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Finite Element simulation and Experimental verification of Infrared Thermal Wave Non-destructive Inspection for the Defects in Welded Joint

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Abstract

Finite element analysis software is used in this simulation ,we design some defects which have different type dimension, and depth in weld with the preprocessor of the soft, heat flux is imposed on one surface where was welded , surface temperature distribution of tested object is computed , cloud maps of surface temperature distribution are obtained by general postprocessor , more creditable message about defect is obtained qualitatively and quantitatively according to thermal character and surface temperature rise . The emphasis is placed on the relationship between the type, dimension and position of defect and the surface temperature rise. In experiment, using the infrared thermal wave nondestructive detection system for steel with weld involve with defects, the high resolution thermal images and temperature change curves about defect in weld were given. The results is that defects in the weld with type, dimension and position can be extracted. The last, the simulated results compare with the experiment results, the conclusion is that two results is validated on each other providing foundation for the establishment of exact and reliable testing standard.

Key words：Finite Element, Infrared Thermal Wave Non-destructive Inspection, welded

1．Introduction

Infrared Thermal Wave Non-destructive Inspection offered the best overall performance in terms of repeatability, ability to detect typical defects in both the composite and the adhesive bond, inspection speed, automation potential, and non-contact (i.e. no surface damage to the part) capability. In Active Infrared Thermal Wave Non-destructive Inspection

[1-6], the surface of a solid sample is excited by some means of external energy such as flash lamps, heat lamps, forced hot air, electromagnetic induction, microwaves, ultrasonic energy, etc., and the subsequent change in surface temperature of the sample is monitored using an infrared imager. In this study, Infrared Thermal Wave Non-destructive Inspection using flash lamp excitation was chosen[7].

Reliable thermal models of probe heating would be a useful tool for predicting temperature rise under a range of operating conditions and they may allow manufacturers to determine how design features affect surface temperature. Finite-element modeling has shown promise for the prediction of tissue heating [8]. This paper reports the design and use of finite-element models to simulate the simulate armor plate with welded joint, and the comparison of predictions of temperature rise at the front face with corresponding experimental results.

1.1.Infrared Thermal Wave Non-destructive Inspection theory

Infrared Thermal Wave Non-destructive Inspection is widely used as an NDT method in a variety of applications; for example, see Refs. [9–11]. In Infrared Thermal Wave Non-destructive Inspection, the most common implementation of thermographic NDT, the surface of a sample is heated with a light pulse from a flash lamp array and the subsequent cooling of the surface is analyzed with an infrared camera. The basis of Infrared Thermal Wave Non-destructive Inspection can be best understood by considering the underlying physical process of interaction of the incident heat pulse with a subsurface defect. Immediately after illumination by a spatially uniform light pulse, the thermal response of a semi-infinite, opaque solid sample with an insulating subsurface defect is described by the heat diffusion equation [12]

$$\nabla \cdot \left[\kappa \nabla T(\mathbf{r}, t) \right] - \rho c_V \frac{\partial T(\mathbf{r}, t)}{\partial t} = - f(\mathbf{r}, t) \tag{1}$$

where T(r, t) (K) is the temperature at position r and time t, f(r, t) (W/m^3) is the heat source function which gives how the heating is applied to a medium, (W/m·K) is the thermal conductivity. The product of density (kg/m3) and specific heat cv (J/kg·K) is the volumetric heat capacity which measures the ability of a material to store thermal energy. The ratio of the thermal conductivity to the volumetric heat capacity is defined as the thermal diffusivity (m2/s)

$$\alpha = \frac{\kappa}{\rho c_V}, \tag{2}$$

which measures the ability of a material to conduct thermal energy relative to its ability to store it. will be treated as a constant through the discussion for the purpose of simplicity even though it can be a function of temperature and position. For a given material, larger thermal diffusivity value means faster response to changes of its thermal environment. On the other hand, the smaller the thermal diffusivity, the longer is the time that is required to reach to a new equilibrium condition in the thermal environment.

In the absence of any sub-surface discontinuity, the surface temperature decay depends on the thermal diffusivity of the bulk material. However, when an insulating sub-surface defect or discontinuity obstructs the flow of heat into the sample, the temperature decay is retarded and the surface region above the defect cools at a slower rate compared to the defect free regions. Thus, the temperature–time signal contains information about the thermal properties of the material being inspected, as well as the subsurface defects or discontinuities.

The relative time and amplitude of the measured signal provides information about the depth and size of sub-surface defects. Typically, subsurface defects are viewed by averaging consecutive image frames from the camera, or viewing the slope (time rate of change) of each pixel over a given time interval [13].

1.2 Modeling approach

In an effort to reduce the development time, Finite-element analysis was used to simulate the steel plate with welded joint. This method allows the solution of complex problems which cannot readily be solved analytically. Problems are subdivided and behavior approximated over each small region: The combined response is then assembled from the individual components [14]. This procedure involves many repetitive calculations and is therefore readily implemented by a computer. The accuracy of the solution depends on the order at which terms are ignored and the number of equations formed for the analysis. In practical terms, a geometry (two-dimensional in this case) is constructed and its material properties and boundary conditions are allocated. It is then split into small regions called finite elements which create the equations to be solved. How complicated these elements are relates to the complexity of the equations and the number of elements relates to the number of equations. For a time-varying thermal analysis, the density, thermal conductivity and specific heat capacity of each material is required (to define heat transport in the materials), together with the convection coefficient for each surface in contact with air and the heat generation per unit volume in appropriate volumes. The finite-element solution routines are then invoked and an approximate temperature distribution solution is generated for discrete intervals of time [15].

2．Experimental and Software simulation

2.1 Materials

The Specimen is the steel plate with welded joint (Fig. 1), in welding process, void and inclusion are entrapped, the goal of our experiment is that inspect the defects in welded joint.

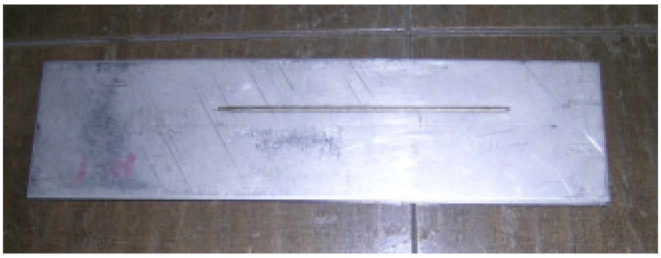


Fig. 1 the steel plate with welded joint

2.2 Equipment

Pulsed thermographic data of the bonded composite p/u box was acquired using a commercial thermographic NDT system, EchoTherm32, Thermal Wave Imaging, Inc.(Fig. 2).

Fig. 2 EchoTherm32 NDT system

2.3 Infrared Thermal Wave Non-destructive Test Results

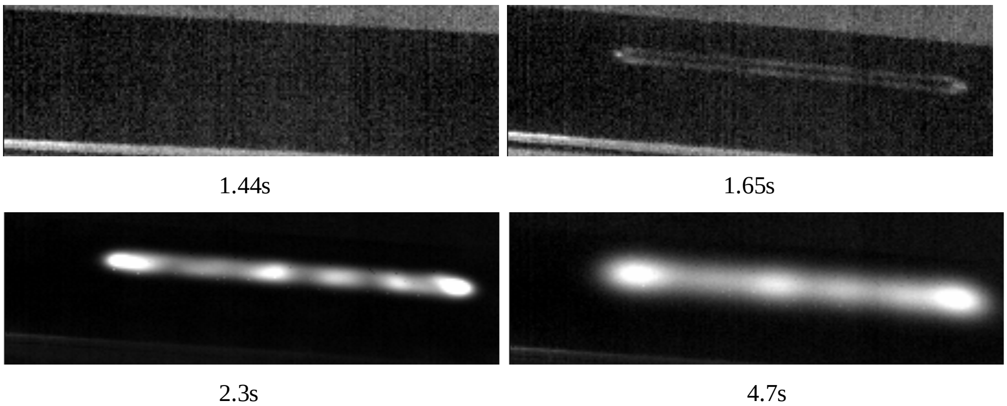


Fig. 3 Ultrasonic-heated thermal wave images of the steel plate with welded joint sample.

Fig 3 shows the thermal images of the steel plate with welded joint sample at different time after the ultrasonic heating pulse applied on its surface at t = 0. The image size is set at 180x118 pixels and frame rate is at 140Hz.The sample surface is anodized to black color to improve its emissivity. The images shown are contrast images. They are obtained by subtract the image frame before the ultrasonic heating pulse from the images after the flash so that only the temperature changes are displayed. It clearly shows the time dependence of the thickness of welded joint.

2.4 Software simulation Results

In Finite element analysis software, we design a model of the steel plate with welded joint (Fig. 4). The red area A3 indicate the heating surface which thermal input is q(q=1×104 W / m2),A1 and A2 indicate the steel , A4 indicate the welded joint.

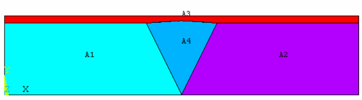


Fig. 4. The model of the steel plate with welded joint

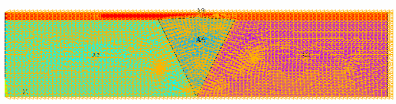
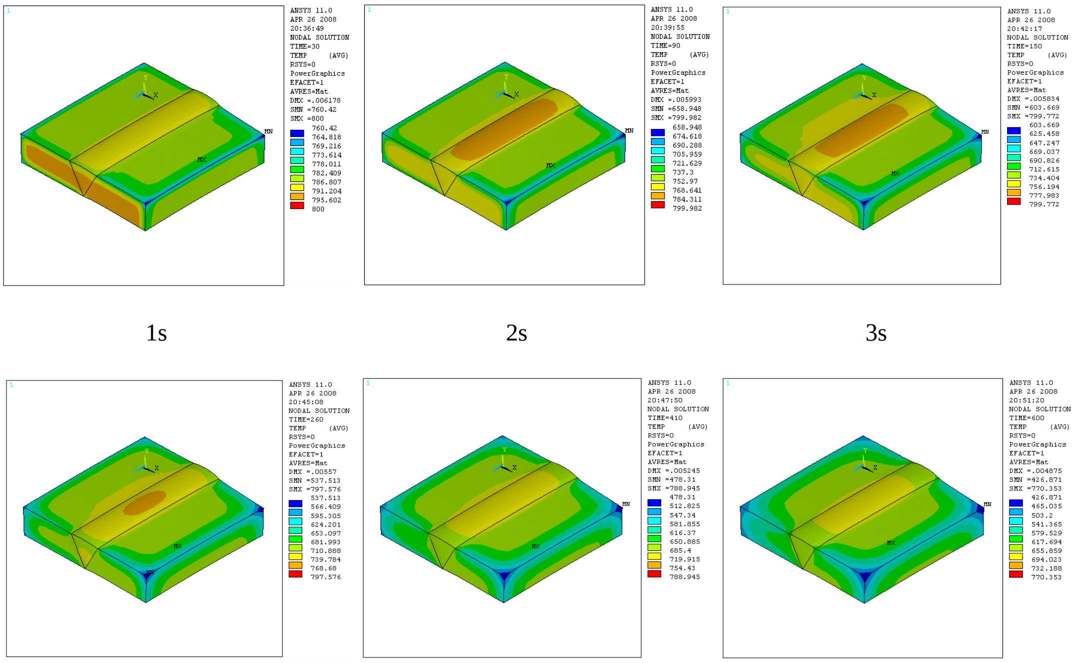


Fig.5. the load of simulation

On the model, we divide the grid that the size of is 0.0001m, then we load the heat flux on the area A3(Fig 5), the temperature of A1,A2,A3 is room- temperature. Finally, we solve the simulation, then get the results.

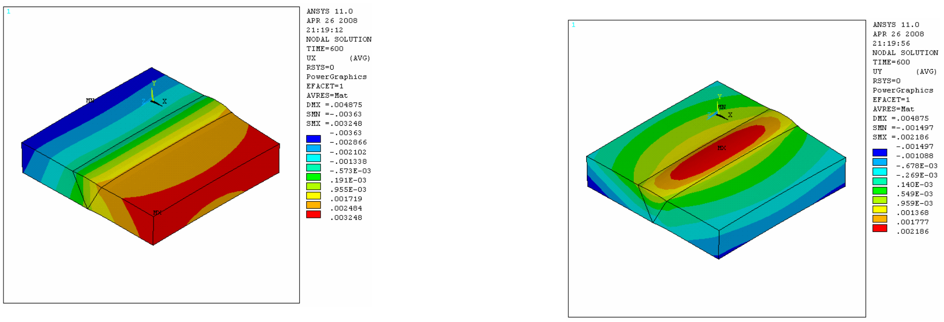


1s 2s 3s

4s 6s 10s

Fig.6.The equivalent diagram of temperature field profile about the model

From the results (Fig 6), we can see that the temperature distribution on the welded joint is different on different position, as variation of the metal's characteristic, thermal diffusion coefficient has changed. from the Variation of stresses field profile(Fig.7.) about the model, we can see the position which defects emerge easily, when use the infrared thermal wave nondestructive detection technique we can prompt find monitoring point.



(1) Variation of stresses in X direction (2) Variation of stresses in Y direction

Fig.7. Variation of stresses field profile about the model

According to date getting from general postprocessor of the software, we draw up the cooling curves of a point on heating plane (A3), and the rise in temperature curves of a point on surface of the mode (A1)l(Fig.8.).we select two points on the steel plane, one point on the plane A1, the other on welded plane(A4), then draw the cooling curves(Fig.9.) of two points, on the curves we can see that the slope coefficient about the curves is different, according to the differences of the slope coefficient, we can identify the thermal characteristic, this can supply the assistance for the infrared thermal wave nondestructive detection.

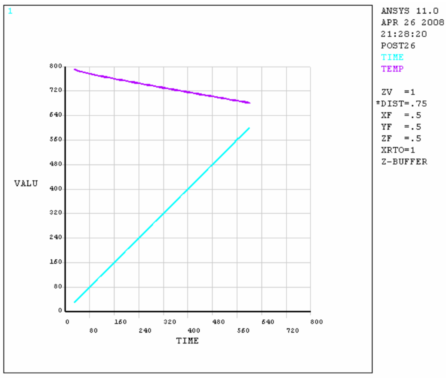


Fig.8. The curves of cooling on heating plane and rise in temperature on surface of the model

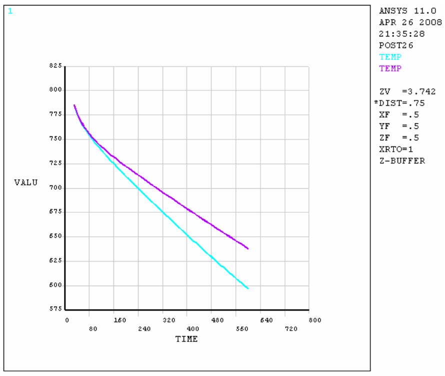


Fig.9. The curves of cooling about different point onsurface of the model

3. Conclusions

The uniformity materials with different characteristics we are selected by means of the finite element analyze software (ANSYS) , and a 3-D sample model was designed to provide the detection with preview of the previous experiment result. The temperature field profiles of the model surface are drawn at different times with the preprocessor and general postprocessor of the software, and then the defect position are confirmed according to the given temperature distribution diagrams. The curves of temperature variation of different defects are drawn based on the analysis of the simulated data. The defect types are determined according to the different slope of the curves. The simulation result indicates that the finite element analyze software can be used for nondestructive evaluation, the simulation result matches with the experiment one. The method can be extended to the detection and the quantitative identification for other kinds of defects under material surfaces.

Acknowledgment

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