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EFFECT OF MICROSTRUCTURE AND RESIDUAL STRESS ON THE MAGNETIC BARKHAUSEN NOISE SIGNAL

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ABSTRACT

Magnetic Barkhausen noise (MBN) measured from ferromagnetic materials contains very fruitful information about the condition of microstructure and residual stress. In this study, specimens of 45 steel and 30Cr steel were subjected to surface laser quenching, which induce changes in both microstructures and residual stress in the tested materials. First, high resolution MBN inspection is applied to contour the profile of MBN parameters along the line perpendicular to the laser moving direction. Second, the residual stress and surface hardness are measured by X-ray diffraction method and Vickers micro-hardness tester, respectively. Third, the effect of microstructure (represented by surface hardness) and residual stress on the MBN parameters (peak height and peak position of the bufferfly MBN profile) is investigated. Linear correlation between the MBN parameters and the surface hardness or the residual stress can be concluded. Finally, the weights of two factors affecting the MBN parameters are simply discussed.

Keywords: magnetic Barkhausen noise, microstructure, residual stress, surface hardness

1. INTRODUCTION

Magnetic Barkhausen noise (MBN) technology can achieve non-destructive evaluation of both the microstructure and residual stress in the surface of the ferromagnetic materials. When the ferromagnetic material is placed in an alternating magnetic field, discontinuous motion of the magnetic domain walls inside the material will disturb the external magnetic field, which can be measured by an inductive coil to show as MBN signal. Numerous studies reported that MBN parameters can act as excellent indicators for characterizing the state of microstructures [1-2], residual stress [3-4], surface hardness [5-6] and fatigue [7-8].

In this study, surface laser quenching technology is employed to induce variations in microstructures and residual stress to the specimens of 45 steel and 30Cr steel. Line-scan MBN inspection is performed to characterize the effect of surface laser quenching on the changes of microstructures and residual stress. The obtained results show that simple linear superposition can be used to describe the combined effect of microstructures and residual stress on the measured MBN profile.

2. MATERIALS AND METHODS

2.1 SPECIMENS PREPARATION

In the experiments, plates of 45 steel and 30Cr steel were selected for surface laser quenching. The dimensions of the specimens are shown in Figure 1. The length of the plate is 140mm and the plate has a width of 50mm and a thickness of 10mm. The laser source is scanned along the *x*-axis direction. The area scanned by the laser source is rapidly heated, while the rest region of the plate keeps at a normal temperature.

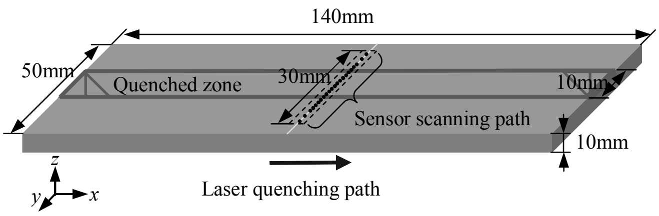

FIGURE 1: THE SIZE OF LASER QUENCHING SAMPLE

Table 1 gives the parameters of surface laser quenching for the two specimens of 45 steel and 30Cr steel. Finally, quenched band with a width of around 10 mm is produced in the center of the sample. After the surface laser quenching process, the microstructures and the residual stress in the quenched zone will be different from that in the base material.

TABLE 1: LASER QUENCHING PARAMETERS

Material	Laser power(W)	Scanning speed (mm/min)
30Cr steel	1500	800
45 steel	1000	200

Nondestructive MBN inspection and residual stress measurement (using X-ray diffraction method) are performed before the specimens are destructively processed for microstructures observation. To observe the metallographic structure of the material in the quenched and unquenched zone, the specimens were cut into small disks, polished down to 0.3μm grit and etched with 4% nital solution, then washed with water, and dried by ethanol. Seen from the metallographic photograph in Figure 2, it can be concluded that after the laser quenching, for both the specimens of 45 steel and 30Cr the surface pearlite and ferrite are transformed into hard martensite. The transition zone in the specimen of 45 steel is mainly composed of martensite, ferrite and troostite. Due to the differences in laser quenching parameters, martensite, pearlite and a small amount of ferrite are found in the transition zone of the specimen of 30Cr.

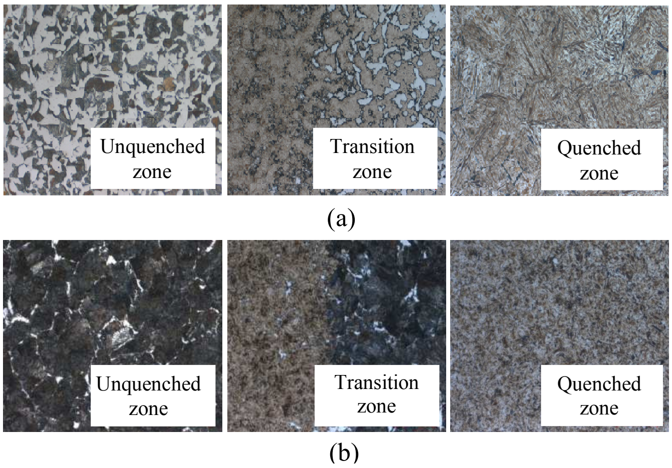

FIGURE 2: OPTICAL MICROGRAPHS OF THE MICROSTRUCTURES IN LASER QUENCHING SAMPLE OF (a) 45 STEEL AND (b) 30Cr STEEL

Residual stress and Vickers surface hardness were alternatively measured along the sensor scanning path as shown in Figure 1. According to the Chinese standard of GB/T7704-2018, Xstress 3000 X-ray stress analyzer (Stresstech) is used to measure the residual stress at the specimen surface point by point. During the residual stress measurement process, CrKα radiation and the chi method are utilized. The tube current and voltage are selected as 6.7 mA and 30 kV, respectively. A collimator with a diameter of 1 mm is selected to achieve high lateral resolution. The exposure time is about 25 seconds, and in the diffraction plane the azimuth angle ψ is set to 0°, ±15°, ± 30° and ±45°. For the CrKα radiation, the diffraction crystal plane is (211) and its stress constant K=318Mpa/(°). The profiles of the residual stress along the scanned lines are shown in Figure 3a.

During the Vickers micro-hardness test, a load of 1kg was applied to the surface of the specimen and the load was removed after 10s. The profiles of the measured surface hardness are shown in Figure 3b. The value of Vickers hardness is mainly determined by the metallographic structure and the profiles of surface harness are shown as rectangular pulse, which indicating that the microstructures in the quenched (or unquenched) region are basically unchanged. A distinct jump in the surface hardness can be observed at the narrow transition region. For the specimen of 45 steel, compression stress with higher value are found in the quenched region against the base material. However, for the specimen of 30Cr, the residual stress change from tensile stress to compression stress when the test location moves from the unquenched region to the center of the quenched region.

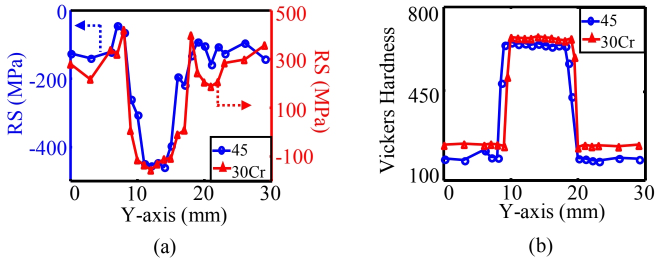

FIGURE 3: TEST MEASURED RESULTS OF RESIDUAL STRESS AND HARDNESS ON THE SPECIMEN SURFACE

2.2 MBN Measurement Experiment

Self-developed MBN scanning device, which is shown in Figure 4a, is used to measure the MBN signal along the line perpendicular to the laser moving direction. The range of line-scan is about 30mm and the scanning step is 0.5mm. Sinusoidal current with a frequency of 50Hz is fed into the excitation coil of magnetizer. A hard disk reader head is used as sensor to measure the MBN signal. The sensor is carried by a four-axis motion platform to scan the established straight line. At each position, MBN measurements are repeated 3 times. The typical averaged butterfly MBN profiles are plotted in Figure 4b.

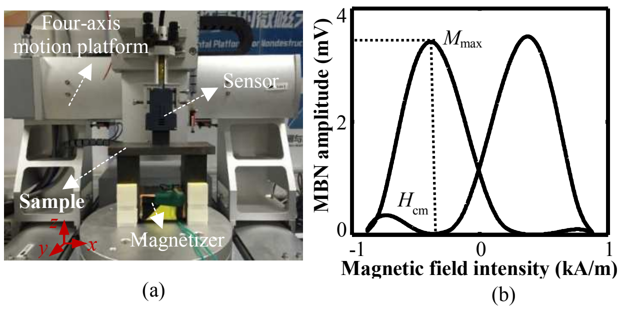

FIGURE 4: EXPERIMENTAL SET-UP AND BUTTERFLY MBN PROFILE

3. RESULTS AND DISCUSSION

The parameters of peak height M_{max} and peak position H_{cm}, which are shown in Figure 4b, are extracted from the measured butterfly MBN profiles. Figure 5 shows the effect of residual stress on the magnetic parameter of M_{max}. M_{max} is evidently increased in the quenched zone. Linear curve fit is applied to the data of residual stress and $M_{max.}$ For the specimen of steel 45 and 30Cr, the R^2 of the fitted curve is found to be 0.8261 and 0.9229, respectively. Similar operation is employed to evaluate the linear correlation between the MBN parameters and the surface hardness and residual stress. The R^2 of the linear fitted curves are listed in Table 2.

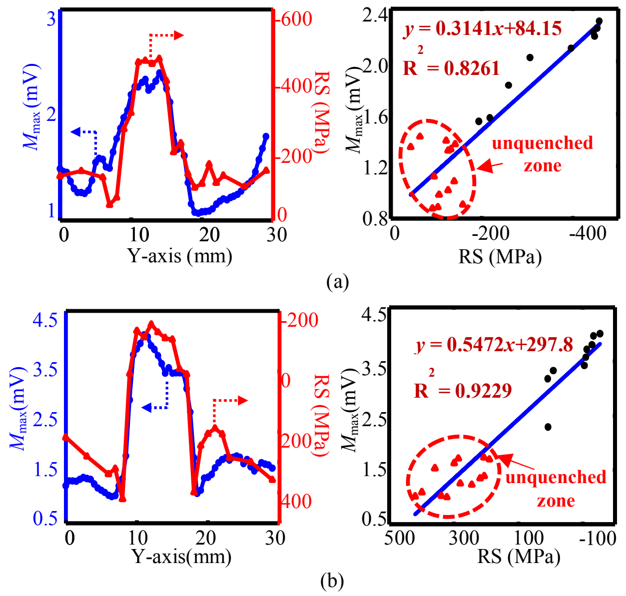

FIGURE 5: THE CORRELATION BETWEEN THE PARAMETER OF M_{MAX} AND THE RESIDUAL STRESS

Both the parameters of M_{max} and H_{cm} linearly depend on the residual stress (or the surface hardness) of the material surface. That may indicate that simple linear superposition can be used to describe the combined effect of microstructures and residual stress on the measured MBN profile. However, the decomposition of the weight of the microstructures and residual stress on the measured MBN profile need further investigations.

TABLE 2: RESULTS OF R^2 FOR DIFFERENCE CASES

MBN parameter	45 steel	R^2	30Cr steel	R^2
M_{max}	RS	0.8261	RS	0.9229
	Hardness	0.8444	Hardness	0.9159
H_{cm}	RS	0.7889	RS	0.8565
	Hardness	0.9199	Hardness	0.8416

4. CONCLUSION

Magnetic Barkhausen Noise scanning test can be applied for evaluating the surface laser quenching induced changes in microstructure and residual stress. Linear dependency of the MBN parameter of M_{max} (or H_{cm}) on the residual stress and the surface hardness can be concluded for the tested specimen. However, the weight of influence of the microstructure and residual stress on the MBN profile needs further investigations.

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