A Study on Hydrodynamics of Melt Expulsion in Pulsed Nd: YAG Laser Drilling of Titanium

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Abstract

Laser drilling of titanium and its alloys is widely used in aerospace industry [1, 2], as it offers selective removal of material at high accuracy and speed. However, laser processing inherits large thermal gradient [3], which melts the surface and helps the molten metal spread around the irradiated vicinity (Marangoni effect [4, 5]). Moreover, when vaporization starts, an impinging force (recoil pressure [4, 5]) acts on the liquid vapor interface, which splashes the molten liquid outside of the irradiated zone. The aforementioned processes produce a keyhole shaped crater, and the splashed out molten metal after cooling adheres around the keyhole forming a re-solidified edge [4, 5]. When a pulsed laser source is used, repetitive thermal cycle induces micro-structural defects [2] and changes the surface properties of titanium. Therefore, to understand and control these processes, a multi-phase (solid, liquid, and vapor) axisymmetric model is computed using COMSOL Multiphysics®. Firstly, the heat transfer module is used to predict the extent of melting and vaporization. Subsequently, the Navier-Stokes (CFD) equation is coupled with the heat transfer model to determine the relative impact of Marangoni convection and recoil pressure-induced melt displacement. Moving mesh feature is used to simulate the melt displacement based on the physical processes involved. The model also studies the effect of different laser intensity profiles (Ideal Gaussian profile (TEM00) and a top-hat profile (Figure 1)) on melt velocity and phase distribution (Figure 2), temperature distribution and the shape of the keyhole (Figure 3, Figure 4). The study is useful in optimizing the laser parameters to obtain features with minimum re-solidification, which in turn affect the surface roughness of the ablated region.

Reference

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3. V, Semak et. al., Temporal evolution of the temperature field in the beam interaction zone during laser material processing, Journal of Physics D: Applied Physics 32.15: 1819, (1999).
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5. V, Bruyere et. al., Comparison between Phase Field and ALE Methods to model the Keyhole Digging during Spot Laser Welding, Proceedings of the 2013 Comsol Conference, Rotterdam, (2013).

Figures used in the abstract

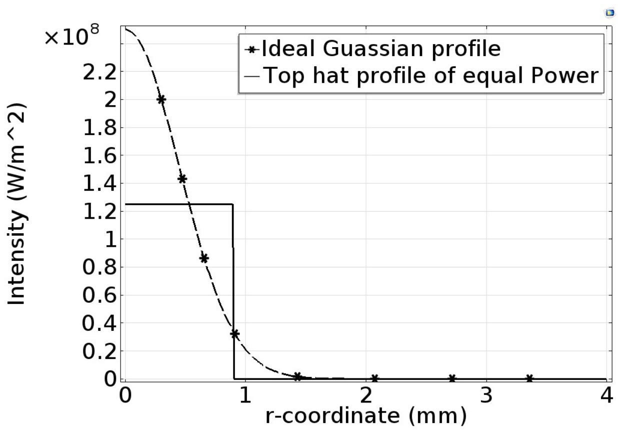

Figure 1: Fig 1: Laser intensity vs radial distance. Peak intensity of guassian beam is 2.5×10^8, Uniform top hat beam profile having intensity 1.25×10^8.

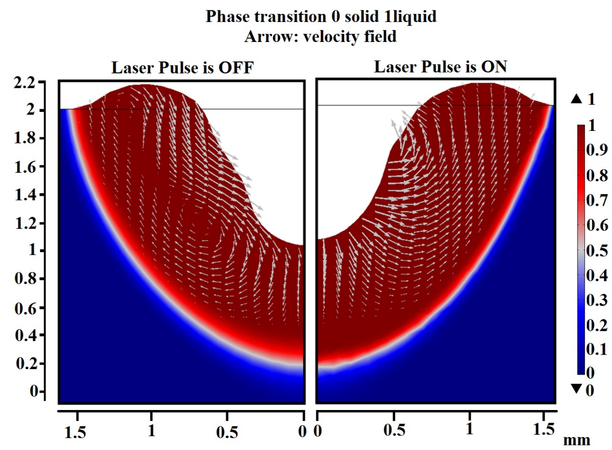

Figure 2: Fig 2: Phase distribution and spatial velocity field (Left: when laser pulse is OFF cooling occurs and only marangoni convection is effective which retracts the molten metal inside the keyhole, Right: When laser pulse is ON recoil pressure acts and splashes the molten metal as shown by the arrow plot).

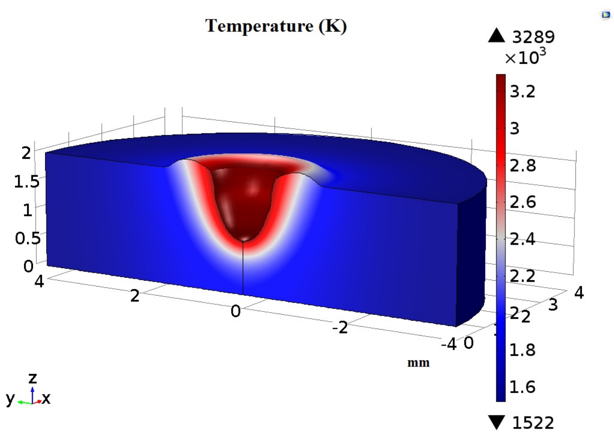

Figure 3: Fig 3: 3D-Temperature distribution and shape of keyhole for guassian intensity, as the guassian intensity have peak at its center the keyhole depth is maximum at center.

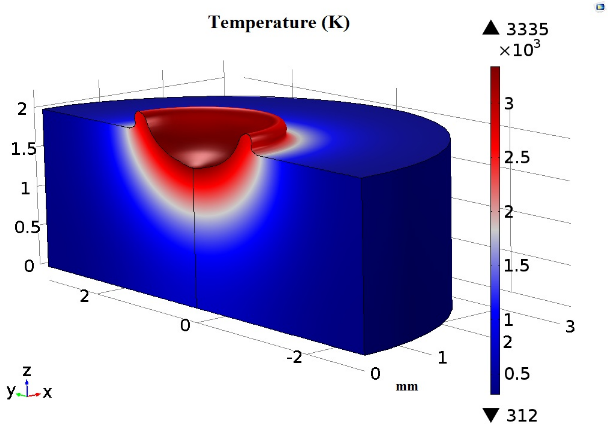

Figure 4: Fig 4: 3D-Temperature distribution and shape of keyhole for top hat intensity, because of uniform intensity the variation of keyhole depth is very little as radial distance increases.