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Infrared Thermal Wave Nondestructive Evaluation for Antioxide Coating on Metal Substrate

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Abstract

A novel infrared thermal wave nondestructive evaluation technique is introduced for coating quality control. Two groups of antioxide coating samples were detected with this method. In this method, a visible light pulse is heated on the surface of the sample and an infrared camera monitors the surface temperature field change continuously. Then the computer analyzes and processes the thermal images for detection. In this experiment, for the coating thickness is range from 10 to 120μm, the capture frequencies of infrared camera were set at 166Hz with whole frame window 320×240 pixels and 900Hz with reduced window 320×15 pixels. Therefore, the high resolution thermal images and temperature change curves were given. The results show that the coatings with different thickness can be distinguished under the frequency of 166Hz for 10-120μm and infrared thermal wave nondestructive evaluation technique is an effective method for rapid, large-area, real-time coating quality detection. But for higher precise and quantity measurement, the narrower pulse length and optimized algorithm is required.

Key words: coating, thickness, thermal wave, nondestructive evaluation

1. Introduction

Coatings are applied on material surfaces to provide as appearance that relates to the color dimensions and the geometrical aspect that features haze and gloss. And protection, presented by its ability to protect against corrosion, and others. The bodies painted with an antioxide coating in order to protect them and increase their durability. Usually, the coatings are so thin in the micron dimension. Well, some of the traditional destructive and nondestructive methods are not suitable for nowadays quick, big-area, real-time detection.

Infrared thermography has two advantages as an inspection method for coated structures: no contact with the surface, enabling it to be applied in wet and dry settings, and area coverage enabling it to be applied in large structures such as, ships, ballast tanks and bridges. But for so widely material and functional coatings, this technology also has its limitations. For a given coating, there is prophasic work to do to make sure that this coating is suitable for the infrared thermal imaging. Usually for a given coating material, we need standard coating

thickness samples with the same coating material. In this paper, we discuss two group of antioxide coating samples thickness detection with this new technology.[1-2]

2. Principle

Basically, pulsed infrared thermography consists to briefly heat the specimen and then record the surface temperature decay. The temperature of the material changes rapidly after the initial thermal pulse because the thermal front propagates, by diffusion, under the surface and also because of radiation and convection losses. The presence of a defect reduces or accelerates the diffusion rate so that when observing the surface temperature, defects appear as areas of different temperatures with respect to surrounding sound areas once the thermal wave has reached them. Consequently, deeper defects will be observed later and with a reduced contrast. In fact, the observation time t is function (in a first approximation) of the squared of the depth z:

$$t \sim Z^2 / a \tag{1}$$

where a is the thermal diffusivity of the material.

In effect, defect detection in pulsed thermography can be thought of as identification of areas where the 1-dimensional assumption breaks down. In principle, detection of the separation between normal (1-dimensional) and anomalous cooling should be simple, and in fact, this is the case for large or very near surface cases. However, as one attempts to detect smaller, deeper defects, or detect the presence of walls, where no deeper reference area exists, the effects of IR camera noise and instability, as well as the random structure (e.g. fibers, porosity, granularity) found in many samples, significantly complicate and limit the ability to discriminate between intact areas and boundaries. Some degree of improvement obtains by considering the time evolution of the surface temperature in the logarithmic domain.[3]

In the logarithmic temperature as time change curves, curves of different thickness samples will deflect from each other at different times. And usually, they deflect at different times in regularity according to their thickness. For a certain coating material, given at least two standard thickness samples, find out the deflection time based on the LogT-logt curves, next plot the thickness calibration curve. Then, other coating thickness products with the same coating materials can be measured.

Fig. 1 and Fig.2 demonstrate the method of paint thickness measurement. The sample is a 10cm×10cm square. Four equally divided regions are uniformly painted with white paint over 1.7mm aluminum substrate. The paint layers over different regions have different thickness(5mil, 10mil, 20mil, and 40mil). To show how different paint thickness causes the temperature difference at sometime after the flash, the nominal paint thickness of each region is indicated and the data taken from four numbered small regions are used for logarithm temperature-time plot shown in Fig.1. Region1 to 3 break away from reference (region 4) at different time which indicate different paint thickness. Fig.2 is the plot of squared paint thickness vs. the breaking time. Note that even the linear relationship between the thickness square and the breaking time has been proved to be very consistent, a well characterized standard is still required to make absolute measurement.

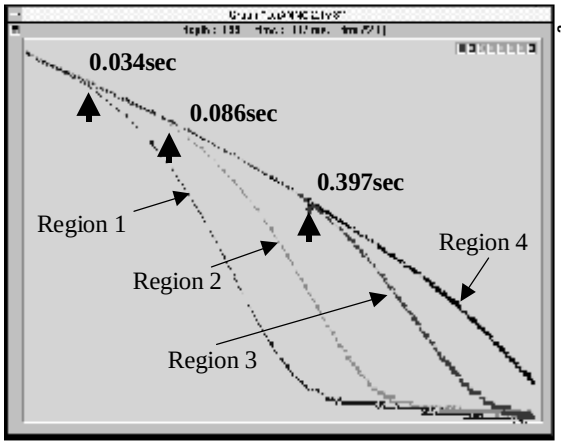


Fig.1 Logarithm scales for infrared camera signal as time change curves.

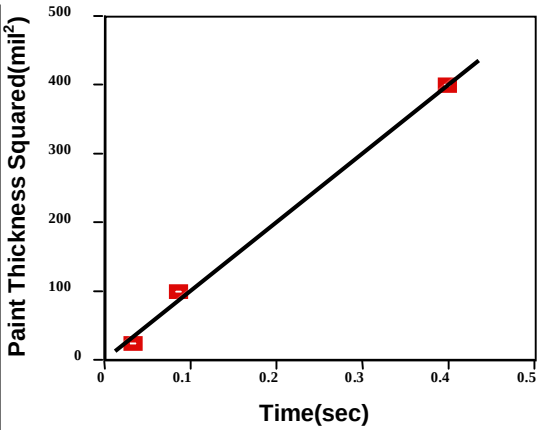


Fig.2 Squared paint thickness vs. breaking time from the reference

3. Experiments and Results

3.1.1 Sample description

Fig.3 is the photo of four antioxide coating samples. Sample (a) is not painted. The thickness of (b)(c)(d) is measured by other method seen in table.1.

Table.1 the thickness measured by eddy nondestructive method

Sample No.	(a)	(b)	(c)	(d)
Coating thickness/μm	/	48-55	78-91	115-125

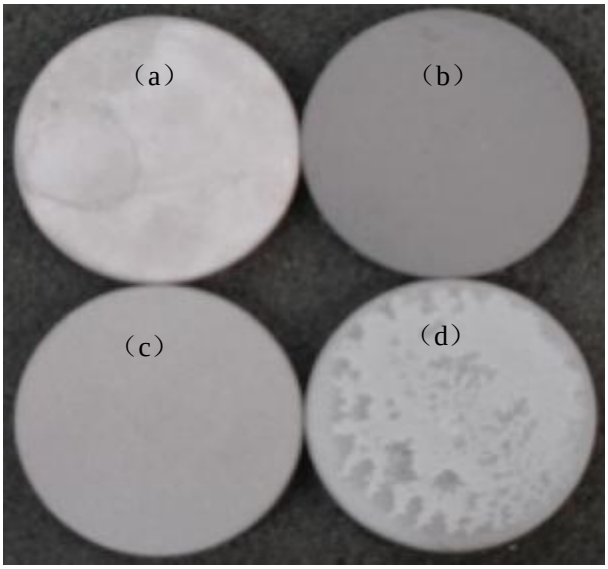


Fig.3 the photo of the samples

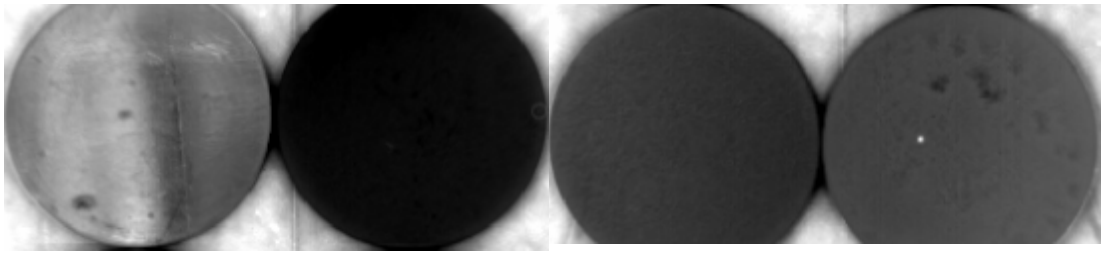
3.1.2 Experiment condition

ThermoScope Ⅱ system, pulse energy is 2.4KJ, the capture frequency of CEDIP camera is 166Hz with 320×240 pixels. The total capture time is 5 seconds.

3.1.3 Thermograph analysis

The thermograph is gray scaled, the lighter one pixel is, the higher the temperature is. Fig4 is the thermograph at 0.03s after flash. In fig.4, Sample (a) is lighter than others because the pulse light is reflected by its metal substrate without coating. While the gray level distributes according to the thickness of coating on sample (b),(c),(d). With the same unit

heat on the surface, the thicker the thickness is, the more time it costs to conduct to metal substrate.



（a） （b） （c） （d）

Fig.4 thermograph at 0.03s after flash

3.1.4 Measurement result

For each sample, we select 7×7 pixels area to plot the logT-logt profile, seen in Fig.5.

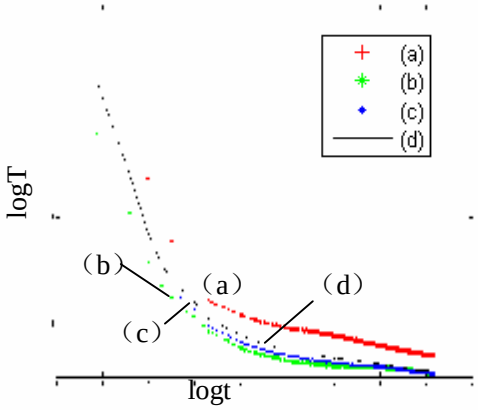


Fig.5 166Hz, logT-logt curves

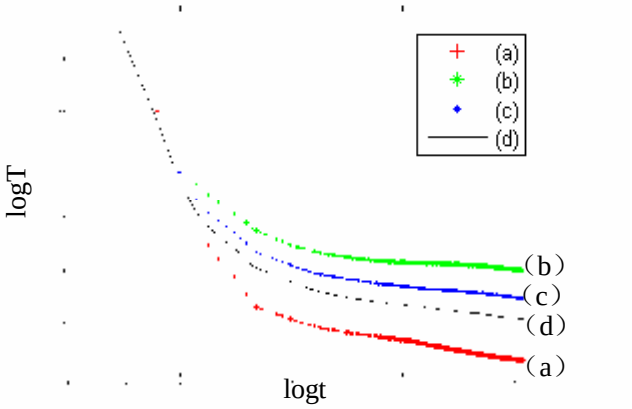


Fig.6 normalized logT-logt curves

In Fig.5 y axis is the logarithm of temperature, x axis is the logarithm of time. We can see the surface temperature of sample (a) is higher than others. So, usually in the coating thickness measurement, we ignore the sample without coating. Based on the thickest thickness coating curve as reference, we find out the deflection time when every other curves deflect to the reference. Because the surface condition or the heat source is not so uniform, the initial temperature is not the same for all of the samples. Fig.5 is not easy to find out the deflection time. Fig.6 is the normalized curves. We can see (b) first deflect to the reference, then (c), (d). But if we want to get exact time, we need much higher frequency to capture the quick change in these coating.

3.2.1 Sample description

Fig.7 is the photo of the second group of four antioxide coating samples. The diameter of the sample is 4cm.

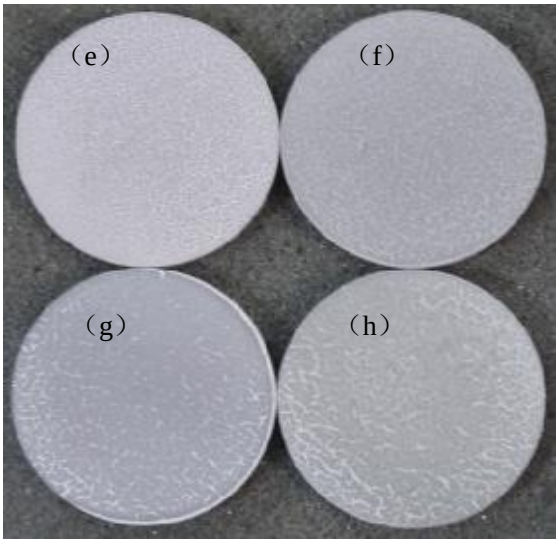


Fig.7 the photo of the samples

The thickness measured by eddy nondestructive method is listed in table 2. In each coating sample, there are five points data for traditional eddy method is a single point measurement.

Table.2 the thickness measured by eddy nondestructive method

sample	(e)	(f)	(g)	(h)
coating thickness/μm	46	71	86	123
coating thickness/μm	45	71	97	120
coating thickness/μm	47	75	95	130
coating thickness/μm	47	70	85	120
coating thickness/μm	44	69	98	124

3.2.2 Experiment condition

ThermoScope Ⅱ system, pulse energy is 2.4KJ, the capture frequency of camera FLIR SC3000 can be achieved to 900Hz with the reduced window 240×15 pixels，the effective detected area is only 15×0.7cm.

3.2.3 Thermograph analysis

Because the field limitation caused by the high capture frequency, we put the four sample in a line. The thermograph only is the partial of the four samples. Fig.8 is the thermograph at 0.001s to 0.017s after flash. The thermograph time resolution is 0.001s. From it we can see the fine distinction. At the time of 0.001s, the gray level is increase according to (e)(f)(g)(h) thickness. The following two frames can distinguish coating thickness. While the (h) is the thickest one, at the sixth frame it continues to keep the highest temperature. After that, heat quickly conducted in the metal substrate and four samples nearly get to the thermal balance. In the thermograph, the gray levels of them are nearly the same.

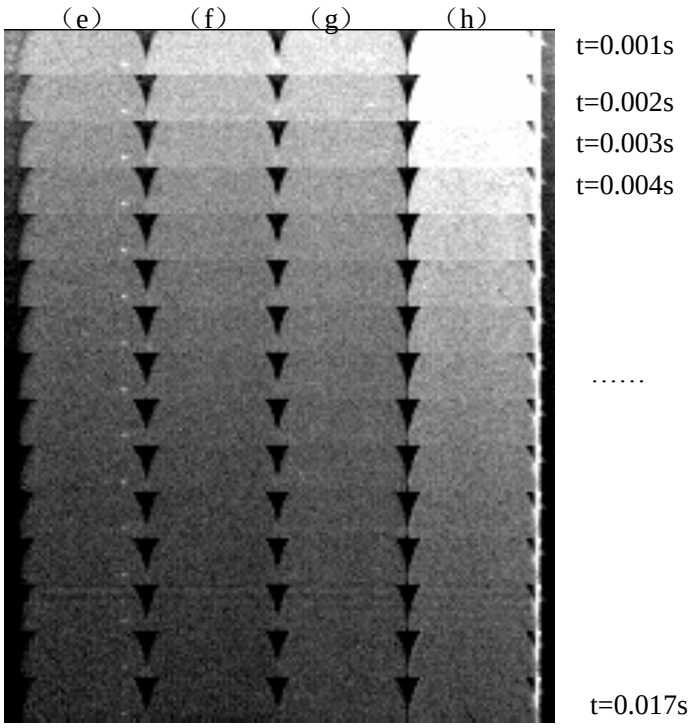


Fig.8 thermograph at 900Hz

3.2.4 Measurement result

For each sample, we select 7×7 pixels area to plot the logT-logt profile, seen in Fig.9. The sample (h) with the thickest coating thickness is on the upper of the curves, while (e) is on the lowest. (f) and (g) are so closed. As the same process method to the first group sample, we normalized the curves, seen in Fig.11. Sample (h) as the reference, (e)(f)(g) at the different time deflect to the reference. After this deflection time, heat conducted to the metal substrate, the slopes of the curves increase obviously. Finally, all samples become to the thermal balance. After changed the samples' location in the filed in order to get the different area of the samples, the results are the same.

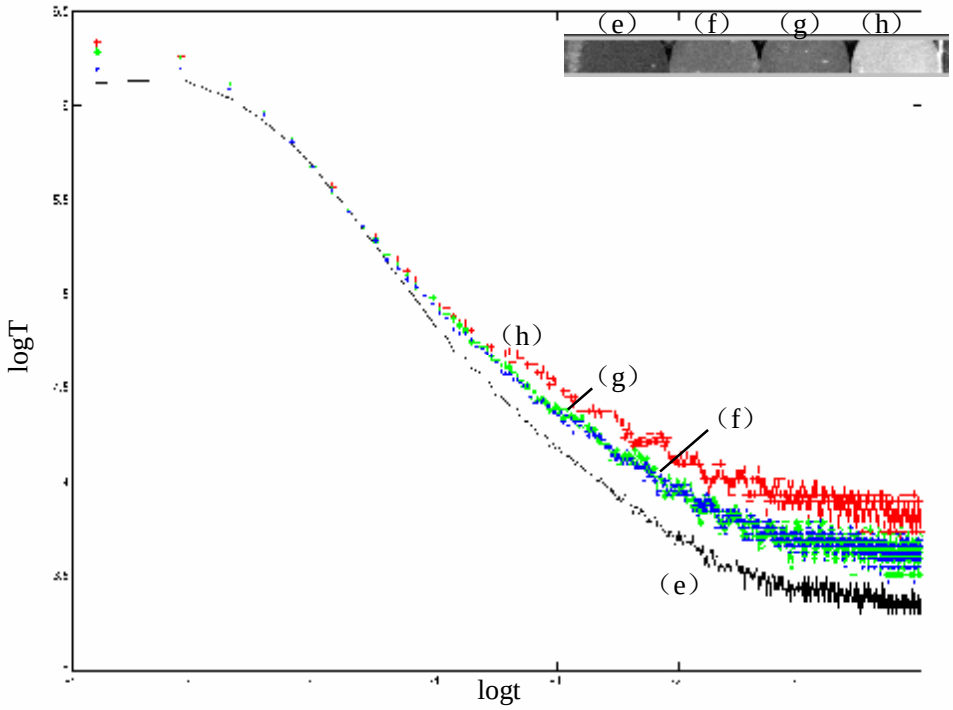


Fig.9 900Hz, logT-logt curves

4. Conclusions

From the experiment results, we can see the micron dimension coating thickness in thermograph series. But as to the quantitative measurement, we can't see the exact deflection time from the logT-logt curves.

The problem may be the pulse width is too long which is longer than the time interval between two successive frames. And the camera work wavelength is a critical factor for coating thickness measurement.

Acknowledgment

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