Statement of retraction


To cite this article: (2012): Statement of retraction, Nondestructive Testing and Evaluation, 27:4, 391-391

To link to this article: http://dx.doi.org/10.1080/10589759.2012.694175

Full terms and conditions of use: http://www.tandfonline.com/page/terms-and-conditions

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.
Statement of retraction

The following article, which was published online by Taylor & Francis on 19th December 2011, has been retracted from publication in *Nondestructive Testing and Evaluation*.


This article has been found to reproduce content to a high degree of similarity, without appropriate attribution or acknowledgement by the author, from the following original article:

JianWei Li, MinQiang Xu, MingXiu Xu and JianCheng Leng. Investigation of the variation in magnetic field induced by cyclic tensile-compressive stress. *Insight*, 53 (9), 487-490.

The journal’s policy in this respect is clear: *Nondestructive Testing and Evaluation* considers all manuscripts on the strict condition that they have been submitted only to *Nondestructive Testing and Evaluation*, that they have not been published already, nor are they under consideration for publication or in press elsewhere.

The article is withdrawn from all electronic editions.
Investigation of the variation in surface magnetic field induced by cyclic tensile–compressive stress

JianWei Li*, MinQiang Xu, MingXiu Xu and JianCheng Leng

School of Astronautics, Harbin Institute of Technology, Harbin 150001, P.R. China

(Received 12 March 2011; final version received 2 August 2011)

The variation of surface magnetic field, induced by applied stress under the geomagnetic field, can be potentially used to evaluate the degree of fatigue damage for ferromagnetic materials. To further investigate the physical mechanism of metal magnetic memory phenomenon, measurements of the normal components of the surface magnetic field intensity, $H_p(y)$, were carried out during rotary bending fatigue experiments under the geomagnetic field. The results showed that normal components $H_p(y)$ vary greatly after application of stress, and then become stable after several cycles. Magnetisation under tensile stress is different from that under compressive stress. Based on dislocations pile-up and the influence of stress on the ferromagnetic domain, these results are discussed.

Keywords: magneto-mechanical effect; surface magnetic field; metal magnetic memory; cyclic tensile–compressive stress

1. Introduction

Owing to magnetic properties being sensitive to the variation of stress in ferromagnetic materials [1–3], magneto-mechanical effect has attracted more and more attention. The effects of stress on static features under an external applied magnetic field, viz. susceptibility, coercivity, permeability, remanence and hysteresis loops, were discussed in [4–7]. However, because of the complexity of magneto-mechanical coupling, there was no reliable theory of magneto-mechanical effect [8].

Based on magneto-mechanical effect, Doubov [9] firstly proposed the metal magnetic memory (MMM) technology. The principle of MMM is that the surface magnetic field contains information about stress state. Recently, this technology has attracted more and more researchers’ attention [7,10–16]. Yang et al. [13] proposed a simple model when they studied the magnetic field aberration induced by cyclic stress within an elastic region. A set of experiments, including static and fatigue experiment, were conducted by Dong et al. [10,11,14, and a linear relationship was derived between the spontaneous field signals and stress. Jian et al. [15] reported that the magnetic gradient was linear with the prior maximum stress no matter whether the stress was elastic or plastic. However, the physical mechanism of the MMM is not clear due to no exhaustive theory support, and many factors can affect the values of MMM signals [10,15,16].

To study the variation of magnetisation induced by stress and to explore the physical mechanism of the MMM, rotary bending fatigue experiments were conducted. The normal
components of surface magnetic field induced by cyclic tensile–compressive stress were measured. Combined with the increase in dislocation and dislocation movement, the results were discussed.

2. Experiment method
The material studied is AISI 1045 steel, which is first water quenched at 840°C and kept for 1 h in a heat treatment furnace, then tempered at 510°C in an oil bath and cooled in water to room temperature. Its chemical composition and mechanical properties are tabulated in Tables 1 and 2. The specimens were in the form of 7.52 mm diameter rod with an annular groove of depth 0.1 mm and width 0.2 mm in the centre to ensure fracture at the prefixed location, as shown in Figure 1. Its surface roughness was 1.6 μm.

According to the Chinese Standard GB4337-84, the rotary bending fatigue experiments are conducted on PQ1-6-type fatigue pure bending machine at a frequency of 47.5 Hz. Each specimen is clamped horizontally and laid in the direction from east to west. The bending moments applied were 12 and 19.8 Nm. The change in stress at one point in the other layers is in the form of cosine. The measured points are on the top at the beginning.

The testing machines manually shut off when the specimen rotated to preset cycles. The normal components of the surface magnetic field intensity of nine points on top of the specimens are measured. Due to the precut artificial crack, point 5 is the location of fatigue crack initiation and propagation. Hence, point 5 is the point of particular concern. So, the specimen was manually rotated to 45, 90, 135, 180, 225, 270 and 315°, and the $H_p(y)$ values of point 5 at different locations were measured as shown in Figure 2. Eight $H_p(y)$ values of point 5 under cosine stress are acquired. Then, another round of cycle began. Magnetic field values, $H_p(y)$, are measured by the TSC-1M-4 tester of stress concentration. Its sensitivity of the magnetic probe is 1 A/m. ‘Hold on’ mode was chosen to dispose the influence of the geomagnetic field. The values measured after clamping are considered as initial magnetic field.

3. Results and analysis

Two fatigue experiment results under bending moments of 12 (specimen 9) and 19.8 Nm (specimen 11) are chosen to be analysed, and the corresponding failure occurred at 69,400 and 14,500 cycles, respectively.

From Figure 3, the normal components $H_p(y)$ vary greatly after application of stress, and then become stable after 50 cycles. The magnitude of change is larger for the points with higher initial magnetic field values. The stable values of $H_p(y)$ were in the range of

| Table 1. Chemical composition (wt%) of tempered AISI 1045 steel. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| C               | Mn              | Si              | Cr              | S               |
| 0.42–0.50       | 0.50–0.80       | 0.17–0.37       | ≤0.25           | ≤0.035          |

| Table 2. Mechanical properties of tempered AISI 1045 steel. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Elasticity modulus | Poisson ratio | Yield strength | Ultimate strength | Elongation |
| 209 (GPa)        | 0.269           | 716 (MPa)       | 934 (MPa)        | 18 (%)         |
Retraction

− 225 to − 25 A/m and − 275 to − 175 A/m under bending moments of 12 and 19.8 Nm, respectively. The range of stable values of $H_p(y)$ under bending moments of 12 Nm was wider than that under bending moments of 19.8 Nm.

The dislocation density dependence on the number of fatigue cycle increases quickly at the beginning of cycling and reach saturation [17]. After saturation is reached, no further changes in the dislocation structure is observed and cycled metal exhibits steady-state behaviour [18,19]. The process of dislocation pile-up from initial state to saturation can be expressed as shown in Figure 4.

The accumulation rate of dislocations pile-up is obtained by subtracting the amount of climbing dislocations from the arriving amount of slipping dislocations in unit time [20]. The process of dislocations pile-up is shown in Figure 4. The new arriving amount of slipping dislocations in unit time is $\rho v b$, $\rho$ is dislocation density, $v$ is the mean velocity of dislocation slip and $b$ is the width of slip band. The leaving amount of climbing dislocations in unit time is the amount of the current dislocations pile-up $n$ multiplied by the velocity of dislocations climbing $\kappa$. Therefore, for a slipping system, the accumulation rate of dislocations pile-up is

$$\frac{dn}{dt} = \rho v b - \kappa n. \quad (1)$$

According to the relationship between the rate of plastic deformation and dislocations mobility proposed by Orowan

$$\dot{\gamma}_p = \alpha b pv, \quad (2)$$

![Figure 1. Specimen shape and measurement points (in mm).](image)

![Figure 2. Measurement direction and location of point 5.](image)
where $\gamma_p$ is the rate of shear plastic deformation and $\alpha (~1)$ is a geometric factor. Substitute Equation (2) into (1), we can obtain

$$\frac{dn}{dt} = \gamma_p - \kappa n.$$  \hspace{1cm} (3)

Equation (3) describes the competition between climbing dislocations and slipping dislocations. From Equation (3), we can conclude that the amount of dislocation pile-up increases as the plastic strain increases in the initial stage of deformation. However, with the increase in plastic deformation, the mobility of lattice vacancy increases. This causes more dislocations to jump out of the dislocations pile-up group. The amount of dislocations pile-up tends to a stable level. This consequence can be obtained by

Figure 3. Normal components $Hp(y)$ of the surface magnetic field of nine points in different cycles: (a) under bending moment of 12 Nm and (b) under bending moment of 19.8 Nm.
integrating with respect to Equation (3)

\[ n = \frac{\dot{\gamma}_p}{\kappa} \left[ 1 - \exp(-\kappa t) \right]. \tag{4} \]

Dislocations pile-up induces the material to harden, and then influence the magnetic property. The influence of material hardening had a significant effect on the magnetic property [21]. So, with the increase in the dislocation density, the value of surface magnetic field decreased. From Equation (4), it can be concluded that dislocation density cannot consistently increase and there is a saturation value. When the dislocation density reached saturation, the surface magnetic field became stable. The range of stable values reduced in width with the increase in bending moment.

Figure 5 showed the values of normal components \( H_p(y) \) of point 5 at different angles at 1000 cycles. At different angles, the stresses were different. An interesting feature was that the values of \( H_p(y) \) below the neutral plane were smaller than that above the neutral plane when the normal components \( H_p(y) \) became stable. As is well known, the material below the neutral plane was subjected to tensile stress, and above the neutral plane the material was subjected to compressive stress. The effect of compressive stress is to tend to
align the magnetic moment of domains so that their larger domains are perpendicular to the stress direction. On the other hand, under tension, the magnetic moment of domains tends to be parallel to the stress direction, as shown in Figure 6. The demagnetisation field under compression is larger than that under tension. Hence, the normal components $H_p(y)$ of the surface magnetic field of point 5 will exhibit as shown in Figure 5.

4. Conclusions

(1) A study of the variation in surface magnetic field has been made on 1045 steel subjected to rotary bending fatigue under the geomagnetic field. A general trend was observed in the variation in normal components $H_p(y)$ of the surface magnetic field with fatigue cycles. Variations in $H_p(y)$ were found to be closely related to dislocation movement. With the increase in the dislocation density, the material hardened and the values of surface magnetic field decreased. When the dislocation density reached saturation, the surface magnetic field becomes stable.

(2) The values of $H_p(y)$ under tensile stress were larger than those under compressive stress. Influence of stress on the ferromagnetic domain gave a good explanation for this phenomenon.

Acknowledgements
The authors would like to appreciate the National Natural Science Foundation of China (Grant No. 10772061), National Science Foundation of Heilongjiang Province of China (No. A200907) and Specialized Research Fund for the Doctoral Program of Higher Education (No. 20092322120001) for their financial support.

References