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Numerical Study Of The Propagating Properties Of A Laser-Generated Surface Acoustic Wave Interacting With A Bracket Structure

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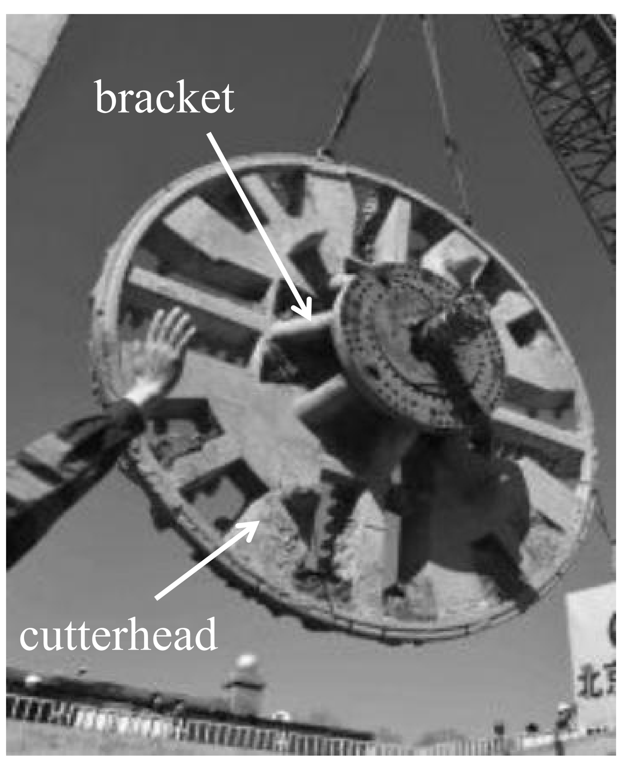
1. Background

- The shield tunneling method has been widely used for construction in tunnels, railways, and subways due to its high efficiency, full automation, minimum effects on ground structures.
- As the core component, the cutterhead is very important. Due to the complex geological surrounding conditions, the long running time makes it easy for fatigue operations to occur.
- All the key parts that were prone to breakage had one thing in common; they all tended to be located in the welding parts.
- A bracket component as a typical part that is easier to generate cracks for. The laser-generated surface acoustic wave detection method is presented.



2. Thermal Conduction Theory

Thermal conductivity equation:

$$\rho c \frac{\partial T(r,z,t)}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(rk\frac{\partial T(r,z,t)}{\partial r}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T(r,z,t)}{\partial z}\right)$$

density; Specific heat; Temperature distribution; Thermal conductivity

The boundary and initial temperature conditions:

$$-k\frac{\partial T(r,z,t)}{\partial z}\Big|_{z=0} = I_0(1-R)f(r)g(t)$$

Energy flow

$$\partial T(r,z,t)/\partial z\big|_{z=h} = 0$$

$$T(r,z,0)=300\ \text{K}$$

→ **Temperature field *vs t***

Navier-Stokes equation:

$$(\lambda+2\mu)\nabla(\nabla\cdot U(r,z,t)) - \mu\nabla\times\nabla\times U(r,z,t) - \alpha(3\lambda+2\mu)\nabla T(r,z,t) = \rho\frac{\partial^2 U(r,z,t)}{\partial^2 t}$$

Lame constants; thermal expansion

The boundary and initial temperature conditions:

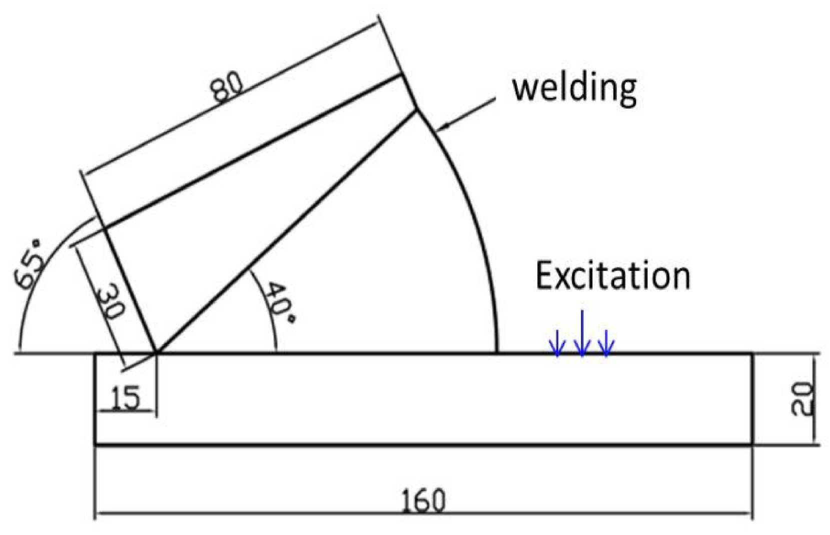
$$\vec{n}\cdot\left[\sigma - (3\lambda+2\mu)\alpha T(r,z,t)I\right] = 0$$

$$U(r,z,t)\big|_{t=0} = \frac{\partial U(r,z,t)}{\partial t}\Big|_{t=0} = 0$$

→ **Displacement field *vs t***

3. Numerical Model

Density (kg/m³)	Thermal expansion (1/K)	Specific heat (J/(kg•K))	Thermal conductivity (W/(m•K))	Young's modulus (Pa)	Poisson's ratio	Reflective coefficient
7850	1.4e-5	451	45.7	210e9	0.3	0.8

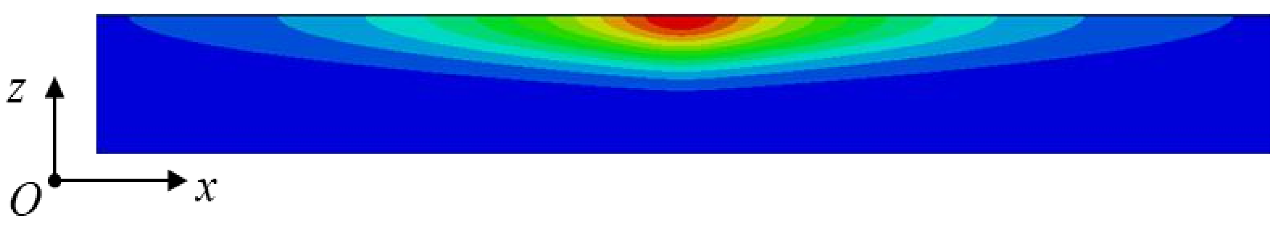


$$f(r) = \frac{2}{a_0\sqrt{2\pi}}\exp\left(-\frac{2r^2}{a_0^2}\right)$$

$$g(t) = \frac{8t^3}{t_0^4}\exp\left(-\frac{2t^2}{t_0^2}\right)$$

4. Results and Discussion

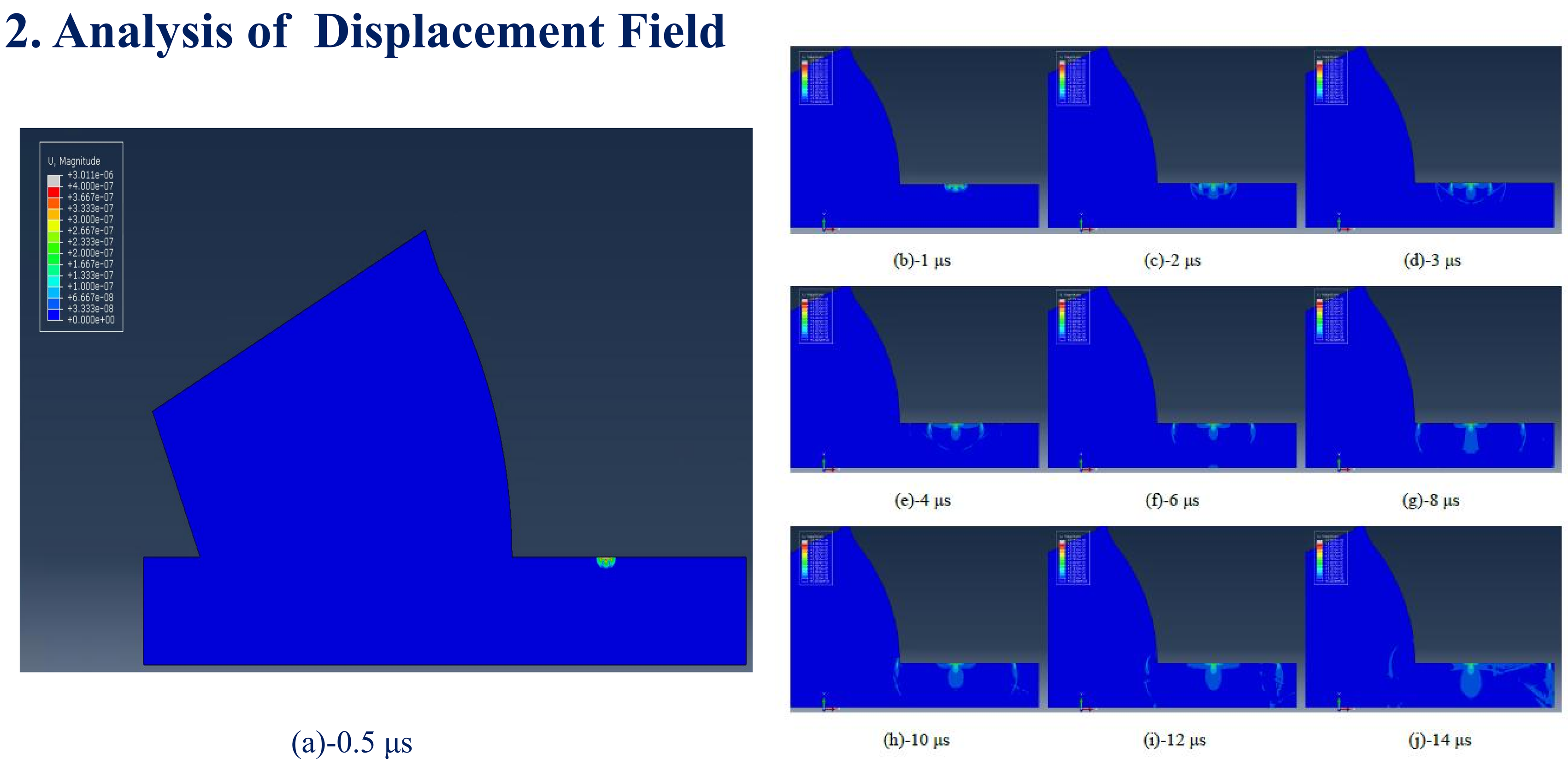
1. Analysis of Temperature Field



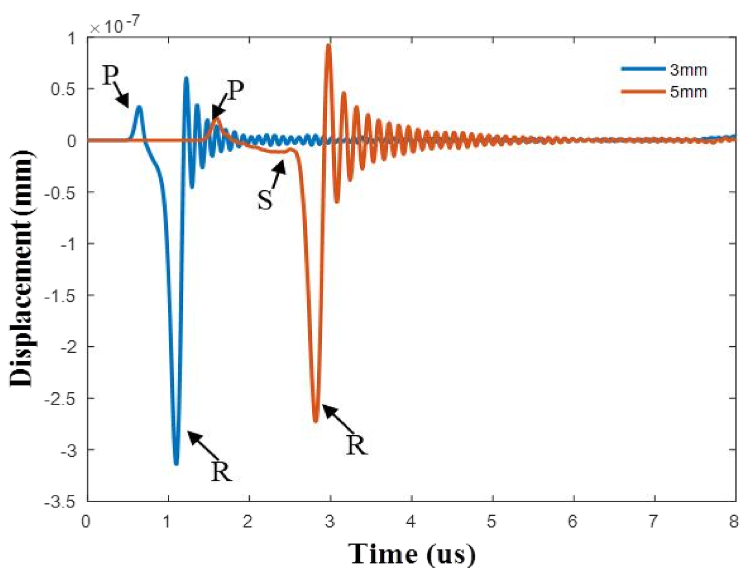
Temperature field distributions in the bracket component at 7 μs

- it can be seen that the maximum temperature is distributed on the surface of the structure.
- It is obvious that the diffusion length of the temperature in the horizontal direction is greater than that in the depth direction.

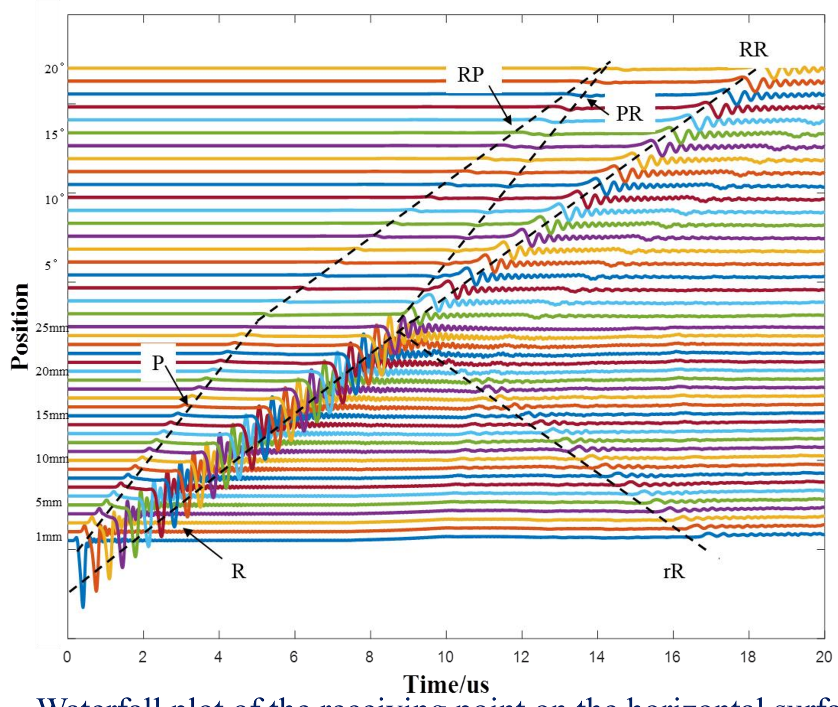
2. Analysis of Displacement Field



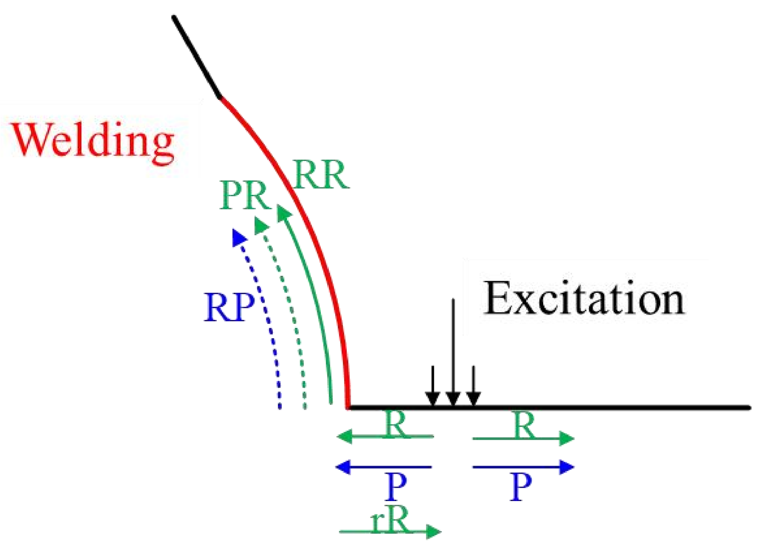
Displacement field in the bracket of cutterhead at different times



Out-of-plane displacements at the distances of 3 mm and 8 mm between the excitation and the receiver



Waterfall plot of the receiving point on the horizontal surface and the welding surface



Detailed propagating properties of laser-generated surface acoustic wave interacting with the bracket structure

- The laser-generated acoustic wave mainly contains three wave modes: longitudinal wave (P), shear wave (S), and Rayleigh wave (R).
- The laser-generated surface acoustic wave propagates to the junction of the welding arc surface and the horizontal surface along with a longitudinal wave and a tiny shear wave. When it encounters the junction, the acoustic wave interacts with the welding and undergoes mode conversion.

5. Conclusion

- A numerical study of the interaction between a laser-generated surface acoustic wave and the bracket component in a cutterhead is studied.
- The basic thermoelastic theory and the finite element model are described. The results show that the displacement field is induced by the laser energy.
- A laser-generated acoustic wave with a longitudinal wave, a shear wave, and a Rayleigh wave propagates along the surface of the bracket structure. When the acoustic wave encounters the junction of the welding and the horizontal surface, it generates a reflected wave, a transmitted wave, and a mode converted wave.
- This propagating phenomenon can be used in the defect detection of a bracket.