Ultrasonic Stress Measurement using the L_{CR} Wave

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Overview

Ultrasonic stress measurement is based on acoustoelasticity, i. e. the relationship of stress and velocity. One technique uses longitudinal waves traveling parallel to the surface, i. e. L_{CR} waves which also are called surface skimming longitudinal waves (SSLW) and longitudinal surface acoustic waves (LSAW).. These longitudinal waves are the most sensitive to stress. Another techniques (acoustic birefringence) use waves traveling across the stress field and the effect depends on whether the particle motion is parallel or perpendicular to the stress field. Sources of error are in the thickness of the couplant, the distance that the waves travel and any material effects such as texture. Standard errors from ± 3.5 MPa (± 0.5 ksi) ± 41.4 MPa (6 ksi) have been shown, depending on the spacing from the sender to the receiver, These estimates are based on the expected instrumentation error of ±2 ns in reading the wave arrival. Minimal surface preparation is needed, usually just wiping the surface clean. Data collection and analysis can be instantaneous, and setup is usually a matter of less than a minute.

Acoustoelasticity

The equation for calculating stress change ($\Delta\sigma$) from the travel-times (Δt) is as follows:

$$\Delta\sigma = \frac{E\left(t - t_o\right)}{L\,t_o} = \frac{E\,\Delta t}{L\,t_o} \qquad \text{Eq. 1}$$

where E is Young's, L is the acoustoelastic coefficient, which must be determined experimentally for the material, and t_o is the travel-time in stress free conditions. The measured travel-time change (Δt) indicates the stress change. Typically, the probe is calibrated in a known stress free zone of the structure and material being evaluated.

Selected Test Equipment and Results

The fundamental components for the L_{CR} method are shown in Figure 1 where the 50 mm probe is resting on a steel plate with a commercial ultrasonic flaw detector and a laptop computer.

The ultrasonic flaw detector in Figure 1 has a travel time resolution of 7 ns which is suitable for resolving stress changes of ± 172 MPa (± 25 ksi) in steel. A thermocouple measures the probe temperature enabling correction for temperature effects in the polymer wedge. The computer incorporates software which automatically calculates the corrected travel time and the stress change. Where a high speed digitizing card is incorporated in a PC or lunchbox computer, travel time measurements of ±0.1 ns are possible, resulting in greater resolution for the system.

The probe is shown in Figure 2 mounted on a pressure vessel near a weld. The hydraulic pressure may be applied to the probe, pressing the couplant from the contact surface, while, at the same time, rotating the wedges about their contact point center to maintain uniform travel time distance. The results of this test are shown in Figure 3 where data were initially taken at a distance from the weld and the probe moved in increments toward the weld. The stress pattern (using Eq. 1) shows an increase of 198 MPa (39 ksi) toward the weld, which is in very good agreement with results of other researchers using a similar vessel and the blind hole drilling method.

Figure 1 Test setup for L_{CR} ultrasonic stress measurement

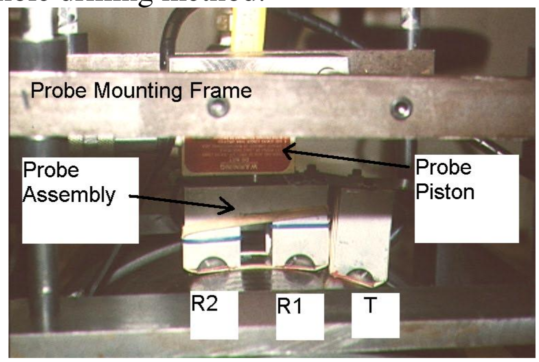

Figure 2 Probe on pressure vessel with hydraulic mounting frame.

Figure 4 shows results from tests on titanium turbine blades where the measured travel times indicated the extent of laser shock peening induced residual stress. Here, the probe was in a single send receive arrangement with a travel path of 25 mm (1 inch).

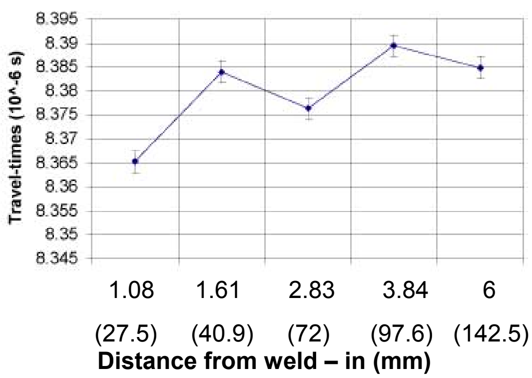

Figure 3 Circumferential travel-times toward weld

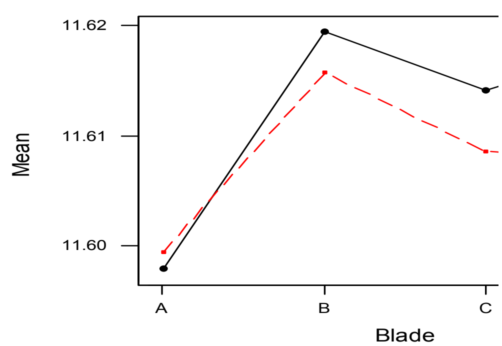

Figure 4 Absolute travel-time (T) from blade group 2 (Set 1 – untreated, Set 2 – treated)

Strengths and Limitations

The ultrasonic technique for stress measurement offers several unique advantages, along with some limitations. The primary advantage is that it can penetrate through the bulk of a material. With acoustic birefringence the wave travels across the thickness of the material and therefore the result is a measure of the average conditions. For the L_{CR} technique, the gradient may be determined by varying the probe frequency and hence the penetration depth in the material. A particular advantage of the ultrasonic techniques is the ease of the measurement which may be made by a well qualified Level III technicians. The technique can be easily integrated with a computer based system enabling rapid data collection and analysis. No special surface preparation is needed, other than wiping the surface free of debris and fluids. The most significant limitations at this time is the limited knowledge of material responses. The acoustoelastic coefficient will vary for different materials and will change depending on crystallographic orientation in metals. Also, there is indication that incorporating a form of surface wave velocity measurement in the process will improve the accuracy of the longitudinal wave methods. These problems will be overcome as the technique is applied to more materials.

Summary

The L_{CR} technique offers a convenient method for nondestructively evaluating stresses in materials, and is particularly suited for measuring stress profiles. While there are many examples of successful application of the technique, there is still much to be done in establishing the exact acoustoelastic constants, the texture effect and the method for accommodating more complex stress fields.

Selected Sources

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