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A simple model for laser drilling

Jeb Collins [a,1], Pierre Gremaud [a,b,*,2]

[a] *Department of Mathematics, North Carolina State University, Raleigh, NC 27695, USA*
[b] *Statistical and Applied Mathematical Sciences Institute (SAMSI), P.O. Box 14006, Research Triangle Park, NC 27709-4006, USA*

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Abstract

A simple mathematical model of laser drilling is proposed. Assuming axi-symmetry of the process around the axis of the laser beam, a one-dimensional formulation is obtained after cross-sectional averaging. The novelty of the approach relies on the fact that even after dimension reduction, the shape of the hole can still be described. The model is derived, implemented and validated for drilling using lasers with intensities in the GW/cm^2 range and microsecond pulses.

Keywords: Laser drilling; Phase change; Free boundary; Numerical methods

1. Introduction

Laser drilling is an important industrial process by which laser pulses are used to drill holes in hard materials. It presents several advantages over conventional techniques such as low heat input into the material, accuracy, consistency, ease to automate and ability to drill very small holes of the order of 10 μm in diameter. This technique is used either with single or multiple pulses.

During drilling, material is removed from the workpiece through two mechanisms: vaporization and melt ejection. The relative importance of each mechanism has been the object of several theoretical studies, see for instance [13]. Some authors have also developed more phenomenological criteria [9], see Fig. 1. In the case of thermal ablation (roughly the lower left part of Fig. 1), the interaction of the laser with the material surface creates a molten pool. As some of the material vaporizes, the pressure of the vapor (recoil pressure) is large enough to push the melt radially outward from the center of the beam leading to melt ejection. On the other hand, in so-called non-thermal ablation (roughly the upper right part of Fig. 1), which corresponds to higher melt surface temperature, the main process by which melt is removed is through evaporation instead of convection as the material vaporizes before it can get convected in any significant way.

* Corresponding author at: Department of Mathematics, North Carolina State University, Raleigh, NC 27695, USA. Tel.: +1 919 515 3085; fax: +1 919 515 0482.

E-mail addresses: jbcolli2@ncsu.edu (J. Collins), gremaud@ncsu.edu (P. Gremaud).

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