Optics & Laser Technology 43 (2011) 1391–1397

Contents lists available at ScienceDirect

Optics & Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

The experimental study of fatigue crack detection using scanning laser point source technique

Chenyin Ni [a,b], Liming Dong [a], Zhonghua Shen [a,*], Jian Lu [a]

[a] School of Science, Nanjing University of Science and Technology, Nanjing 210094, People's Republic of China
[b] College of Science, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, People's Republic of China

ARTICLE INFO

Article history:
Received 28 April 2010
Received in revised form
13 February 2011
Accepted 5 April 2011
Available online 6 May 2011

Keywords:
Laser ultrasound
Non-destructive evaluation
Surface acoustic waves

ABSTRACT

For the purpose of better understanding the interaction of Rayleigh wave and the fatigue crack in a metallic sample, a set of experimental setups is built, based on the scanning laser source (SLS) technique, utilizing a point source to take place of the line source to generate surface acoustic waves (SAWs), and an interferometer is to detect the SAWs signal. The information of the crack (such as position and length) can be obtained by utilizing a two-dimensional scan of the material surface. This paper focuses on the detection of visible and invisible fatigue crack by using this point-source-based scanning laser source technique, and comparing the results with those of conventional pitch-catch technique. The result shows that with two-dimensional scanning, and analyzing the amplitude of the generated SAWs, not only the visible fatigue can be identified, but also the invisible fatigue crack can be discriminated. As a result, the sensitivity of the scanning point laser source technique is higher than the conventional pitch-catch technique.

1. Introduction

A surface breaking crack is a kind of flaw in the surface of the material caused by surface strain. Once it occurs, the stress underneath the crack caused by outside force will make it grow fast, finally resulting in material rejection. In this case, the inspection of the surface breaking cracks, especially the non-destructive evaluation (NDE), now plays a very important role in industrial fields [1–3].

The surface acoustic wave (SAW) is suitable for surface crack evaluation due to its high sensitivity to the surface crack. The pulsed-echo and pitch-catch techniques in far-field are the main techniques [4–6] in surface breaking crack non-destructive evaluation using laser generated SAWs: detecting and evaluating cracks according to the far-field characteristics of the SAW when the generating laser is far away from the crack area. There are two main ways: one of which is evaluating the surface crack by detecting and studying the change of the signal noise ratio [7], especially the amplitude change when the Rayleigh wave interacts with the surface breaking crack; and the other is the time-of-flight diffraction (TOFD) technique [8]. The accuracy of the former method relies on the signal noise, and the change of Rayleigh wave amplitude is too weak to be identified when the crack size is much smaller than the wavelength of the Rayleigh wave so that this technique is not suitable for small crack evaluation. TOFD technique evaluates the surface breaking crack by identifying the propagating time of ultrasound wave diffracting from the crack tip. This technique has a high accuracy in crack length and depth evaluation because it utilizes the propagation time instead of signal amplitude. However, these identification methods can be easily affected by the crack orientation, and only fit in detecting the crack that has the same magnitude with the ultrasound wave in size.

In order to improve the crack detection capability, a scanning laser line source (SLLS) technique was reported by Kromine et al. [9]. A pulsed laser line source is employed to scan over the top surface of a specimen in the direction normal to the length of the line source. Detection point is located several millimeters away from the generating area to receive ultrasound wave signals. When the laser source scans to the near field of the crack (within 1 mm), the signal enhances rapidly and the center frequency signal changes significantly determining the crack location. At the same time, the amplitude of ultrasound wave generated is not easily affected by the crack orientation, so the sensitivity is improved effectively. Mass spring lattice model is provided by Sohn and Krishnaswamy [10–12] to simulate the mechanism of SLS technique generating SAWs. Cooney and Blackshire [13] evaluated the cracks in aerospace material by using the scanning laser line source technique.

Though the scanning laser line source can evaluate the crack effectively for evaluating cracks with much shorter length compared to the line source, or some cracks "attached" on some other geometry, this technique is not sufficient. For example, if the crack grows along the tip of an artificial slot, due to the length of the line source, it is hard to distinguish if the reflection is from the slot or from the crack. Moreover, these limitations for detecting with line source could bring some "blind areas" when using the

* Corresponding author.
E-mail address: shenzh@mail.njust.edu.cn (Z. Shen).

0030-3992/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.optlastec.2011.04.003

line source utilizing a 2-D scan on the sample surface. In this paper, based on the scanning laser source technique, the point laser source is used instead of the line source. By doing so, one can not only avoid the "blind areas" when employing the line source in 2-D scan, but the length of the crack can also be evaluated, which is not possible using line source. In order to do this, a set of experimental systems for detecting the ultrasound wave generated by scanning laser point source in steel specimen with crack are built, and through the experimental result, the sensitivities of conventional pitch-catch method and the scanning laser point source technique to artificial slot, visible fatigue crack and invisible crack are studied.

2. Experimental setup and methods

2.1. Sample preparations and parameters

Two samples used in this paper are high strength steels with size 130 mm × 30 mm × 15 mm. In each sample, there is an artificial slot made by wire-cutting, with the length of 13 mm, width of 100 μm, as shown in Fig. 1. Pressure loads were applied on both samples, which were then observed and photographed with a microscope; the photographs are shown in Fig. 2(A) and (B). It is easy to see that in sample A, there is a fatigue crack at the tip of the artificial slot, while in sample B, such a fatigue crack is absent.

2.2. Experimental system and method

The experimental system for detecting the ultrasound wave generated by scanning laser source in steel specimen was built. Fig. 3 is the schematic diagram of the measurement setup. Pulsed laser with a wavelength of 1064-nm and repetition rate of 5 Hz was generated by a Nd:YAG laser (DAWA 100 made by Beamtech), attenuated and focused into a point source after a set of a prism and a cylindrical lens were placed on a precise motorized translation platform to achieve scanning detection. The energy of the pulsed laser was 0.4 mJ, which is insured to generate the ultrasound wave in the thermo-elastic mechanism. A photodiode with a rise time of 100 ps obtained the laser beam reflected by a beam splitter and triggered the oscilloscope to record data.

A two-wave mixing interferometer (TEMPO made by Bossanova) was located at the detection point to detect and transform micro deformation to electronic signal. A laser beam with a wavelength of 532-nm irradiated the specimen surface as a detection point. When pulsed laser generated SAWs on the surface of specimen, SAWs

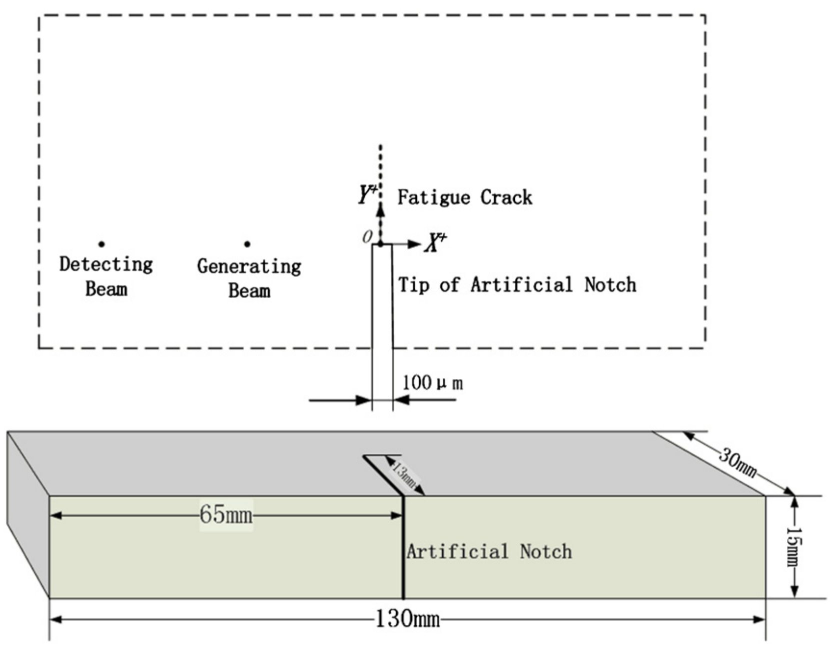

Fig. 1. Schematic diagram for sample surface.

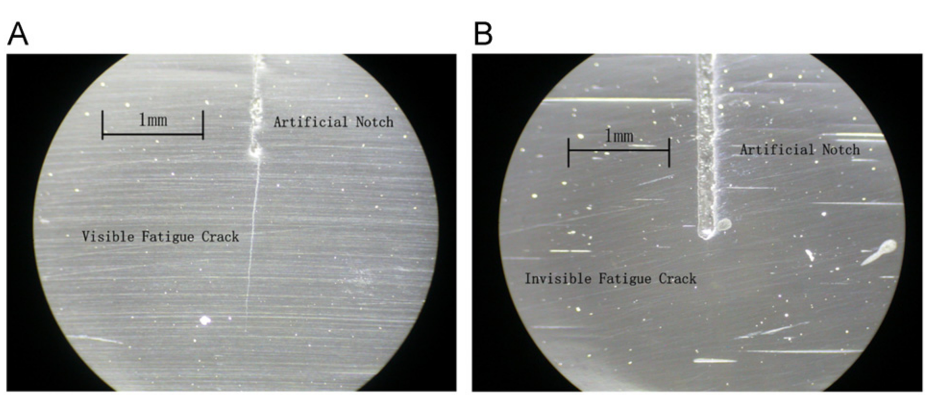

Fig. 2. (A) and (B). Photographs of sample surfaces.