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Statistical Identification of Fatigue Life using Metal Magnetic Memory Technique

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Abstract: Due to various external stresses, high temperature, and high pressure for an extended period, the internal organizational structure for carbon steel components changes resulting in stress deformation and microscopic damage. Identification of cracks is critical, particularly during the earlier stages. This study presents the life prediction for the carbon steel component by observing the Metal Magnetic Memory (MMM) signals at different cycles of the specimen. It was carried out utilizing one of the Non-Destructive Testing (NDT) methods for evaluating components without affecting their continued use. In this paper, two specimens of carbon steel SAE 1045 that underwent with bending test and MMM (TSCM-2FM) were used to collect signals. The MMM signals were compared using MATLAB software's kurtosis statistical approaches to determine the material's failure point. According to the findings, the closer the crack distance (40 - 60mm), the greater the stress concentration (300 - 430 A/mm). The results indicate that when the kurtosis value approaches 3, the specimen is on the verge of failing. It can be concluded that the study can be used to predict the lifespan of carbon steel components.

Keywords: Metal Magnetic Memory (MMM), Carbon Steel, kurtosis, Statistical Analysis, MATLAB

1. Introduction

Fatigue damage is a mechanical failure when mechanical structures are subjected to constant stresses over long periods (Mohammad et al., 2020). Crack damage is one of the most critical failure mechanisms in industries because stress in the material varies with a continual change in condition (Norman et al., 2021). In addition, fracture failure poses a threat to mechanical structures, prompting research into various approaches for detecting, screening, and anticipating crack damage instruments in materials (Ni et al., 2018).

This research aimed to gauge industry and scholarly information to identify the carbon steel component's lifespan. The state of the material during operation can be evaluated, as well as the component's remaining life. MMM distinguishes itself because the signals can be obtained even after the damaged equipment or specimen. The MMM approach for ferromagnetic materials uses self-magnetic signals, which eliminates the need for an external magnetic field during measurements (Xie et al., 2022). As a result, the MMM signals were collected from the damaged materials subjected to the bending test. After that, the signals were statistically evaluated to determine the proper crack position owing to fatigue loading (Ren et al., 2019).

This paper aims to analyze the relationship between MMM parameters towards the different cycles and distance of the specimen using a statistical approach and develop a mathematical model for life prediction with other loads using a statistical method.

2. Research Methodology

2.1 Preparation sample

Two types of specimens (carbon steel SAE 1045) were used, where specimen 1 was with a smooth surface and specimen 2 with a hole with a depth of 1 mm. The plate-shaped specimens measured 300 mm in length, 25 mm in width, and 4 mm in height. Fig. 1 shows the image of specimen preparation. Both the specimens were marked with a line measuring 60 mm on the rear surface of the specimens. It ensures that the MMM device wheel is driven straight to detect the stress concentration zone. Two lines were drawn from the centre of the hole measured as 1mm and 3 mm. The magnetic field intensity, Hp (A/mm) of each specimen, was recorded, which shows that line 3 is the furthest distance while line 1 is the shortest distance to the crack.

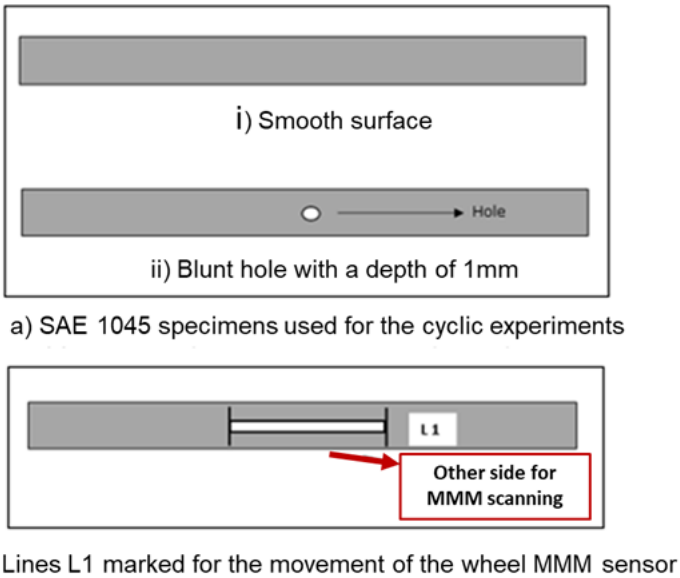

Fig. 1. Specimen preparation (a) two SAE 1045 specimens and (b) line L1 marking for wheel movement

MMM monitoring was employed using Tester of Stress Concentration TSCM-2FM. The examination device is customizable and has two flux-gate transducers and a one-wheel length-tallying device. It can be used to inspect and review virtually any test objects, including those with complex shapes. The stress concentration tester is a device for measuring, recording, and processing diagnostic data concerning stressed-strained states of equipment and structures using the metal magnetic memory technology and its software, commonly known as the metal magnetic memory diagnostic data processing program. The collected signals were then analyzed using a statistical approach. The global statistical approach kurtosis was used to identify the crack severity.

The equation (1) gives the kurtosis formula:

$$\text{Kurtosis} = \frac{\sum_{i=1}^{N}(Yi - \bar{y}^4)/n}{S^4} \quad (1)$$

Where yi is the original sample time signal, $\bar{y}$ is the mean value of the sample, n is the number of samples, S is the standard deviation.

3. Result and Discussion

3.1 MMM Signal for Specimen 1 and 2 at Different Distance for Several Number of Cycles.

Fig. 2 and Fig. 3 show the signals collected by MMM for specimen 1 and specimen 2 at different distances for several cycles. A comparison of various cycles (0: black, 3000:red, 15000:blue, and 30000:green) was performed on specimen 1 and specimen 2 at line 1 mm and line 3 mm to determine the signal difference concerning the hole distance.

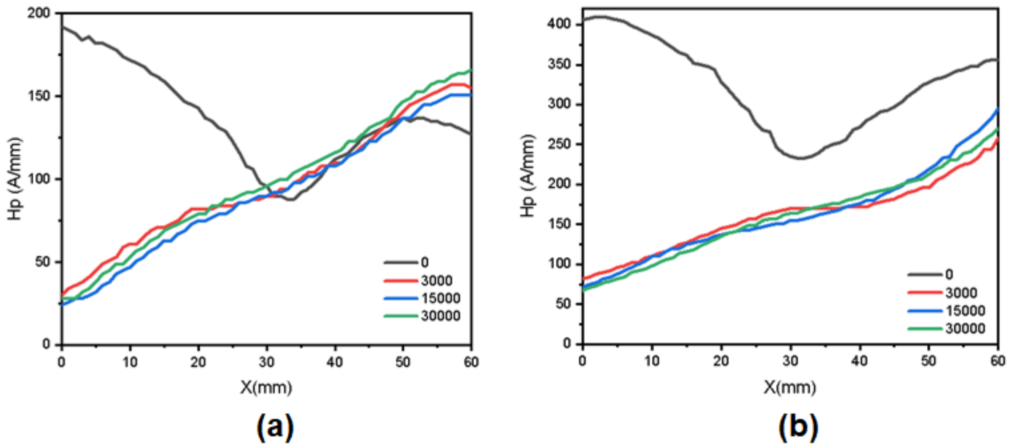

Fig 2. Hp value towards distance at several numbers of cycles for specimen 1 (a) at line 1 mm (b) at line 3 mm.

Fig. 2 (a) shows the comparison of signals for specimen 1 with no hole at line 1 for several cycles. From the Fig 2 (a) graph, it can be observed that the highest value of Hp exists at 190 A/mm contributed by line 1 at 0 cycles compared to the other cycles. Fig. 2 (b) shows the comparison of signals for specimen 1 with no hole at line 3 for several cycles. It can be observed that the highest value of Hp exists at 400 A/mm contributed by line 3 at 0 cycles when compared to the other cycles. The initial magnetic values are considerably high since the specimen was not demagnetized. This results in the Hp value being high in the initial stage (Karthik et al., 2012). The demagnetizing process is essential to remove the magnetic fields in the material that counteracts (Hu et al., 2008).

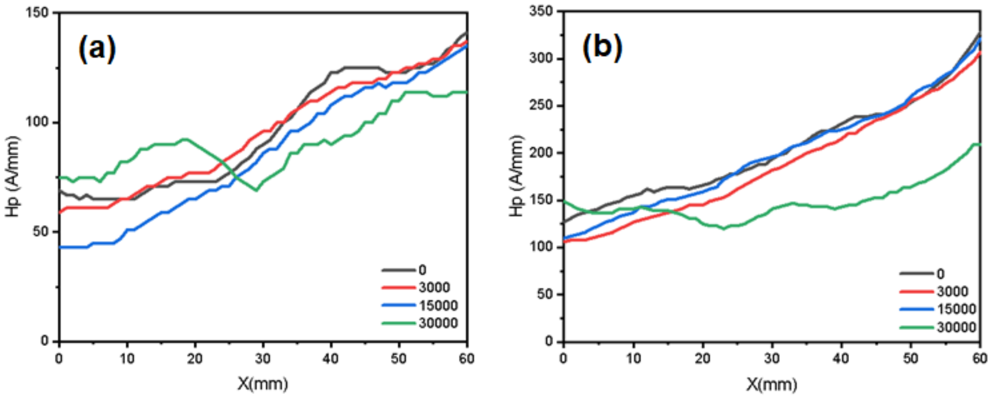

Fig 3. Hp value towards distance at several numbers of cycles for specimen 2 (a) at line 1 mm (b) at line 3 mm.

Fig. 3 (a) shows the comparison of signals for specimen 2 with a hole at line 1 for several cycles. From Fig. 3 (a), it can be observed that the Hp (A/mm) trend of each cycle is not constant since there is a hole in the specimen. Fig. 3 (b) graph shows the comparison of signals for specimen 2 with a hole at line 3 for several cycles. It can be observed that the values are not constant, and deflection occurs in Hp values, and there's a hole in the specimen. Both the specimen's Hp value increase at the length of 40 mm onwards, which indicates that it's nearing the crack position.

3.2 Comparison of specimens 1 and 2 at a different distance for selected cycles.

Fig. 4 and Fig. 5 show the comparison between line 1 and line 3 for 0 cycles, and 30000 cycles are prepared for specimen 1 and specimen 2 to observe the signal difference towards the crack distance. The 0 cycles are chosen as the initial stage to undergo the comparison while 30000 cycles as the maximum stage.

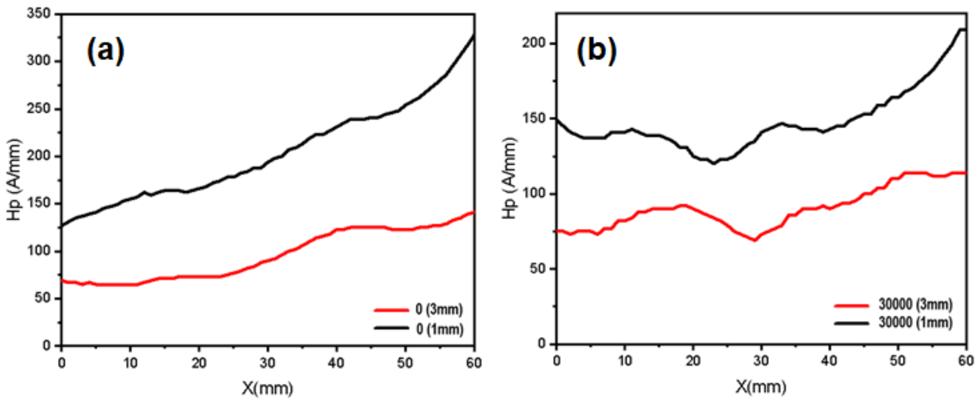

Fig 4. Comparison of cycles for specimen 1at line 1 and line 3 (a) 0 cycle (b) 30000 cycles

Fig. 4 (a) shows the comparison of specimen 1 for 0 cycle load at the distance of line 1 and line 3. The value of line 1 and line 3 of specimen 1 represented by the graph shows a high difference. It can be observed that the highest value of Hp exists at 410 A/mm contributed by 0 cycles of line 1, while the value of Hp for 0 cycles of line 3 exists at 190 A/mm at the distance of 0 mm. These higher signals are observed, indicating that the stress concentration is higher and the specimen was not demagnetized (Bao et al., 2016; Hu et al., 2008). Then it can be observed that the Hp value at the distance of 60 mm shows 350 A/mm for line 1 and 120 A/mm for line 3. The lowest value can be observed at line 3 because the line is far away from the crack compared to line 1. Fig. 4 (b) shows the comparison of specimen 1 for 30000 cycle loads at line 1 and line 3. It can be observed that there is a higher Hp value on line 1 compared to line 3. The Hp value exists at 260 A/mm for line 1 while 160 A/mm for line 3 at the 60 mm distance. It is because line 1 is nearer to the crack area. The specimen in line 3 has a lower value of Hp because the crack distance is far compared to the specimen in line 1.

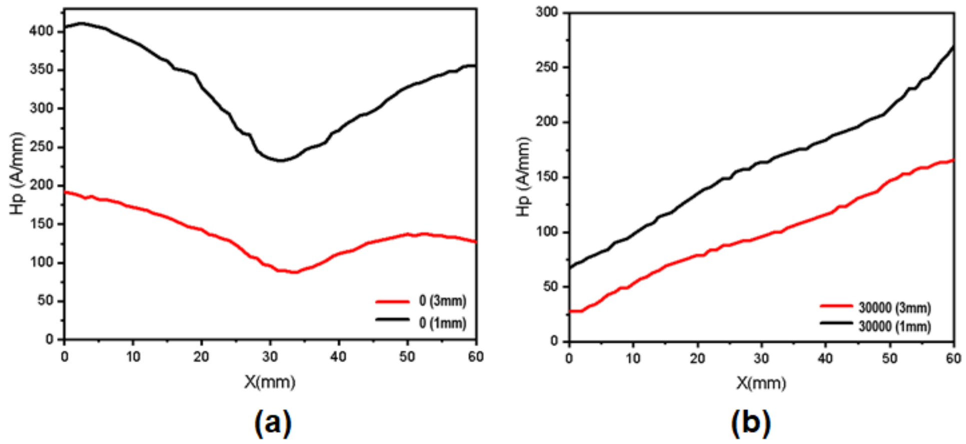

Fig.5. Comparison of cycles for specimen 2 at line 1 and line 3
(a) 0 cycle (b) 30000 cycles

Fig. 5 (a) shows the comparison of Specimen 2 at line 1 and line 3 for 0 cycle load. As seen in the graph, the values of line 1 and line 3 of Specimen 2 are different, as indicated. The Hp value is 328 A/mm for specimen on line 1 and 125 A/mm for specimen on line 3 for the distance of 60mm. These higher signals are observed, indicating that the stress concentration is higher in the initial stage. It can be observed that a higher Hp value exists on specimen 2 for line 1 at 328 A/mm due to the line is the closest to the crack when compared to line 3. Fig. 5 (b) shows the comparison of Specimen 2 at line 1 and line 3 at 30000 cycle loads. It can be observed that a higher Hp value exists on line 1 at 150 A/mm and 75 A/mm on line 3 for the distance of 0mm. The Hp value exists at 209 A/mm for line 1 while 116 A/mm for line 3 at the 60 mm distance. The higher Hp value can be observed in line 1 because the line is nearer to the crack when compared to line 3.

3.3 Data Analysis using Statistical Global Parameter

The kurtosis for specimen 2 at line 1 and line 3 was calculated in MATLAB using the data signal obtained from the metal magnetic memory approach. Fig. 6 displays the results by histogram graph. The graph depicts the results of the kurtosis value to determine the relationship between MMM characteristics and crack distance.

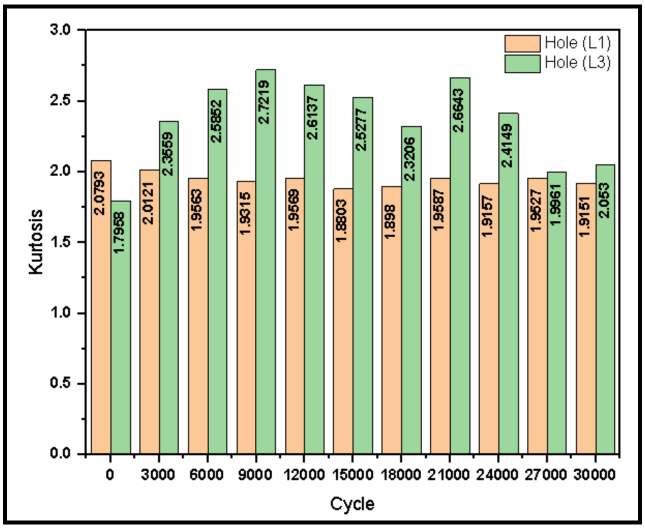

Fig 6. Kurtosis results in Histogram

The kurtosis result in the histogram shows that the material's kurtosis is less than 3 for both the respected lines indicating that it is in good condition. A signal having relatively flat peaks has a kurtosis of less than three (De Silva, 2006; Zhu et al., 2014). If the kurtosis value is negative, the material will fail at any time, and extra caution is required. It is known from the previous study as the kurtosis value shows peak distribution whenever there is any faulty occurrence (Caesarendra et al., 2016; Immovilli et al., 2012).

3.4 Kurtosis Data for Specimen 2 at Line 1

Fig.7 shows the graphical result of specimen at line 1 provides a more reliable R-squared value, R^2 better than specimen at line 3, which made it the reason for the choice. According to the graph, it could be seen that the percentage value of the equation range is 70-75 % which shows that the data readings are in stable form with a reliable standard equation (Bhende et al., 2014). Moreover, the specimen at line 1 is the nearest line to the crack location when compared to line 3. It shows that as the number of cycles is increased, the kurtosis value will be decreased. Therefore, it can be a suitable parameter to assess the damage experienced by the component. According to Li Chong, higher metal memory signals indicate that the material is more prone to the deterioration (Chongchong et al., 2016).

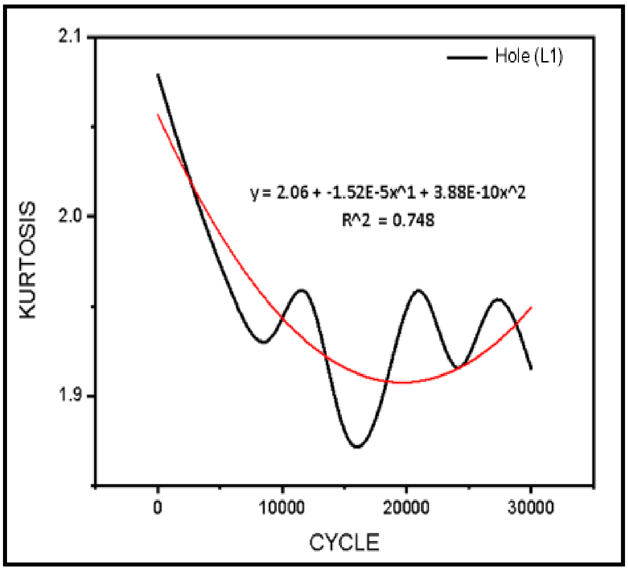

Fig.7. Graph of kurtosis for specimen 2 at line 1

3.5 Mathematical Model Equation as Output

The test has been run at several cycles, and the signals have been analyzed statistically using the global parameter called kurtosis. Kurtosis is widely used in assessing engineering faulty in many applications. Also, from the plot, a new equation was established. The modified equation can be shown in equation (2) where the K_m is the kurtosis value for MMM, and the Nc is the number of cycles. Using this equation, the crack location of the SAE 1045 carbon steel specimens, in this case, can be predicted.

$$\mathbf{K_m} = 2.06 + -1.52E - 5\mathbf{N_C}^1 + 3.88E - 10\mathbf{N_C}^2 \quad (2)$$

4. Conclusion

The capacity of the MMM to detect the stress concentration zone during crack site identification in SAE1045 carbon steel specimens was established in this investigation. The Hp value increases as the crack distance approach, according to the results acquired from MMM signals. Therefore, it can be deduced from specimens 1 and 2 that the position of the fracture can be detected with its greater Hp value at a minimum distance of 60 mm from the fracture. Aside from that, the kurtosis data show that the tendency is rising toward failure. It can also be argued that when the result changes above the value of 3 or to a negative value, it indicates failure. As a result, the state of the material can be determined by using the kurtosis model to predict the specimen lifespan.

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6. References

Bao, S., Fu, M., Hu, S., Gu, Y., & Lou, H. (2016). A review of the metal magnetic memory technique. International Conference on Offshore Mechanics and Arctic Engineering,

Bhende, A. R., Awari, G. K., & Untawale, S. P. (2014). Comprehensive bearing condition monitoring algorithm for incipient fault detection using acoustic emission. *Jurnal Tribologi, 2,* 1-30.

Caesarendra, W., Kosasih, B., Tieu, A. K., Zhu, H., Moodie, C. A., & Zhu, Q. (2016). Acoustic emission-based condition monitoring methods: Review and application for low speed slew bearing. *Mechanical Systems and Signal Processing, 72*, 134-159.

Chongchong, L., Lihong, D., Haidou, W., Guolu, L., & Binshi, X. (2016). Metal magnetic memory technique used to predict the fatigue crack propagation behavior of 0.45% C steel. *Journal of Magnetism and Magnetic Materials, 405,* 150-157.

De Silva, C. W. (2006). *Vibration: fundamentals and practice*. CRC press.

Hu, B., Chen, G., Shen, G., Li, L., & Chen, X. (2008). Study on Magnetic Memory Method (MMM) for fatigue evaluation. Proc. of 17th World Conference on Nondestructive Testing,

Immovilli, F., Bianchini, C., Cocconcelli, M., Bellini, A., & Rubini, R. (2012). Bearing fault model for induction motor with externally induced vibration. *IEEE Transactions on Industrial Electronics, 60*(8), 3408-3418.

Karthik, J., Chaitanya, K., & Sasanka, C. T. (2012). Fatigue life prediction of a parabolic spring under non-constant amplitude proportional loading using finite element method. *International Journal of Advanced Science and Technology, 46,* 143-156.

Mohammad, M., Murthy, S., Adnan, M. A. M., Norman, M. A. M., & Zakaria, H. (2020). A statistical approach of crack distance determination using metal magnetic memory technique. *Proceedings of Mechanical Engineering Research Day, 2020,* 204-205.

Ni, C., Hua, L., & Wang, X. (2018). Crack propagation analysis and fatigue life prediction for structural alloy steel based on metal magnetic memory testing. *Journal of Magnetism and Magnetic Materials, 462*, 144-152.

Norman, M. A. M., Waduth, M. F. A., Adnan, M. A., Mohammad, M., & Abdullah, A. Z. M. (2021). An Investigation into the Capabilities of Artificial Neural Networks (ANN) in Predicting the Location and Depth of Crack on Beam. *Selangor Science & Technology Review (SeSTeR), 5*(1), 1-10.

Ren, S., Ren, X., Duan, Z., & Fu, Y. (2019). Studies on influences of initial magnetization state on metal magnetic memory signal. *NDT & E International, 103*, 77-83.

Xie, Z., Zhang, D., Ueda, T., & Jin, W. (2022). Fatigue damage analysis of prefabricated concrete composite beams based on metal magnetic memory technique. *Journal of Magnetism and Magnetic Materials, 544*, 168722.

Zhu, J., Nostrand, T., Spiegel, C., & Morton, B. (2014). Survey of condition indicators for condition monitoring systems. Annual Conference of the PHM Society,