Abstract

The ultrasonic infrared thermal wave method is a new nondestructive testing technique. It is remarkably sensitive and convenient for detection of small vertical cracks, such as fatigue cracks in metals. Pulses of ultrasonic launched by the ultrasonic emitter as heat source are excited into the sample, if there are some cracks in the material, they will be revealed through their heat generation, as the resulting surface temperature distribution which is observed by an infrared camera. A computer collects and processes the thermal images according to different properties of samples to get the satisfied effect. In this paper, firstly, a steel plate and an organic glass plate with fatigue cracks we designed were tested, the thermal image showed the subsurface cracks intuitively. Then we tried to test five laser welded seams which are welded by different welding powers, and the results gave some advices in selecting of laser power, which is an important factor in evaluating the quality of the welded seams. The ultrasonic infrared thermal wave nondestructive detection promises to be a sensitive, fast, wide-area, intuitively interpretable nondestructive evaluation technique that can be used on a wide variety of materials. It is significative for the nondestructive testing in manufacture produce and applications of aviation.

Key words: ultrasonic infrared thermal wave, nondestructive evaluation, crack, laser welded seam

1. Introduction

With the development of some new technologies, such as aviation, the requests of security and reliability become higher and higher. Although some traditional nondestructive technologies, such as ultrasonic, whirling current, X-radial and magnetic particle testing, are applied widely, some limitations and shortage are also apparent. So many new technologies in this fields emerge end to end[1].

In recent years, thermal wave imaging technology has been successfully applied to many kinds of materials, such as metals, ceramics, polymers, composites, thin films, coatings and even biological samples[2-3]. Ultrasonic infrared thermal wave technology which is sensitive to fatigue cracks hided in the sample use ultrasonic as heat source. Because ultrasonic wave can spread quickly in the sample, the crack in the sample can usually be detected less than 1s. It has the obvious advantage compared with some traditional technologies (whirling current, X-radial, and so on). It requires no fluid or magnetic particle intrusion, and requires no...
penetrating radiation\textsuperscript{[4]}. Also compared with the flash light impulse method, which heat the whole surface of the sample, the ultrasonic infrared thermal wave technology only make use of the heat origins from the friction of the flaws in the sample. So it can heat the flaws selectively, and the heat wave can’t be influenced by interference or nestification during its transmission to the surface of the sample. So the changes of the sample’s surface temperature are more obvious, and the Signal-to-Noise of thermal image will be higher.

2. Fundamental Principle

After the ultrasonic impulse generated by the ultrasonic gun induced externally to a sample, the ultrasonic wave which carried energies can transmit rapidly in the sample. In most solids, the transition of acoustic wave is almost instantaneous (for example, the velocity of acoustic wave in the steel sheet is about 6km/s, i.e. acoustic wave can transmit 100m in the intervals of two frames of an infrared camera whose frame frequency is 60Hz). So, for some samples, the ultrasonic wave can create effective heat exiting in a location which is far away from the excitation source.

When the ultrasonic waves transmit into the defects, its mechanical vibration will decay rapidly. It is primary because the friction between the interface of the cracks, or the elastic property of the non-uniform areas is much more different than any other areas, consequently, thermoelastic effect and hysteresis effect are generated. Because of direct conversion from mechanical to thermal energy, heat is released by friction precisely at locations where defects such as cracks and delaminations are located. Flaws are exited at specific mechanical resonances. So it can heat the cracks selectively, and the signal-to-noise of result is much higher.

As soon as the ultrasonic power is excited into the sample, the infrared camera controlled by the computer begins to collect the thermal information of the surface of sample. The information got by the camera will be sent to the computer, and then the sequence of the thermal image will be shown visualized after analyzed and processed by the special software, so that the size and position of the cracks in the subsurface of the structure can be identified. The sketch map of the principle of ultrasonic infrared technology is shown as fig.1.

3. Experimental Setup

The chief parts that build up the typical ultrasonic infrared thermal wave NDE system are the ultrasonic excitation system, IR camera and the computer. The sketch map of experimental setup is shown as fig.2.

The source of ultrasonic excitation is a Branson, Model 2000aed 20 KHz ultrasonic welding generator. The model of infrared camera is JADE III, which has an array detector size of 320×240 elements, and has a temperature resolution better than 0.02 degree Kelvin. The collecting frequency and time can be adjusted, and its work wave range is 3.7\(\mu\text{m}\) to 4.8\(\mu\text{m}\). We use special software to analyze and process the digital information.
4. Experiment and Results

4.1 stainless steel plate

Fig.4 shows the photo of the stainless steel plate whose area is 86.5mm × 60mm. There is a man-made crack which is approximately 20 mm long extended from the hole in the stainless steel plate.

![Fig.3 The photo of the stainless steel and the sketch map of the crack](image)

Use a bench clamps to fix the sample in order to ensure the sample can’t move while the ultrasonic is being excited in. The distance between the IR camera and sample is about 40cm. Then open the computer and ultrasonic device, adjust the position of IR camera so that the sample has suitable position in the field of view, and adjust the focal distance of IR camera. The ultrasonic weld time is 0.05s, and the force we used is 44N. The IR camera uses the frame frequency of 50Hz to collect thermal information in 8s. Fig.4 is the sequences of the thermal images.

As can be seen from Fig.4, after the ultrasonic power was excited into the sample, the vicinity of the crack was heated up by friction or thermoelectric effect and hysteresis effect, as the bright area shown in the first and second frame. The shape and position of the crack can be seen clearly.
4.2 organic glass plate

The sample is an organic glass plate whose area is 120mm × 80mm. By way of illustration, in fig.5 we show selected frames from a sequence of Sonic IR images taken of the fatigue crack.

The first frame in this sequence was recorded prior to turning on the heat pulse. The next three frames show the initial heat generation in the vicinity of the crack, as the sound pulse is turned on. The crack appeared distinctly. The last two frames show the progressive thermal diffusion and return towards thermal equilibrium.

4.3 laser welded plates

There are five laser welded plates, all of them are two stainless steel plates welded together by a line of laser. The width of the weld line is about 1mm, and the welding velocity is 4m/min. The laser powers are respectively, 2.8KW, 3.2KW, 2.4KW, 2.0KW, 2.6KW. The photo of one of the samples is shown as Fig.6.

The rear face of the welded seams is lacquered to increase infrared reflectance in order to reduce the experiment error because of the reflecting surface. The force we used in this experiment is 200N, ultrasonic weld time is 0.3s, and the frame frequency of the IR camera is...
100Hz. The thermal images of the welded seams are taken after the sound pulse is excited into the sample for 0.8s, as Fig.7 shown.

![Front face of the weld seam](image1.jpg)

![Rear face of the weld seam](image2.jpg)

**Fig.6 Photo of the welded seam**

![Thermal images of the welded seam](image3.jpg)

**Fig.7 Thermal images of the welded seam**

We can see from Fig.7 that there is a dark-line in middle of every welded seam and a bright region around the dark-line except 4# sample. The dark-line indicates that it is bonded tightly, because the friction and acoustic impedance is small, no heat generated in the middle of the seams. Around the dark line is the transitional area of the welded seam and no welded area, the two steel plates are not welded together completely but just contact with each other. The ultrasonic energy can cause friction of the transitional area and then transform to heat. So the temperature of the area which is bright in the figure is higher.

But there’s no dark-line in 4# sample, indicating that the welded seam is not bonded tightly, the laser power is too low to penetrate the stainless steel completely. The quality of the weld seam is not satisfied.

How to identify the condition of over-burning according to thermal image needs further research.

### 5. Conclusion

In this paper, it gives an introduction of the sonic infrared thermal wave technology according to the principle and experiments. There are many advantages of this technology, it can heat the subsurface cracks selectively, and the signal-to-noise of results is much higher, compared with the flash pulse method. So it is remarkably sensitive and convenient for detection of small vertical cracks, such as fatigue cracks in metals. In a small fraction of a second, such cracks reveal themselves as subsurface thermal wave sources, and are readily detected through the use of IR cameras. It also can be used to test the quality of the welded seams, and gives some analysis and advices of the effects of laser power on the quality of the welded seams. Thus, ultrasonic infrared thermal wave technology promises to be a sensitive, fast, intuitively interpretable nondestructive evaluation technique that can be used on many kinds of conditions.

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Reference