Simulation of laser induced ultrasound in metals by mass spring lattice model

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Laser generated ultrasonic waves is numerically simulated by mass spring lattice model by considering the laser illumination as a vertical force, which is valid in the ablation regime. Few surface acoustic wave modes including surface skimming longitudinal wave, surface skimming shear wave, and Rayleigh-like wave are recorded in aluminum and copper plates. The results indicate that the excitation efficiency of ultrasound in aluminum plate is higher than that in copper plate. The normal component of the displacement at the epicenter has only the longitudinal wave mode and the shear wave mode appears wthen the detection position has a deviation from the epicenter. In addition, the amplitude increases and the arrive time delays with the deviation distance.

OCIS codes: 140.0140, 160.0160.

Mass spring lattice model (MSLM) was presented by K. Harumi[1] early in 1978 to simulate the propagation of ultrasonic waves in solids and the most merit of this method is the flexibility in dealing with the boundary of the solid. This model was accepted and developed in recent years by Yim and Sohn[2] in the field of laser-induced ultrasound in the thermoelastic regime. However, the efficiency of the thermoelastic excitation is low in metals. One of the methods to improve the excitation efficiency without damaging the sample is to add an absorbing layer to the sample surface and it is considered acting as a vertical force like that in the ablative regime. This work paper is to model the generation of ultrasound in metals in this case by a laser line source.

A line-shaped pulse laser illuminates on the surface of an isotropic metal along the z axis so that the MSLM is built in the cross section (x-y plane) of the metal, as shown in Fig. 1.

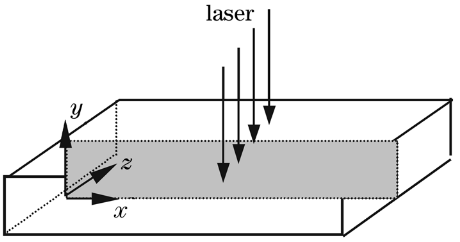

Fig. 1. Schematic of laser line source.

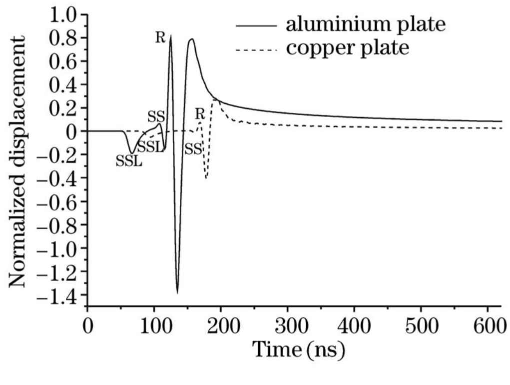

Fig. 2. Surface acoustic waves in aluminum and copper plates. R: Rayleigh-like wave.

The two-dimensional (2D) wave equations can be described as

$$\begin{aligned}\rho\frac{\partial^2 u}{\partial t^2} &= C_{11}\frac{\partial^2 u}{\partial x^2} + (C_{12}+C_{33})\frac{\partial^2 v}{\partial x\partial y} + C_{33}\frac{\partial^2 u}{\partial y^2},\\ \rho\frac{\partial^2 v}{\partial t^2} &= C_{22}\frac{\partial^2 v}{\partial y^2} + (C_{12}+C_{33})\frac{\partial^2 u}{\partial x\partial y} + C_{33}\frac{\partial^2 v}{\partial y^2} + F,\end{aligned} \tag{1}$$

where u and v are the displacements in the x and y directions. ρ is the density and C_{ij} are the elastic constants. The laser acting is considered as a vertical force F. Here, $F = F_0 g(t)$, $g(t)$ can be written as

$$g(t) = (t/t_0)\exp(-t/\tau_0). \tag{2}$$

The idea of MLSM is that the materials are considered as mass lattices connected by ideal springs, the detailed description could be found in Ref. [3]

The wideness and thickness of metal plates in our calculation are taken as 20 and 2 mm, respectively. The calculated ultrasound waves on the excitation sides of two metal plates, aluminum and copper, are plotted in Fig. 2. Since plate thickness is much larger than the wavelength of the generated ultrasound, several modes of surface acoustic waves are detected. The fastest wave mode is the surface skimming longitudinal (SSL) which propagates with the longitudinal wave velocity. It is noticed that, unlike the positive monopolar pulse generated by thermoelastic mechanism[4], this SSL mode is a negative monopolar pulse. The secondly arrived mode is the surface skimming shear (SS) wave propagating with the shear wave velocity. On the neck of this SS mode is a bipolar Rayleigh-like wave with big amplitude. It is clear that the amplitudes of surface acoustic waves in aluminum plate are larger than that in copper plate under the same laser illumination, which indicates the generation efficiency in aluminum is higher than in copper plate.

The bulk waves detected at the epicenter of these two metal plates are plotted in Fig. 3. The arrival time for these bulk waves is 312 ns in aluminum plate and it is 457 ns in copper plate, which coincide the flight time of longitudinal wave propagating a distance of the plate thickness. Hence, only bulk longitudinal waves are detected at the epicenter and they are positive monopolar pulses. In addition, their amplitudes confirm the higher generation efficiency in aluminum plate.

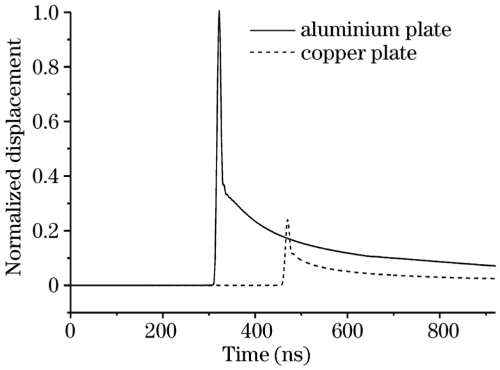

Fig. 3. Epicenter waves in aluminum and copper plates.

We also recorded the displacement waves at 350 and 700 μm deviated from the epicenter position as shown in Fig. 4. Besides the longitudinal mode like that at the epicenter position, a shear wave mode appears when the detection position has a small deviation from the epicenter and this shear wave delays with the increase of the deviation. All these recorded displacement are the y-direction components and the shear mode has no y direction component at the epicenter, therefore, there is no shear wave mode in Fig. 3. When the detect position has a small deviation from the epicenter, the y-direction component of the shear mode occurs and the amplitude increases with the deviation distance.

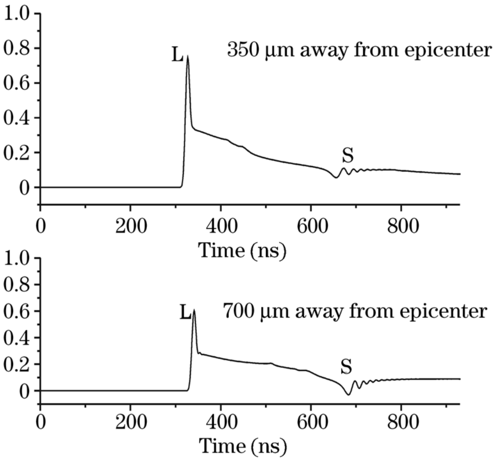

Fig. 4. Normal displacement detected at the back side. L: longitudinal mode; S: shear wave mode.

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