ISSN (Print) 1226-1750
ISSN (Online) 2233-6656
Journal of Magnetics 24(2), 281-285 (2019) https://doi.org/10.4283/JMAG.2019.24.2.281

Comparison between Magnetic Field Distribution Analysis and Metal Magnetic Memory (MMM) Testing Results Around Artificial Cracks under Loads

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(Received 28 June 2018, Received in final form 8 May 2019, Accepted 8 May 2019)

In this research, the behavior of the metal magnetic memory (MMM) signals near the artificial cracks located the back side of A572 specimens are tried. The materials are used as power transmission tower material. The variations of the MMM signals with the applied tensile loads are studied. It is found that both the tangential component, *Hp*(*x*), and the normal component, *Hp*(*y*), are effectively showed the stress concentration zone (SCZ) caused by discontinuities. The results of modeling and MMM technique showed that the loads create residual stress and lead to the change of magnetic field strength around artificial cracks in the specimen and that is relatively different from the crack free area. This research is useful for expending MMM method as a tool of nondestructive testing method for detecting subsurface flaws.

Keywords : Metal magnetic memory (MMM), power transmission tower, magnetic field signal, stress concentration zone

1. Introduction

The concept of magnetic memory of metals was first introduced in 1994, and it was not used in the technical literature before that time. Introduced in the 1990s, metal magnetic memory method (MMM) has proven to be effective in characterizing the early damage of ferromagnetic materials, especially the micro-damage due to local stress concentration (Doubov, 1998; Doubov, 2001; Wilson *et al*., 2007; Yang *et al*., 2007) [1, 2]. Evaluation of the stress concentration degree by means of nondestructive techniques has thus become critical for the safety assessment of these engineering components. Different from the extensively used magnetic testing (MT), MMM picks up the self-magnetic flux leakage of ferromagnetic materials under the combined operation of the external load and the ambient geomagnetic field. And its magnetic leakage happens distinctively when there are damages such as cracks, flaws, and corrosions.

The variations of the MMM signal and its gradient with the applied loads were studied. It showed that the magnetic curves of the notched specimens in the discontinuity area change abnormally and increasingly prominent as the tension increases [3]. The theoretical modeling based on the Biot-Savart law suggested it can possibly detect the location, shape, and dimension of a crack with the MMM testing curve [4]. However such experiments and studies tried to access only for surface side open cracks. The influence of tempering temperature on the magnetic memory amplitude of 2Cr13 steel was investigated and MMM signal analysis showed that tempering reduced the internal stress [5].

Recently, many field experiences have been carried out to investigate the stress concentration effects on the variations of the MMM signals of ferromagnetic steels. One study investigated the variations of the *Hp*(*y*) signal and its slope coefficient with different load levels and explained the experimental results by different mechanisms (Dong *et al*., 2009) [6]. Others found that in static tension experiment, the variation of the *Hp*(*y*) signal is effective in differentiating deformation stages, and the gradient of the *Hp*(*y*) signal is an indicator of stress concentration (Yao *et al*., 2012a). Similar results were obtained in bending fatigue experiments, which suggests that the variation of the *Hp*(*y*) signal can potentially be used as a measure to assess the stress status (Huang *et al*., 2014a; Leng *et al*., 2009) [3].

One of the most critical and complex issues in the

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modern non-destructive test (NDT) of reliability of various welding is pointing out a “weak location” which is influenced by a complex system of factors such as structural inhomogeneity, weld flaws, and structural process-induced stress concentrations. To find out these kinds of abnormal states is critically required after fabrication of welded joints.

The technique for determination SCZ (Stress Concentration Zone) could be performed using by MMM. The SCZ is associated with the action of stresses and strains induced by working loads. Under such conditions, the formation of SCZ induces the developing further defects.

2. Modeling Around Artificial Cracks

According to the magneto elastic effect, residual stress always makes residual magnetization which is an irreversible phenomenon. If stress exceeded the average value of internal stress in the metal (σi), they will cause the magneto elastic gain of magnetization, $\Delta M\sigma$, in the presence of at least a small magnetic field, Ho. For example, the always existing magnetic field of the earth represents such a field. Under these conditions, the magneto-elastic gain of the magnetization is equal to [7]

Fig. 1. (Color online) Specimens for tensile test.

$$\Delta M\sigma(Ho,\ \sigma_{load}) = \Delta M(Ho) + \Delta M\sigma(Ho,\ \sigma_{load}):$$
$$\Delta M\sigma >> \Delta M(Ho) \qquad (1)$$

Where $\Delta M(Ho)$ is the magnetization gain from the Ho field.

2.1. Theoretical modeling analysis

It was established experimentally that the distribution of

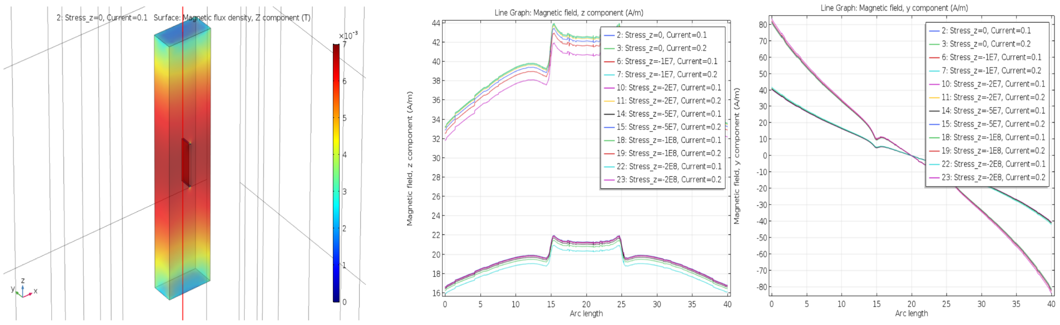

(a) Magnetic modelling (b) field distribution of $Hp(x)$ (c) field distribution of $Hp(y)$

Fig. 2. (Color online) Magnetic modeling of longitudinal crack’s field distribution of $Hp(x)$, $Hp(y)$.

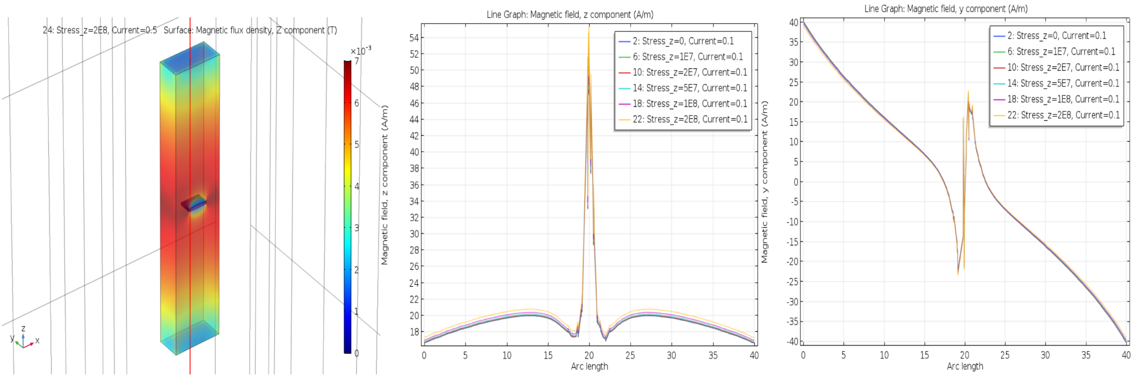

(a) Magnetic modelling (b) field distribution of $Hp(x)$ (c) field distribution of $Hp(y)$

Fig. 3. (Color online) Magnetic modeling for longitudinal crack and field distribution of $Hp(x)$, $Hp(y)$.

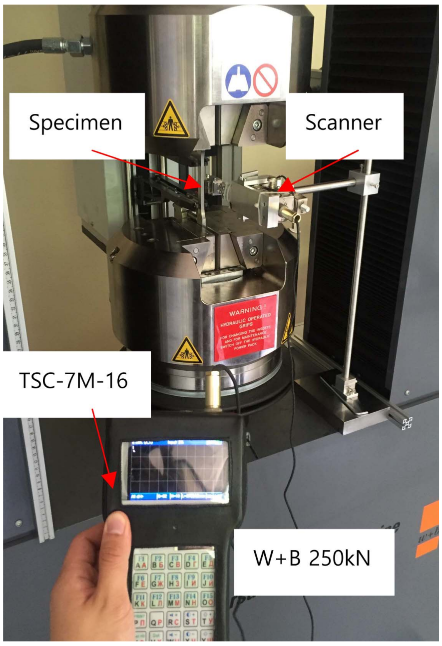


Fig. 4. (Color online) Tensile test and scan set up.

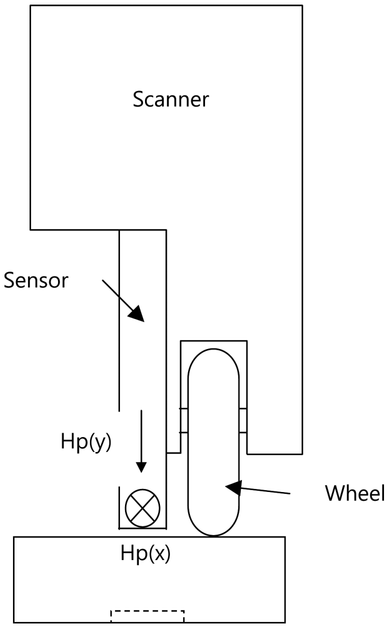


Fig. 5. Scan position of specimen.

magnetization, $\Delta M\sigma$, in an elastically-load material and corresponding magnetic leakage field, $Hp(y)$, $Hp(x)$, measured along the material surface follows the distribution of load stress, σ_{load} (Dubov, 1995) [7].

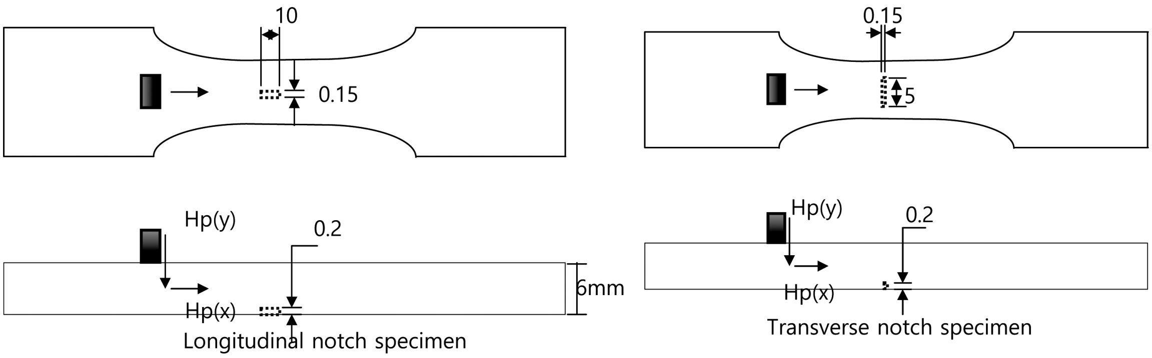
Before tensile test numerical studies were investigated, which provided some quantitative results about the effects of discontinuity depth, width, and residual magnetic field modeling around the cracks were performed with COMSOL Multiphysics and magnetostrictive model is nonlinear isotropic. The longitudinal crack modeling results are Fig. 2. The transverse crack results are Fig. 3.

3. Study of the Residual Magnetic Field of Notch under the Tensile Load

After magnetic behavior modelings, tensile tests were conducted, the tensile machine was W+B 250 kN, MMM equipment was TSC-7M-16, the existing earth field was calibrated in the Fig. 4. at value 32A/M. In the Fig. 5. scanning pose, sensor position, and a notch under specimen were shown.

The study of the relation between the residual magnetic field and various levels of applied stress according to the relative elongation rate from the necking length were studied. The tensile specimens are shown in Fig. 1. The specimens are fabricated such as 6 mm thickness with longitudinal cracks and transverse cracks each. The A572 has different types of notch according to the direction and dimension. Longitudinal notch dimensions are 10 mm long and 0.2 mm depth, and transverse notch dimensions are a 6 mm length and 0.2 mm depth (Fig. 6).

MMM data were gathered from at holding the state of 10 %, 15 %, 20 %, 25 % of necking length. Fig. 7. shows



Longitudinal notch specimen
Transverse notch specimen

Fig. 6. Longitudinal crack and transverse crack dimension and scanning directions.

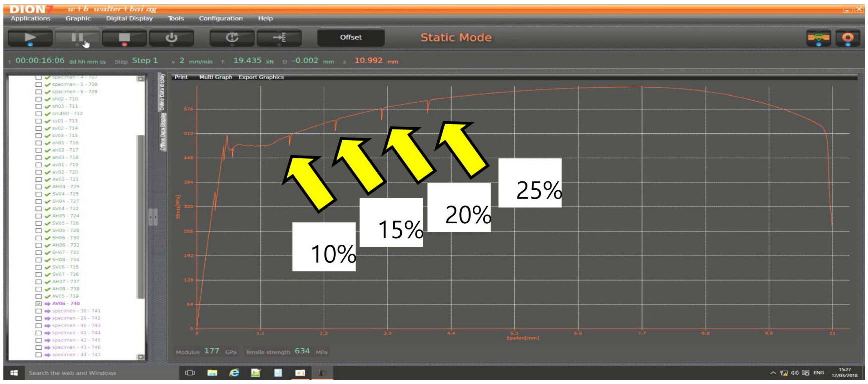


Fig. 7. (Color online) Data pick up points of tensile test.

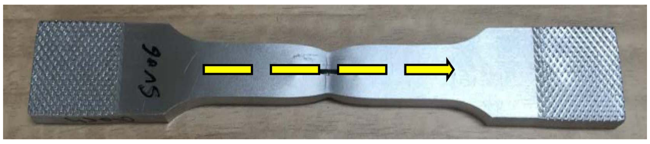


Fig. 8. (Color online) Scan direction of specimen.

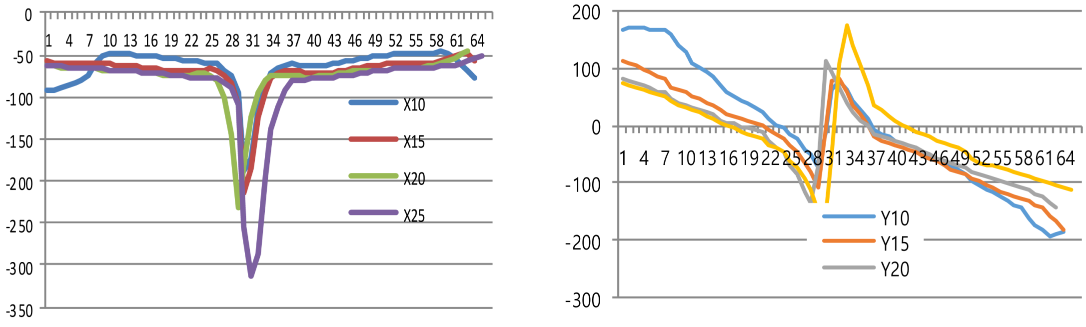
data pick up points of during tensile tests. And all specimen are scanned along the center line of it (Fig. 8).

Study and modeling of surface crack tried and confirmed that the metal magnetic memory method is effective to figure out abnormal conditions around the cracks [3, 4].

We scanned from the back side and we got a similar phenomenon but a bit lower strength data compare to crack surface scan results. The magnetic strength *Hp*(*x*) direction was opposite due to the sensor's scan position, it possibly detected the crack position same as surface scan.

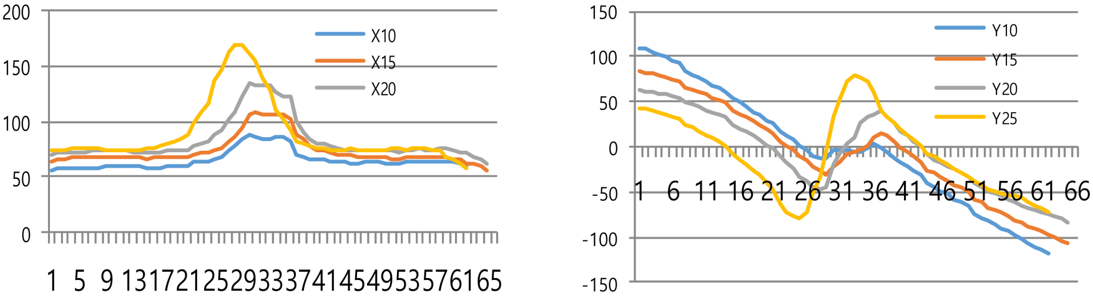
The experiment results of surface scan of the transverse crack are Fig. 9. and back side scan results are Fig. 10. And the longitudinal crack's back side scan results are Fig. 11.

When it comes to the longitudinal crack signals of *Hp*(*x*) at Fig. 11. showed the dot lines length of Fig. 11. is quite the same as the crack length of 10 mm.



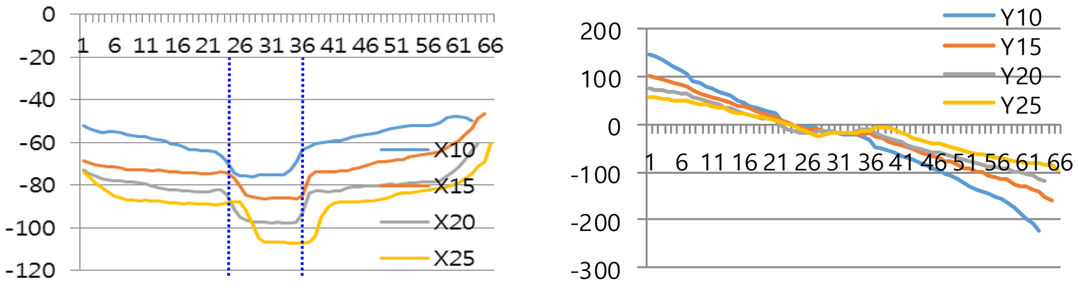
(a) surface crack's distribution of *Hp*(*x*) (b) surface crack's distribution of *Hp*(*y*)

Fig. 9. (Color online) Transverse surface crack's magnetic distribution *Hp*(*x*) and *Hp*(*y*).



(a) transverse crack's distribution of *Hp*(*x*) (b) transverse crack's distribution of *Hp*(*y*)

Fig. 10. (Color online) Transverse crack's magnetic distribution *Hp*(*x*) and *Hp*(*y*) of backside scan.



(a) longitudinal crack's MMM *Hp*(*x*) (b) longitudinal crack's MMM *Hp*(*y*)

Fig. 11. (Color online) Longitudinal crack's magnetic distribution *Hp*(*x*) and *Hp*(*y*) of backside scan.

Table 1. Tensile test results of specimen.

Material	Notch Type	Necking Length (100 %)
A572	transverse	13.40 mm
	longitudinal	15.90 mm

The backside scan results of tensile tests showed that the directions of crack affected the magnetic strength signals significantly, and the variation of the *Hp*(*y*), *Hp*(*x*) signals can be used to indicate the stress concentration state and they confirmed almost the same reenactments of magnetic distribution patterns of modeling results. They also figured a novel formula for quantitatively evaluating the impact of stress concentration of the MMM signals in ferromagnetic steels, which means MMM is a real alternative method to detect subsurface flaws as an NDT technique.

4. Conclusions

The test results showed that theoretical modeling of magnetic field distribution and MMM testing around artificial cracks under stress were well related. One of the effective results was that this study showed the MMM technique can detect cracks at the backside surface and it can also call approximation measure of crack length, it means that MMM technique can be applied as a method to detect subsurface flaws and it is far more effective than magnetic testing.

References

[1] Wilson, J. W., G. Y. Tian, and B. Barrans, Sensors and Actuators A : Physical **135**, 381 (2007).
[2] Yang, E., M. M. Li, and X. Chen, J. Magn. Magn. Mater. **135**, 72 (2007).
[3] Sheng Bao, Meili, Yibin Gu, and Huangjie Lou, Material Evaluation **75**, 397 (2017).
[4] M. Jin, Material Evaluation **75**, 1391 (2017).
[5] Long Feifei, Yang Yang, Wang Jianzeng, and Dai Guang, Material Evaluation **76**, 845 (2018).
[6] Dong, L. H., B. S. Xu, S. Y. Dong, L. Song, Q. Z. Chen, and D. Wang, NDT & International **42**, 323 (2009).
[7] Dubov, Metal Magnetic Memory Method Training Handbook, Enegodiagnostika (2017) pp 14-15.