THERMO-ACOUSTICS OF PULSED LASER-INDUCED PHASE TRANSITION IN TUNGSTEN BY FDTD NUMERICAL CALCULATION

I.A.Veres[1], **Z.N. Utegulov***[2], **A.Every**[3]

[1]Research Center for Non-Destructive Testing GmbH, Altenberger Str. 69, 4040 Linz, Austria; [2]Nazarbayev University, Kabanbai Batyr Ave. 53, Astana 010000, Kazakhstan; *zhutegulov@nu.edu.kz; [3]Wits University, 1 Jan Smuts Avenue, PO Wits 2050, Johannesburg, South Africa

INTRODUCTION.

Metal-to-liquid phase transition in refractory metals can be generated by laser-irradiation of the surface. Short laser pulses can lead to surface heating, melting or evaporation. During laser-induced melting, the molten mass loses its rigidity and the generation of the shear waves is significantly influenced by a shallow melt pool, while the propagation of longitudinal waves remains less influenced [1]. This work investigates the metal-to-liquid phase transition induced by a nanosecond pulsed-laser with potential application for laser-based remote and localized examination of refractory materials present in harsh environment (Fig. 1). Thereby, the generation of the elastic waves is described by the coupled heat conduction and elastic wave equations and solved using a numerical technique [2].

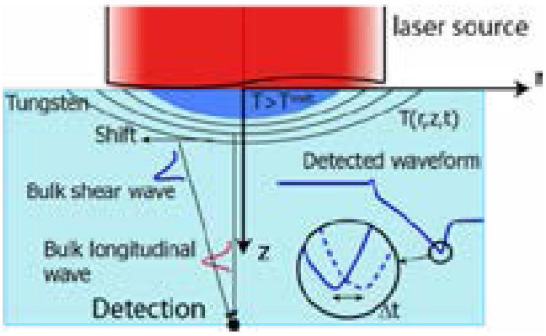


Figure 1. *Experimental setup for studying metal melting using a pulsed-laser technique.*

METHODS.

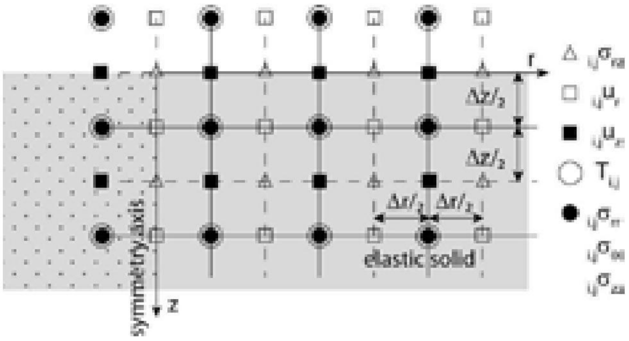
The delay between the shear and the longitudinal wave arrivals at the onset of melting along the epicentral axis has recently been observed experimentally [1]. This time delay will be reproduced in this work using numerical FTDT technique based on the solution of the coupled heat and wave equations. Laser-generation of ultrasound is governed by the coupled heat and wave equations [2]:

$$K\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)+\frac{\partial^2 T}{\partial z^2}\right)=\rho c_v(T+\tau T)-q$$

$$\rho\ddot{u}_r=\frac{\partial\sigma_{rr}}{\partial r}+\frac{\partial\sigma_{rz}}{\partial z}+\frac{1}{r}(\sigma_{rr}-\sigma_{\theta\theta}),$$

$$\rho\ddot{u}_z=\frac{\partial\sigma_{rz}}{\partial r}+\frac{\partial\sigma_{zz}}{\partial z}+\frac{1}{r}\sigma_{rz},$$

Spatial discretization of thermal conduction and acoustic wave equations is implemented with finite differences using staggered grids and axial symmetric boundary conditions. Temperature dependent isotropic mechanical properties are assumed for tungsten. The melting is assumed to occur between 3530-3700K where the thermophysical properties strongly change. Above melting (3700 K), a longitudinal wave velocity of c_L=3005 m/s is assumed with a bulk modulus of $B=c_L^2\rho$=173.89GPa. The material properties at room temperature are given as: E^0=408 GPa, n^0=0.28, c_v^0=136 J(kgC)$^{-1}$, K^0=173W(mK)$^{-1}$. The heat equation was solved in a "thermal window"[2] with a spatial discretization of dr = 180 nm, dz = 116 nm. The discretization of the wave equation was successively increased to dr = 630 nm and dz = 408 nm to the boundaries of the modeled area.



RESULTS AND DISCUSSION.

A tungsten plate with 3.12 mm thickness was investigated. The full width at half maximum of the simulated laser pulse was 4.127 ns with a diameter of 250 mm. A typical epicentral waveform represents positive maximum corresponding to the arrival of longitudinal acoustic wave and the minimum corresponding to the shear wave arrival (Fig. 2). Simulations were carried out for incident peak power densities between 140 and 195 MW/cm^2. For peak power densities above ~170 MW/cm^2 (corresponding to the melt threshold) the arrival of the shear wave shows a significant, increasing shift associated with the development of laser-induced molten pool.

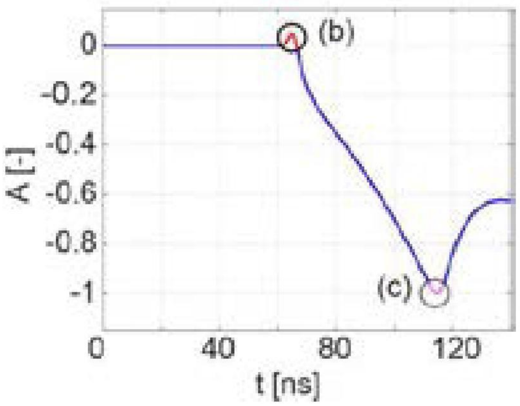


Figure 2. A typical epicentral waveform. The positive maximum (b) corresponds to the longitudinal and the minimum (c) to the sheer wave arrival.

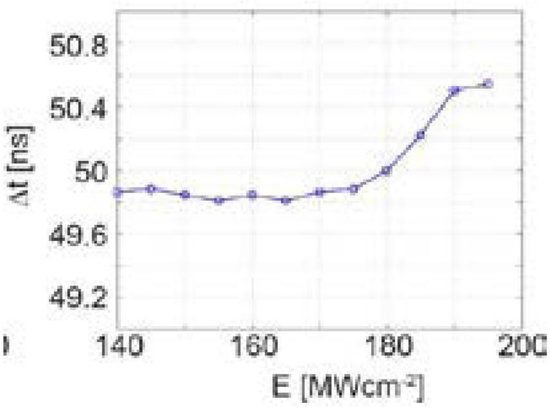


Figure 3. The difference between sheer and longitudinal wave arrival time.

CONCLUSION.

In the presented work metal-to-liquid phase transition induced by a pulsed-laser was investigated. A numerical FDTD technique based on the solution of the coupled heat and wave equations was applied. It was demonstrated that the laser-induced melting leads to the development of a melt pool which significantly influences the generation of the elastic waves and can be utilized for localized and remote monitoring of the laser pulse-induced solid-to-liquid phase transition in refractory metals preset in harsh environments.

ACKNOWLEDGMENTS.

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