic field. Their mean magnetic field is about 2.1×10^{-5} T. The experimental error is less than 1.5% from the changes of mean magnetic field intensity of the same specimen. The mean amplitude of magnetic field of Fig. 4 is 0.85% larger than that of Fig. 5. So considering experimental error, it is obvious that stress induced magnetic field abnormality above the surface of ferromagnetic materials is independent of geomagnetic field.

4 CONCLUSION

Residual stress affects the direction of ferromagnetic material domains and thus forms the magnetic field abnormality above the surface of specimen. Contrast experiments show that in the formation of stress induced magnetic field abnormality above the surface of inspected ferromagnetic material, geomagnetic field gives little contribution.

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