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Fold Mark Characterization Using a Magnetostrictive Probe

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The JSC340P steel is a primary material for a vehicle roof panel. It's subject to alternating line defects of bright & dark across the rolling direction. The alternating lines can be found with grinding the strip surface but difficult to be recognized and quantified. A proprietary magnetic stress sensor was applied to measure the stress variation of the steel strip surface. The principle of the sensor used was the magnetostrictive method and the magnetic anisotropy method. A sample of steel strip was measured along the rolling direction and a stress undulation curve was obtained. FFT (fast fourier transform) of the curve exhibited a strong magnitude at the wavelength of 15-20mm, which coincided with the pitch of the defect by visual inspection, and the alternate lines were measure. The peaks and troughs of the curve are corresponding to the bright and dark lines on the sample surface. With multiple repetitive experiments, the sensor was validated to be capable of characterizing the defect.

Keywords: Roof panel, Line defect, Magnetic stress sensor, FFT

1. INTRODUCTION

The JSC340P steel is a primary material for a vehicle roof panel[1]. The steel strips were inspected and ground with an oilstone before stamping, and the alternate line defects of bright & dark across the rolling direction were found on the strip surface. The alternate line defect is called a fold mark. Fig.1 shows the diagrammatic view of the strip. The strip surface is wavy and the surface waviness is difficult to be recognized before grinding. The surface of the steel strip needs to be ground by oilstone and the alternate line defects of bright & dark will be visible. The wavelength of the defect is about 15~20mm. Fig.2 shows the image of the steel strip surface after grinding. The severity levels of the defect can be checked by clear levels of the alternate line.

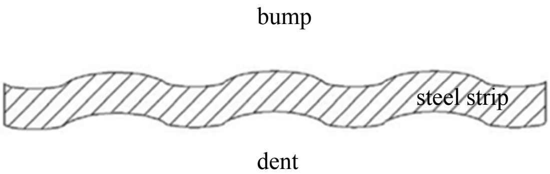

Fig.1. The diagrammatic view of the steel strip.

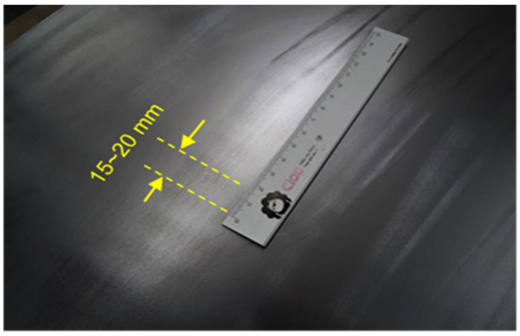

Fig.2. The image of the steel strip surface after grinding.

The fold mark is caused by a residual stress of the steel strip. This paper tries to characterize the defect by measuring the stress. The stress is generally measured by the strain gauge method, but it is difficult to measure the slight stress level. This paper presents another alternative technology to measure slight stress, the magnetic method. The stress measuring method using magnetic anisotropy is a simple non-destructive method of measuring and evaluating the stress[2]. Magnetic method correlations between material properties, magnetic parameters, steel microstructural parameters and the stress[3]. Stress is the main impact factor. A sample of steel strip was measured along the rolling direction and a stress undulation curve was obtained. FFT of the curve exhibited a strong magnitude at the wavelength of 15-20mm, which coincided with the pitch of the defect by visual inspection, and the alternate lines were measured. With multiple repetitive experiments, the sensor was validated to be capable of characterizing the defect.

2. EXPERIMENTAL METHOD

The fold mark is characterized by a magnetostrictive probe which is an improved stress measuring probe [(4)]. Fig.3 is the side and bottom view of the magnetostrictive probe. The Driving coils are marked as red and the induction coils as blue. The 100Hz AC magnetic flux from the driving coils will become closed circles with the nearest induction coils. Fig.4 is the magnetostrictive method. When the object of measurement has no stress, the magnetic fluxes of the x-direction and y-direction are the same. The voltages of the induction coils will measure zero volts. When stress is applied to the object, the permeability increases slightly in the direction of stress (x-direction or y-direction). The magnetic flux will increase with the direction of stress. The voltages of the induction coils will induce the magnetic flux difference between x-direction and y-direction, and the voltages (V) are given by Eq. (1):

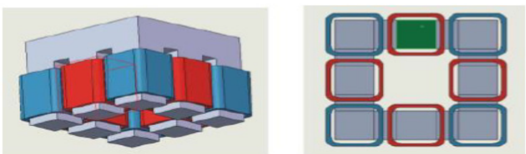

Fig.3. The side and bottom view of the magnetostrictive probe.

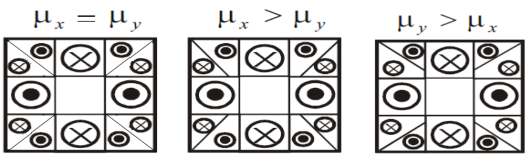

Fig.4. The method of the magnetostrictive probe.

$$V = K(\sigma_x - \sigma_y) \quad (1)$$

Where, K: is a constant determined by excitation conditions, coil conditions, magnetic properties of the material, etc. σ_x-σ_y: is the difference in stress.

The steel strip sample needs to be put on a flat surface in order to avoid extra stress before measuring and the surface will be marked every 2mm along the rolling direction according to the measured area resolution of the sensor at 2x2 mm^2. The center of the probe will be aligned with the marks and the length of the measured line is about 240~260mm. The sample was measured along the marked line and the stress undulation curve will be obtained. The stress undulation curve consist of the fold mark stress, longer wavelength stress (caused by the shearing machine, transport, or other external forces), and noise. The longer wavelengths (>80mm) appear less than three times in a measured line and the resolutions of the wavelengths are too low and the width of the fold marks were longer than 10mm compared with previous observation. Therefore, the stress curve will be cut off for longer wavelengths (>80mm) and shorter wavelengths (<10mm). Then, the undulation curve can be exhibited as a frequency spectrum with FFT and the frequency spectrum can be analyzed for the difference in wavelength fold marks on the steel strip surface.

3. RESULTS AND DISCUSSION

In order to confirm the stress which was measured with the magnetostrictive method could to characterize the fold mark. Multiple repetitive experiments were executed for this paper. The following are the feasibility experiments of the magnetostrictive method.

3.1 The repeatability of the method

The sensor needed to be checked that the same stress curves were obtained in different examples at the same place of the sample. In this experiment, the stress was measured 3 times at the same place on a steel strip sample. Fig.5 shows the magnetic values and FFT of the steel strip sample. The magnetic values were slightly different between the 3 times experiment but most locations of the peaks and troughs were similar. The peaks of the FFT were found at the same wavelength, 20~24mm. The same curves with 20~24mm wavelength were obtained at different measurements, and the repeatability of the method could be confirmed.

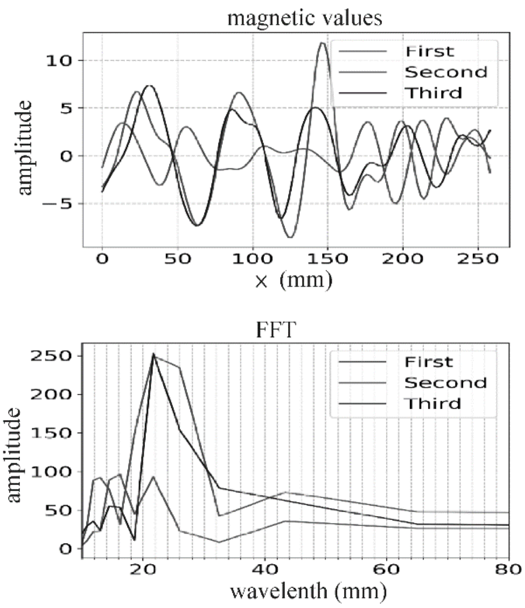

Fig.5. The magnetic values and FFT of the steel strip sample.

3.2 The measurement of the smooth surface sample

In this experiment, a smooth surface sample without a fold mark would be measured. The sample was measured and the magnetic values were obtained. Fig.6 shows the magnetic values and FFT of the smooth surface. No strong peak of the FFT was exhibited, and the amplitude was smaller. There was no obvious wave on the surface and no special wavelength was measured by the probe.

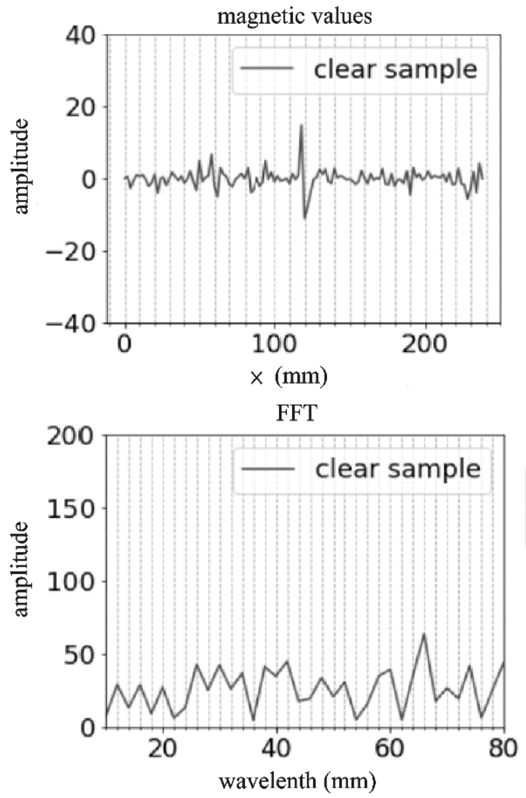

Fig.6. The magnetic values and FFT of the smooth surface.

3.3 The measurement of the fold mark

Fig.7 shows a sample with the fold mark. The pitch of the fold mark is about 11~15mm. The probe measured the stress along the rolling direction and stress undulation curve was obtained. The wave with a wavelength of 11~15mm must be obtained from the stress undulation curve. Fig.8 shows the magnetic values and FFT of the fold mark sample. The magnetic values are hard to recognize the special wave, but the FFT of the stress is very clear. The FFT exhibited a strong magnitude at the wavelength of 11-15mm, which coincided with the pitch of the defect by visual inspection, and the alternate lines were measure.

3.4 The Similarity between the magnetic values and the image of the fold mark

The magnetic values are difficult to recognize in the wavelength of the above-mentioned experiments. The longer undulation curve is too complicated to distinguish the wavelength of the fold mark, and the FFT can help to exhibit the wavelength. If the undulation curve was separated in to a small part, the relationship between the magnetic values and the image of the fold mark was clearer. Fig.9 shows the magnetic values and the image of the fold mark. It is obvious to distinguish that the peaks of the stress curve are corresponded to the bright zone of the fold mark. Some parts of the image are difficult to separate the bright and dark, and so the image was converted to a grayscale curve. The stress curve and the grayscale curve have high similarity. The peaks and troughs of the two curves were placed on the same place. The stress can characterize the fold mark, and the sensor was validated to be capable of characterizing the defect.

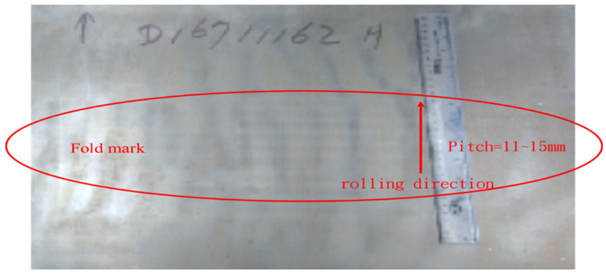

Fig.7. The fold mark sample with the wavelength of 11~15mm.

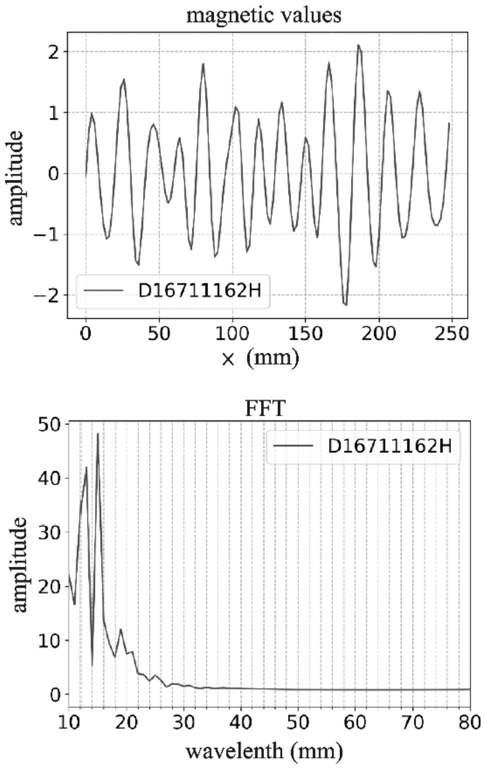

Fig.8. The magnetic values and FFT of the fold mark sample.

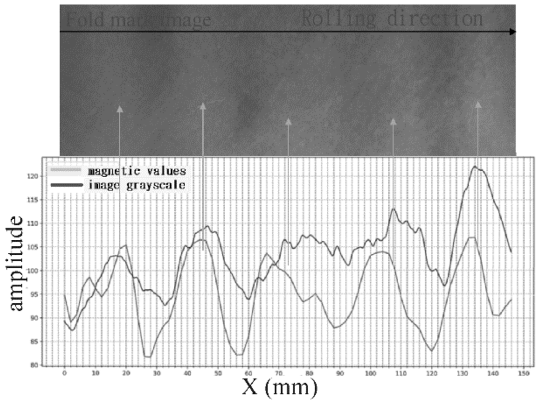

Fig.9. The comparison between the magnetic values and the image of the fold mark.

4. CONCLUSIONS

The fold mark is difficult to distinguish, it can only be found with grinding the strip surface. After grinding the surface, the fold mark is still difficult to recognize and quantify unless the degree of the fold mark is serious. As usual methods, the inspector collated the fold mark with the limited sample after grinding. According to the clarity of the fold mark, the severity level was confirmed by five degrees. The inspection of the fold marks heavily rely on personal experience. A new measuring method is presented in this paper. The feasibility of the method can be seen in the following statement.

1. The repeatability of the method was confirmed. The same experiment conditions were obtained with similar stress curves. The main peaks of the FFT were found in the same places.
2. The stress curves corresponded to the fold mark. No strong peaks were obtained from the FFT of the smooth surface sample.
3. An obvious fold mark sample with the wavelength of 11-15mm was measured. FFT of the stress curve exhibited a strong magnitude at the wavelength of 11-15mm which coincided with the pitch of the defect by visual inspection.
4. A comparison of the stress curve and the fold mark image was presented. It is obvious to distinguish that the peaks of the stress curve correspond to the bright zone of the fold mark. The method is confirmed to characterize a fold mark.

With multiple repetitive experiments, the magnetostrictive probe was validated to be capable of characterizing the defect. And the fold mark can be recognized and quantified by the measured values.

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