



Effect of non-magnetic inclusions in magnetic specimens on defect detection sensitivity using active infrared thermography



B.B. Lahiri^a, S. Bagavathiappan^a, Libins T. Sebastian^b, John Philip^{a,*}, T. Jayakumar^a

^a Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu 603102, India

^b Department of Optoelectronics, University of Kerala, Thiruvananthapuram 695581, India

HIGHLIGHTS

- Effect of non-magnetic inclusions on defect detection sensitivity is studied using IRT.
- Low frequency magnetic field induced heating is used.
- The peak temperature contrast decays monotonically with defect depth.
- Defect regions are identified from the horizontal temperature profiles.
- Established the applicability of this technique under shop floor conditions.

ARTICLE INFO

Article history:

Received 8 October 2014

Available online 20 November 2014

Keywords:

Infrared thermography
Magnetic induction thermography
Non-magnetic inclusion
Magnetic flux leakage
Mild steel

ABSTRACT

We study the effect of non-magnetic inclusions in the defect regions on defect detection sensitivity using alternating magnetic field assisted infrared thermography. The effect of inclusions on the resulting surface temperature profiles around the defect regions are monitored using infrared thermography under the magnetic excitation. Four mild steel specimens with simulated rectangular slots of depths 8.0, 3.3, 3.0 and 5.0 mm, filled with three different non-magnetic inclusions, viz. clay, grease and wax are studied. Under an alternating magnetic field excitation, the induced eddy current in the mild steel specimens produces Joule's heating on the surfaces, which is monitored in a non-contact way. As the non-magnetic inclusions act as a thermal insulator to the alternating magnetization induced heating, a clear thermal contrast at the defect boundaries is seen. The defect regions are clearly discernible from the thermal images and defect widths are estimated from the horizontal temperature profiles. It is observed that the temperature difference between the defect and defect-free regions initially decreases with time up to a certain time (called inversion time) and beyond that the temperature difference increases with time for clay and grease filled defects. The peak temperature difference between the defect and defect-free regions decreases with defect depth due to the magnetic flux leakage from the defect regions. The normalized temperature decay rate, determined from the blind sides of the specimens, is found to decrease with the defect depth. The sensitivity of the depth estimation procedure is higher for inclusions with lower thermal diffusivity values. This study shows the efficacy of low frequency alternating magnetic field induced heating procedure for the detection of defects filled with non-magnetic inclusions in magnetic specimens using active infrared thermography.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Plain carbon steel is used for the roof slab of prototype fast breeder reactor (PFBR) [1]. It is also considered as a potential

candidate for construction of safety vessels of future breeder reactors. Mild steel is extensively used in industries like electrical, oil and gas pipelines, construction and transportation [2,3]. To prevent catastrophic accidents due to pre-mature failure of the fabricated components during manufacturing or in-service, non-destructive evaluation (NDE) techniques are being used. For magnetic components such as carbon and mild steels, magnetic flux leakage (MFL) is one of the widely used NDT techniques [4–6]. Infrared thermography (IRT) is yet another NDT technique, where the temperature changes of an object is measured in a non-contact manner by

* Corresponding author at: Head, Smart Materials Section and Radiography & Thermography Section, Nondestructive Evaluation Division, Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu, India. Tel.: +91 44 27480500x26447; fax: +91 44 27480356.

E-mail address: philip@igcar.gov.in (J. Philip).

Nomenclature

Symbol	Quantity		
q	rate of energy emission (W)	H_{int}	internal magnetic field (A m^{-1})
A	area of emitting surface (m^2)	H_{MFL}	magnetic leakage field (A m^{-1})
ε	surface emissivity (dimensionless)	Q_{loss}	volumetric heat loss (W)
σ	Stefan Boltzmann's constant ($\text{W m}^{-2} \text{K}^{-4}$)	E	electrical field (V m^{-1})
T	absolute temperature (K)	σ_E	electrical conductivity (S m^{-1})
k	thermal conductivity ($\text{W m}^{-1} \text{K}^{-1}$)	V	volume (m^3)
ρ	density (kg m^{-3})	T_0	initial temperature at time $t = 0$ s (K)
c	specific heat ($\text{J kg}^{-1} \text{K}^{-1}$)	T_{max}	maximum temperature at the end of the heating phase (K)
α	thermal diffusivity ($\text{m}^2 \text{s}^{-1}$)	d	defect depth (mm)
e	thermal effusivity ($\text{J m}^{-2} \text{K}^{-1} \text{s}^{-0.5}$)	t_{inv}	inversion time (s)
H_a	applied magnetic field (A m^{-1})		

measuring infrared rays emitted from the surface of the object using an infrared camera [7,8]. The temperature of the object is determined from the intensity of the emitted radiation using Stefan-Boltzmann's law, which is described below [8].

$$\frac{q}{A} = \varepsilon \sigma T^4 \quad (1)$$

Here, q is the rate of energy emission (W), A is the surface area of the emitting surface (m^2), T is the absolute temperature (K), σ is the Stefan-Boltzmann's constant ($\sigma = 5.676 \times 10^{-8} \text{W m}^{-2} \text{K}^{-4}$) and ε is the emissivity of the surface. For a perfect black body, $\varepsilon = 1$ and for real surfaces, $\varepsilon < 1$. For active thermography, external heat stimulation is used, whereas, for passive thermography, no external heating is used. Detailed discussion about various IRT based experimental procedures, data analysis techniques and numerous applications can be found elsewhere [8–13].

Recently, we have demonstrated a new active IRT based defect detection methodology for ferromagnetic specimens using low frequency (50 Hz) alternating magnetic field induced heating [14]. Our results indicated a temperature difference between the defect and defect-free regions that decayed exponentially with defect depth which was attributed to the reduction in the induction heating due to leakage of magnetic flux in the vicinity of the defect regions. The frequency of the applied alternating magnetic field is limited to 50 Hz because of two reasons (a) it enables the magnetic excitation using a conventional a/c source (b) the excitation wavelength is approximately 10^7 times larger than the specimen dimension which falls within the validity of the quasistatic approximation for calculation of magnetic leakage field using analytical dipole models [15]. Further, as the thermal diffusivity of metallic material is higher, in a time interval of few seconds the heat waves diffuses through a distance greater than the penetration depth of the particular material corresponding to the applied electromagnetic wave [16].

In the present study, we investigate the effects of non-magnetic inclusions on thermal contrast (temperature difference between the defect and defect-free regions) and temperature decay rates during IRT based defect detection in mild steel specimens. In the previous study [14], the proposed methodology was validated for idealized defects under laboratory conditions. However, during on-site or shop-floor inspection, the components are often contaminated with inclusions, like clay or dirt inclusions in the defects for submerged oil and gas pipelines or slag inclusions in welded specimens. Therefore, an understanding on the effects of such inclusions on thermal contrast and temperature decay rate is a pre-requisite for industrial adaptation of the proposed low frequency alternating magnetization assisted active thermography technique. Such non-magnetic inclusions act as an insulator and do not contribute to the alternating magnetic field induced heating

of the parent specimens. Nevertheless, the presence of such inclusions can modify the surface temperature distribution due to wide variations in the thermo-physical properties (like thermal conductivity, specific heat, density etc.) with respect to the parent metal. Although in an earlier study, the influence of external magnetic field on defect contrast during induction thermography was investigated [17], the influence of non-magnetic inclusions on IRT based defect detection sensitivity is not attempted. The main objective of the present study is to elucidate the effect of non-magnetic inclusions on thermal contrast and the defect detection sensitivity.

Rectangular slots of various depths were fabricated in four mild steel specimens and the slots were filled with three different non-magnetic inclusions, viz. clay, grease and wax. The specimens were subjected to a 50 Hz alternating magnetic field which caused the specimen temperature to rise due to Joule's heating. The observed thermal contrast and defect detection sensitivity with inclusions have been explained using the thermo-physical properties of the inclusion materials.

2. Materials and experimental methods

2.1. Materials

Four mild steel specimens with artificially made rectangular slots of various depths were used in the present study. The depths (and widths) of the rectangular slots for the specimens A1, A2, A3 and A4 are 8.0 mm (3.0 mm), 3.3 mm (3.0 mm), 3.0 mm (5.5 mm) and 5.0 mm (3.0 mm), respectively. Three different non-magnetic inclusions, viz. clay, grease and wax were used for filling the rectangular slots. The thermal conductivity (k), density (ρ), specific heat (c), diffusivity ($\alpha = k/\rho c$) and effusivity [$e = (k\rho c)^{0.5}$] of clay, grease, wax and mild steel are shown in Table 1 [18–24]. Defect and blind sides of the specimens were black painted to increase the surface emissivity.

2.2. Experimental methods

The rectangular slots were filled with the non-magnetic inclusions. Care was taken to avoid formation of voids within the inclusions. The specimens with non-magnetic inclusions were dried at normal room temperature (30 °C) for a day before applying black paint on the defect side of the specimens. Before each experiment, the samples were thoroughly cleaned with water and acetone to remove residual contaminations. A low frequency magnetizing yoke (MAGNAFLUX, Model: Y7, 220 V, 2.5 Amp, 50 Hz) was used for magnetizing the specimens which were placed in between the two arms of the magnetizing yoke in such a way that the applied magnetic field lines cut across the rectangular slots. The

Download English Version:

<https://daneshyari.com/en/article/8146952>

Download Persian Version:

<https://daneshyari.com/article/8146952>

[Daneshyari.com](https://daneshyari.com)