Eddy Current Thermography: System Development and its Application in NDT

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ABSTRACT :

Eddy Current Thermography (ECT) is an integrative technique which combines eddy current and thermographic NDT in order to provide an efficient method for defect detection. The technique is applicable to electrically conductive material and has the ability to detect surface and subsurface defect. ECT is a non-contact technique; has the ability to provide instantaneous response and high scanning speed that makes it reliable for defect detection and assessment. The technique combines electromagnetic excitation of the work-piece via a coil carrying current, heating of the material by induction and inspection by transient infrared thermography. In this paper, the development of ECT system is detailed, including coil design for global and local heating of samples, and optimisation of excitation parameters (frequency, power, heating duration etc). Results from 3D FEM simulation and experimental investigations are also presented to provide the overview of underlying phenomena and application of ECT. The work demonstrates the effectiveness of the developed ECT system and technique in defect detection and assessment.

Keywords: eddy current thermography, non-destructive testing, 3D FEM, defect

ABSTRAK:

Eddy Current Thermography (ECT) adalah teknik integratif yang menggabungkan arus pusar dan thermografi NDT untuk menyediakan kaedah yang berkesan untuk mengesan kecacatan. Teknik ini boleh digunakan untuk bahan konduktif elektrik dan mempunyai keupayaan untuk mengesan kecacatan permukaan dan sub-permukaan. ECT adalah teknik yang tidak memerlukan sentuhan pada permukaan yang diuji; mempunyai keupayaan untuk memberi tindak balas serta-merta dan kelajuan pengimbasan yang tinggi yang menjadikan ia efektif untuk mengesan kecacatan dan penilaian. Teknik ini menggabungkan pengujaan elektromagnet bahan yang diuji melalui gegelung yang dialirkan arus, pemanasan bahan secara aruhan dan pemeriksaan melalui termografi inframerah transien. Dalam kertas kerja ini, pembangunan sistem ECT diperincikan, termasuk reka bentuk gegelung untuk pemanasan sampel secara global dan local, dan pengoptimuman parameter pengujaan (frekuensi, kuasa, pemanasan tempoh dan lain-lain). Hasil daripada simulasi 3D FEM dan kajian eksperimen juga turut dipersembahkan untuk memberikan gambaran keseluruhan fenomena asas dan aplikasi ECT. Secara keseluruhan kerja yang telah dijalankan menunjukkan keberkesanan teknik dan sistem ECT yang dibangunkan dalam mengesan dan menilai kecacatan.

Kata kunci: *eddy current thermography*, ujian tanpa musnah, 3D FEM, kecacatan

1. INTRODUCTION

Over the last few decades, there is a growing need for non-destructive testing (NDT) in both industrial and research fields. Many industrial field has been using NDT for the inspection and monitoring of material discontinuities such as defects on the surface or subsurface of the electrically conductive material [1]. The techniques is important in maintaining the safety of the equipment and as for inspection of in service components. Basic of five conventional NDT methods which are formerly known are eddy current testing, magnetic particle inspection, radiography, visual testing and liquid penetrant method [2].

Eddy current thermography technique can be used for surface and subsurface defect detection of conductive parts [1]. Joule heating process associated with the eddy current flow permits the detection of flaw in the material [3]. The method of inspection comes in package with the infrared technology to capture the distribution of heat on components being tested in the form of two dimensional images and video images. Non-destructive testing by using thermography technique is the innovation of infrared camera that led to the improvement in spatial resolution, frame rate and temperature sensitivity [4]. This technique has transform into a stand-alone technique which is able to provide quantitative information via the acquisition and images sequences analysis [5].

Based on the principle of ECT, the process of eddy current induction and heat diffusion were integrated with the infrared radiation range from the IR camera. Thermographic data and images captured by the infrared camera can be assessed and interpret to provide both qualitative and quantitative information of the defects in the inspected samples [6]. This technique is able to detect hidden, subsurface defects even in complex geometry components [7].

2. PROCEDURE

2.1 Experimental Setup

Eddy current thermography is based on the theories of phenomena of eddy current in electromagnetic and joule heating behavior. Figure 1 is the schematic of eddy current thermography system including coil, IR Camera, eddy current generator, control and data processing computer.

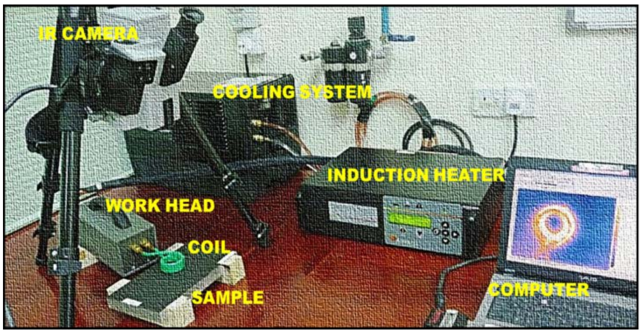

Figure 1: Eddy Current Thermography System (Advanced NDT Lab, Malaysia Nuclear Agency)

The analysis is conducted over the austenitic stainless steel plate sample readily with artificial crack. The excitation sub-system is based around commercial induction heating system, with a maximum excitation power of 2Kw, a maximum current of 480A_{RMS} and high frequency electromagnetic wave range of 50kHz to 500kHz. The infrared camera of micro-epsilon thermoimager is chosen for the work, which is able to detect range of temperature from -20degC to 100 degC, from 0degC to

250degC and from 150degC to 900degC. The camera has three options of saving image data which are in TIFF (*.tiff) that saving image (snapshot) as radiometric picture in TIFF format that will be able to analyses the data by using Matlab and another two options of saving are in Text(Image data, *csv) and Text (Temp. profile data, *csv) [9].

The initial setup of the experiment is started with the excitation parameter (frequency, power, heating duration) on the induction heater and the cooler (Flowmax) that able to flow water inside the probe to avoid overheating of the coil during the experiment. The infrared camera is connected to the processing computer readily installed with thermoimager software for data connection and setting of the infrared camera. The process is started all together simultaneously until the raw data of the image captured by infrared camera has been captured for further process of data analysis.

2.2 Simulation Setup

The simulation models were established as shown in Fig. 2. In this work, a simulation models with specific artificial defect were constructed in COMSOL software by applying the phenomena of joule heating and heat transfer included some of the physics parameter of the sample. The model has been solved through COMSOL AC/DC module representing the overview of the underlying phenomena of the investigated sample. The sample with dimension of 150mm x 83mm x 25mm and the length of defect 23.7mm with 7.6mm depth is investigated.

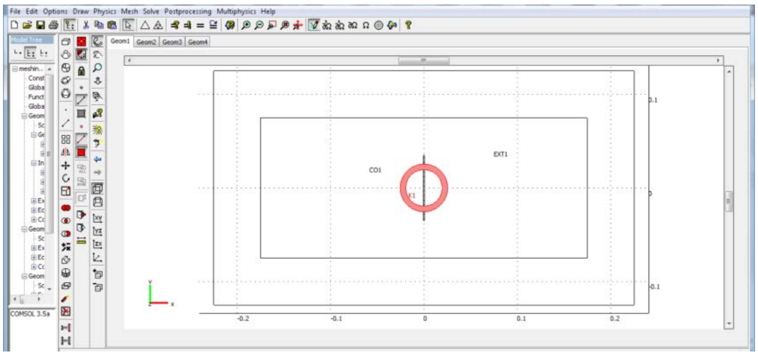

Figure 2: The orientation of simulation by COMSOL FEM Multiphysics

2.3 Coil design for global and local heating

Eddy current excitation is originated by the alternating current. When the coil is excited, the time varying magnetic field is induced which consequently produces the induced eddy current. As reported by (Yin *et al.*,2013), coil design, position and the material of the coil is one of the contributing factors to the phenomena of eddy current excitation towards the material being tested [10]. Fig. 3 shows the coil design in laboratory as for any related experimentation.

Figure 3: The design of coil in the laboratory

3. RESULT AND DISCUSSION

3.1 Experimental setup

The qualitative and quantitative result of eddy current thermography can be obtained by processing the infrared image using the thermoimager software. The presence of the defect inside the sample has made the diversion of eddy current to complete its path. By this phenomenon, the defect can be visualized via the comparison of the color contrast at the region of the defect and the free defect region. Temperature at the defect region is slightly higher compared to another region. The signal of temperature can also be an indicator to observe the presence of defect. Fig. 4 shows the visual formation of defect on the sample being tested.

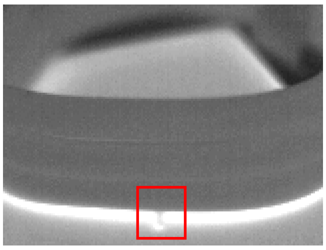

Figure 4: The red square shows the location of visual formation of defect

3.2 Simulation setup

The overview of the underlying phenomena of eddy current thermography can be understand by doing the simulation. Based on the simulation results, the theoretical eddy current distributions, physics parameter and the heating propagation of the defect can be described as shown in figure 5. Figure 5 (d) shows the point graph of temperature along the heating duration of the experiment. The temperature is increasing along the increment of heating duration. The graph shows that the heat propagation and diffusion is increasing until more than 20.1^{0}C. This phenomenon provided the information that increasing temperature is comparable to the heat diffusion in the sample being tested after the induction heating. The visualization of defect during the simulation also indicates the real defect formation on the experimental test. The simulation result is validated by the analysis of Matlab and comparison method of another NDT Technique.

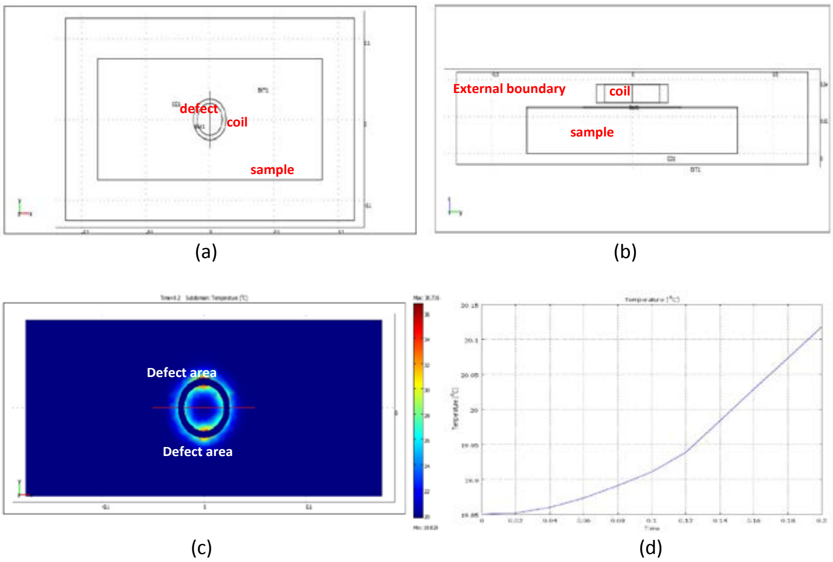

Figure 5: The simulation of COMSOL FEM Multiphysics.

3.3 Coil design for global and local heating

The coil design of the experiment is circular copper coil with outer diameter of 51.07 mm and inner diameter of 39.11 mm. The coil is just larger than the size of defect. According to the study conducted by ???., the size of the coil just enough to cover the defect on the sample being tested. The best placement of the coil is in perpendicular to the defect as it is the best location to trap the formation of defect after heat propagation and diffusion throughout the sample.

4. CONCLUSION

This paper provides a comprehensive summary of research works on eddy current thermography by investigated austenitic stainless steel plate designed with artificial defect. The technique is an advanced non-destructive (NDT) technique that has the ability to provide both results in qualitative and quantitative information by analysis throughout specific software. Modelling and simulation and visualisation for NDT evaluation has been reviewed. It has an important bearing to enable users to understand the physical phenomena of the process throughout the experiment. The effectiveness of the developed ECT system and technique in defect detection and assessment should be investigated for further implementation.

5. REFERENCES

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