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Detection of Cracked Position Due to Cyclic Loading For Ferromagnetic Materials based on Magnetic Memory Method

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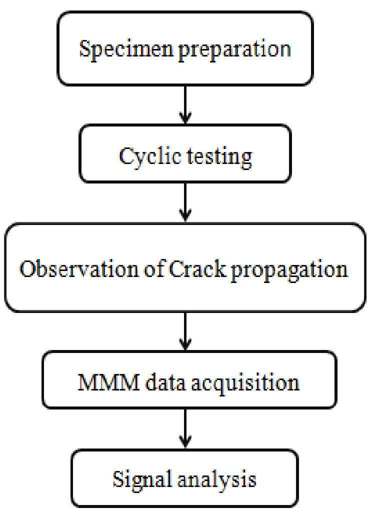
Graphical abstract



Abstract

In this paper, metal magnetic memory (MMM) method is used to detect the micro-crack position on the ferromagnetic material due to the fatigue process by determining to the stress concentration zones in the metal surfaces. The MMM method was carried out on mild steel using Instron 8874 universal tensile testing machine with different values of the ultimate tensile strength (UTS) varies from 75%, 80% and 85% until the specimens fails. An equipment of stress concentration indicator was used to measure the magnetic flux leakage, Hp patterns in the specimens. The results indicated that the position of a crack on the specimen that failed due to fatigue test was correlated with the scanning interval from the magnetic flux leakage signals. Therefore, the MMM method provides the potential possibility to detect the position of fatigue damage or defect in the metal components.

Keywords: Fatigue damage, magnetic flux leakage, crack position

Abstrak

Dalam kajian ini, kaedah isyarat ingatan logam magnetik (MMM) akan digunakan untuk mengesan lokasi retakan-mikro pada bahan feromagnet di dalam proses ujian lesu dengan menentukan zon penumpuan tegasan pada permukaan logam. Kaedah MMM telah di jalankan ke atas keluli lembut menggunakan mesin ujian universal tegangan, Instron 8874 dengan berpandukan kepada perbezaan nilai-nilai kekuatan tegangan muktamad iaitu sebanyak 75%, 80% dan 85% sehinggalah spesimen patah sepenuhnya. Alat penunjuk penumpuan tegasan telah digunakan untuk mengesan corak kebocoran fluks magnet, Hp pada spesimen. Hasil ujikaji menunjukkan bahawa kedudukan keretakan yang berlaku pada spesimen dalam ujian lesu dapat dikorelasikan bersama dengan imbasan corak yang terhasil daripada kebocoran isyarat magnetik fluks pada permukaan spesimen. Oleh itu, kaedah MMM ini mempunyai keupayaan yang tinggi bagi mengesan kedudukan kerosakan lesu atau kecacatan dalam komponen logam.

Kata kunci: Kerosakan lesu, kebocoran magnetik fluks, lokasi retak

1.0 INTRODUCTION

The MMM method is a passive magnetic technique which is based on the magneto-mechanical effect. This effect is a property of ferromagnetic materials when it was given an applied load and then changed their shape or dimensions during the process of magnetization of magnetic domain structure. The magnetic flux signals appear and generate in the stress concentration positions of metal components and it can be determined by measuring the MMM signal lines of Hp [1, 2]. MMM method can assess the actual stress status and deformation of equipment by identifying the crack damage of metal region in the early stages, providing a strong scientific basis in failure and life assessment of metal components [3, 4].

This method has a special capability to investigate or detect stress concentration zones (SCZ) as the main sources of local fracture mechanism in metal components [5-7]. It analyzes spontaneous magnetic leakage field distribution on tested components surface. In the previous research on MMM technique, Kang C. *et al*. (2011) were analyzed the detection position of micro crack on the side of an actual gear and load effect using MMM method. Followed by Xing H. *et al*. (2011) were analyzed the MMM signals which represent the fatigue characteristics in the rotary bending fatigue analysis. This was further enhanced by Wu D. *et al*. (2010) were studied the correlation of crack growth rate, da/dN and magnetic flux normal signals, Hp in three-point bending fatigue tests.

However, there is a lack in term of their experimental results that can identify the potential of the MMM method for detecting the crack position in metal components. In this paper, through tensile fatigue experiment, the authors were investigated the correlation between fatigue life cycles and magnetic flux signals based on metallographic observation. The relation to the position of cracks that failed due to fatigue test and the magnetic flux leakage signals was also studied.

2.0 THEORY

The previous study from A.A Dubov (2006) showed that there are presence of cyclic loads and stresses, Δσ action in most of metal part works and in presence of Earth's field. From Figure 1 below shows that a magnetic induction increment ΔM_{σ}^{1} in every cycle and $\sum_{1}^{n} = \Delta M_{\sigma}^{1}$ can reach sizable value and exhibit magnetic flux leakage. The previous experiments results show that $\sum_{1}^{n} = \Delta M_{\sigma}^{1}$ become stable after several cycles. When the fatigue crack begins to propagate, Δσ of each cycle will increase because of the decrease of the bearing area, and ΔM_{σ} of each cycle will increase corresponding. So the ΔM_{σ} of each cycle differ with corresponding crack size and crack growth rates, which make the cumulative rate of magnetic signal different. Therefore, the magnetic signals may have different characters at different fatigue stages.

ΔM_{σ}^{1} = Magnetic induction increment of a cycle
Δσ = Variation of periodic load

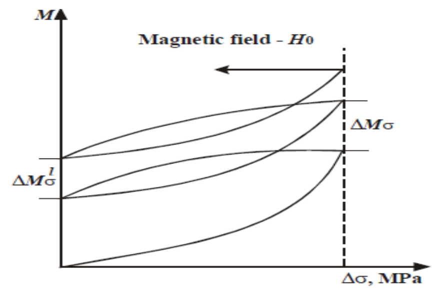


Figure 1 Schematic diagram of magnetic memory effect (A. Dubov, 2006)

3.0 EXPERIMENTAL

3.1 Material Selection

The material from mild steel is used for the specimens, which was applied widely in various industrial engineering applications instead of their good in mechanical properties and relatively low cost. Tensile specimens of central dimensions 50 mm (length) x 7 mm (width) x 3 mm (thickness) are machined from the mild steel flat-plate (as shown in Figure 2) according to the International Standards of ASTM: E606 [11].

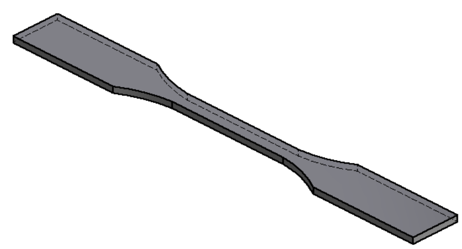


Figure 2 The geometry of the specimen

3.2 Inspection Procedure

Before starting this experiment, the specimens must undergo the preliminary demagnetized process that based on alternating field demagnetization principle in order to eliminate the disturbance that introduced by the manufacturing process. The test was performed on mild steel using Instron 8874 universal testing machine. The normal component, Hy of the SMLF were recorded by TSC-1M-4 instrument, scanning sensor type2 with a testing frequency of 8 Hz and constant loaded in 15.0 kN. The specimen was first loaded with a pre-set value at a crosshead rate of 2 mm/min and 75% UTS value and then unloaded but still held in its clamp position. Next, the Hy signal was collected directly along the scanning line which refers to an online-unloading. After that, the specimen was loaded with increasing of the number of load cycles until a specimen fails, and the above procedures are repeated with different of UTS values (80% and 85%).

4.0 RESULTS AND DISCUSSION

The specimens were prepared and tested with the different values of UTS in the variable rate of 75%, 80% and 85% until the specimen fails. From the results, it can be seen clearly in the graph that the relationship between magnetic flux leakage with scanning interval distance for all cycles involved in 75 %, 80 % and 85 % UTS values that shown in Figure 3, Figure 4 and Figure 5.

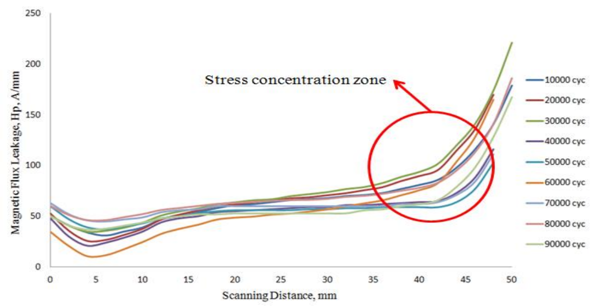


Figure 3 Graph of magnetic flux leakage signals with scanning interval distances in 75% UTS

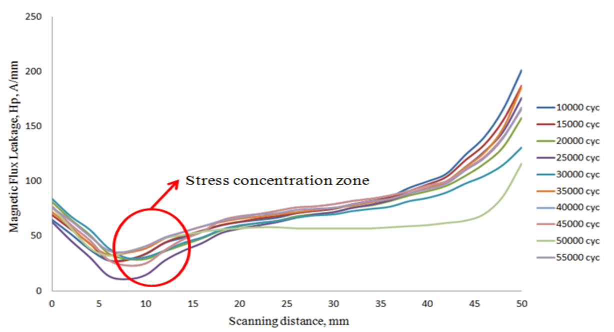


Figure 4 Graph of magnetic flux leakage signals with scanning interval distances in 80% UTS

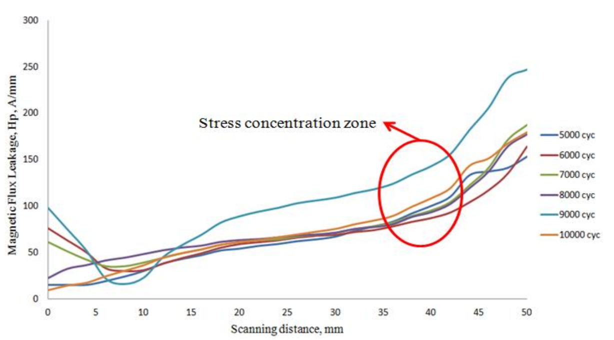


Figure 5 Graph of magnetic flux leakage signals with scanning interval distances in 85% UTS

Theoretically, there have three levels of fatigue failure, which are the first is the process of crack nucleation. The second stage is the process of crack growth while the last stage is the failure of the material. Due to fatigue load cycles increasing, dislocation accumulation to certain causes crack nucleation. As a result of this stage, it would grow into the micro-crack that eventually propagates to macro-crack until the material is fail. The first stage is usually happens when load cycles is applied to a first cycle of up to 10% of the total cycles to fracture [12, 13].

According to result from Figure 3, the intensity of magnetic flux changed drastically at a distance of 34 – 48 mm, in which the stress concentration zones are detected. This is due to the occurrence of the slippage in the crystalline structure that will lead to the formation of micro-crack on the specimen [14]. When the micro-cracks begin to form in the distance, the formation of macro-cracks will take place and caused a failure to the specimen. It is clear when the fracture of the specimen that occurs in zones of stress concentration at a distance of 34 – 48 mm can be seen in the Figure 6 [15].

Figure 6 Condition of specimen after failure in region of 34-48 mm, 75% UTS

In addition, it is found that as shown in Figure 4, the drastically change occurred in region of 10 – 12 mm, in which the intensity of the magnetic flux increased rapidly in the fracture region that represents the zone of stress concentration in the specimen. This also can be seen clearly in the Figure 7 below.

Figure 7 Condition of specimen after failure in region of 10-12 mm, 80% UTS

Last but not least, according to Figure 5, the intensity of magnetic flux shows a sharp increase in the middle of the specimen at a distance of 34 – 42 mm. The signal given shows clearly that the occurrence of stress concentration zones in the central region of the specimen. This is further strongly proven that the specimen was fractured in the middle of the region that shown in Figure 8. Moreover, the maximum number of load cycles in 85% UTS was much lesser (10000 cycle) compared to the number of load cycles in 80% (55000 cycle) and 75% (90000 cycles). This is due to the high stress force has been given to the specimen and it helps to enhance the initiating the cracks in the lower cycle value.

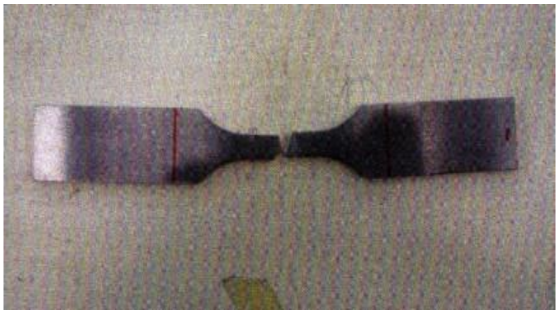


Figure 8 Condition of specimen after failure in region of 34-42 mm, 85% UTS

5.0 CONCLUSION

The main objective of this study is to identify the magnetic flux leakage signals of mild steel due to fatigue test with different fatigue life cycles until it fails. In order to determine the capability of the MMM method for detecting of crack position, the metallographic observations in experimental were investigated. Therefore, it can be concluded that the MMM method has a capability to detect crack position in the fatigue process by showing a sharp increase in magnetic flux leakage signals that represent the zone of stress concentration in the metal components.

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