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Direct observation of a laser-excited circular acoustic wave crossing a solid-liquid interface by photoelasticity imagine technique

Quan sát trực tiếp một sóng âm hình cầu sinh ra bởi tia laser đi qua một bề mặt phân cách rắn-lỏng bằng phương pháp quang đàn hồi

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Abstract

The interaction of a laser-excited circular acoustic wave in water on an epoxy-resin surface was studied directly and visually by photoelasticity imaging technique. The result shows the direct image of the pressure wave, shear wave, and Scholte waves, which are the three typical acoustic waves excited when an acoustic wave crosses a solid-liquid interface. This technique provides a clear, whole field image of the phenomena; and is a promising method to study the acoustic phenomena at the interfaces.

Keywords: Photoelastic images; laser-excited acoustic wave; scholte wave.

Tóm tắt

Sự tương tác của một sóng âm hình cầu gây nên bởi tia laser trong nước lên một bề mặt epoxy-resin được nghiên cứu trực tiếp và trực quan thông qua phương pháp chụp ảnh quang đàn hồi. Kết quả cho thấy hình ảnh trực tiếp của sóng áp suất, sóng ứng suất, sóng Scholte, là ba loại sóng điển hình sinh ra khi một sóng âm hình cầu đi qua bề mặt phân cách rắn-lỏng. Kĩ thuật này cung cấp một hình ảnh toàn cảnh rõ nét của hiện tượng, và là một phương pháp triển vọng để nghiên cứu các hiện tượng âm học tại bề mặt phân cách.

Từ khóa: Hình ảnh quang đàn hồi; sóng âm gây nên bởi tia laser; sóng Scholte

1. Introduction

The theory of an acoustic wave across a solid-liquid interface, its experimental studies, and applications have been vastly investigated for decades. However, they are still the objects of several research works because of promising and important applications. It has been known that when an acoustic wave traveling in a liquid interacts with a solid surface, it will excite in the solid the pressure wave (P-wave), shear

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wave (S-wave), and surface acoustic waves (SAWs) [1], [2]. Although it has been well understood, we have yet to have a direct image of the phenomenon. Conventional methods used to investigate the bouncing of an acoustic wave on the solid-liquid interface represent the acoustic waves as electric signals rather than the image of real wavefronts [3], [4], thus unable to provide a direct whole-field image of the phenomena. To investigate the laser-induced shock process, we have developed a custom-designed photoelasticity imaging technique with the unique ability to visualize the transient wavefronts inside a solid target [4]. When applying this technique to observe the coupling of the acoustic wave on a liquid-solid interface, we were able to provide a direct image of the typical acoustic wavefronts excited inside the solid.

In this experiment, we used a nano-second pulsed laser to excite a circular acoustic wave in the water. This circular acoustic wave interacted with an epoxy-resin surface. Photoelastic imaging technique was used to capture the image of acoustic wavefronts excited inside the solid target during the interaction. We report the observed P-wave, S-wave, and Scholte wave with high spatial and temporal resolution.

2. Material and methods

2.1. Laser-excited acoustic wave

A circular acoustic wave was excited by tightly focusing a 60mJ, 1064nm laser beam in pure water. The breakdown in the water induced a plasma of which the expansion led to the formation of a circular acoustic wave. This circular acoustic wave traveled in water before interacting with an epoxy-resin target (5.8x20x28 mm^3). The target surface was roughed to get the roughness of Ra=1mm. The focal position was set 0.5~1 mm above the solid surface.

2.2. Imaging system

The imaging system is similar to our previous report [5], [6] and only a brief description is provided here. We used a pump-and-probe system with a polariscope added to provide a photoelasticity image. An ICCD camera was used together with a set of Neutral-Density filters as a recording device. The camera gate width was 40 ns. The delay time was defined as the interval between the pump and probe pulses and was adjusted by a delay generator. With this system, the observable interval can reach several seconds with a time resolution of 100 ns.

3. Results and discussions

Figure 1 shows a typical circular acoustic wave excited by focusing a nano-second pulsed laser in the water. The black area at the center is the image of a cavitation bubble. The sharp black circle is the image of the excited acoustic wave. Although water is transparent to the wavelength of 1064nm, by tightly focusing the nano-second pulsed laser beam inside the water, the breakdown occurred. After that, the laser absorption by inverse Bremsstrahlung occurred, leading to the formation of a high-temperature, high-pressure plasma. This plasma expanded rapidly and induced a shock wave, which slightly changed into an acoustic wave as propagating away from the focal region.

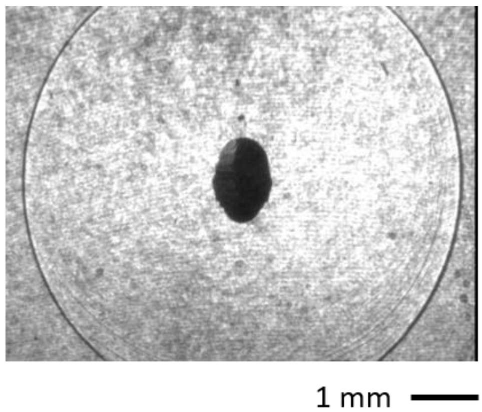

Figure 1: A typical image of a laser-excited circular acoustic wave in water. Delay time: 2000 ns. The laser came from above.

Figure 2 shows the interaction of a laser-excited acoustic wave with an epoxy-resin surface. The delay time is 1500 ns. In Figure 1a, the target was put 1.1 mm below the focal point. In Figure 2b, the target was put 0.6 mm below the focal point. When the circular acoustic wave interacted with the solid target, it was partly reflected back to the liquid as the reflected wave. Because water and epoxy resin have a good match in impedance, the reflected wave is much weaker than the transmitted wave. When the target is 1.1 mm below the focal point, we hardly observe the reflected wave, however, the reflected wave can be seen when the target is put 0.6 mm below the focal point. Since epoxy resin has higher water acoustic velocity, there should be a lateral wave that is tangent to the reflected wave at the total reflection angle. However, this wave was almost not detected in our image.

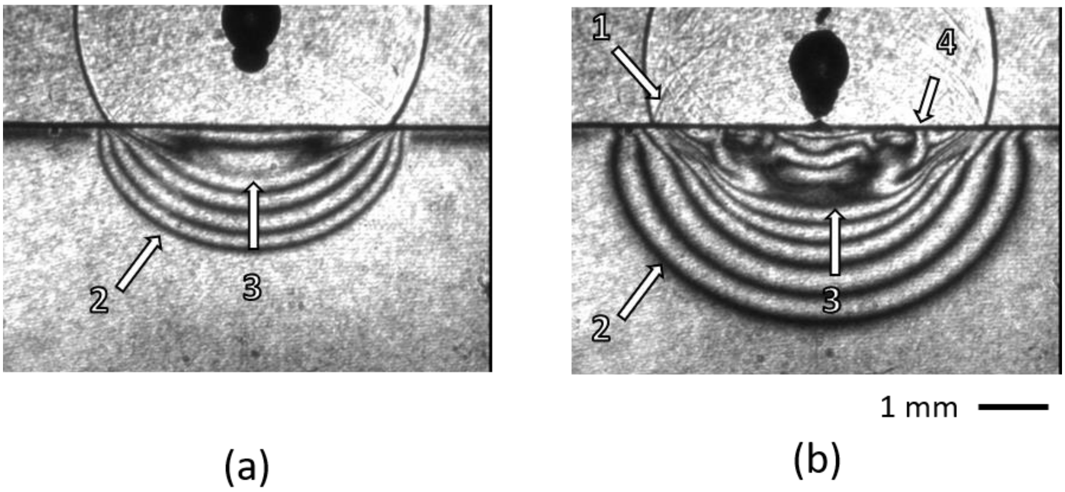

Figure 2: Photoelastic image of laser-excited acoustic waves in the solid. Delay time: 1500 ns. The laser came from above. The focal point is located (a) 1.1 mm above the target and (b) 0.6 mm above the target. The acoustic waves are numbered as 1: reflected wave,2: P-wave, 3: S-wave. 4: Scholte wave.

The acoustic wave transmitted into the solid target induced the stress waves inside the target, which were represented by the sharp, black photoelastic fringes. The fastest wavefront in the solid is the pressure wave (P-wave) which is a longitudinal wave and travels at the acoustic velocity in the solid. The shear wave (S-wave) is a transverse wave and travels at the velocity slower than the P-wave. The S-wave velocity in epoxy-resin was measured in our previous research to be 1120 m/s[7].

At a solid-liquid interface, two kinds of typical surface acoustic waves can be observed. Scholte wave and leaky Rayleigh wave. The Scholte wave always exists while the leaky Rayleigh wave can only exist if the acoustic velocity in water is lower than the shear velocity in the solid. In our experiment, the S-wave velocity is lower than the acoustic velocity in water, which is 1490 m/s, thus the leaky Rayleigh wave does not exist. In our image, the Scholte wave can be detected as showed in Figure 2b. From the image, the velocity of the Scholte wave was estimated to be approximate 1160 m/s, which is close to the shear velocity in the solid. This result agrees with the reported results [2], [8], [9], thus confirming the observed wavefront is Scholte wave.

4. Conclusions

By using a custom-designed photoelasticity imaging technique, we have provided a direct image of the interaction between a laser-excited acoustic wave and a solid surface. The image was able to show clearly the P-wave, S-wave, and Scholte waves, which are the three typical acoustic waves excited when an acoustic wave crossing a solid-liquid interface. This technique provides a clear image of the phenomena; thus, proposes a new and promising method to study the acoustic phenomena at the interfaces.

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