Femtosecond Laser Serial Sectioning: A New Tomographic Technique

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ABSTRACT

In the past decades materials behaviour has often been predicted from microstructural information obtained by 2D techniques, which may not necessarily capture the spatial and microstructural inhomogeneity of the material. However, some properties – such as fatigue, are very sensitive to these imhomogeneities. Thus development of techniques that can acquire 3-D tomographic materials information has become a priority. The focus of our research is the development of a new and efficient serial sectioning tomographic technique which utilizes femtosecond lasers.

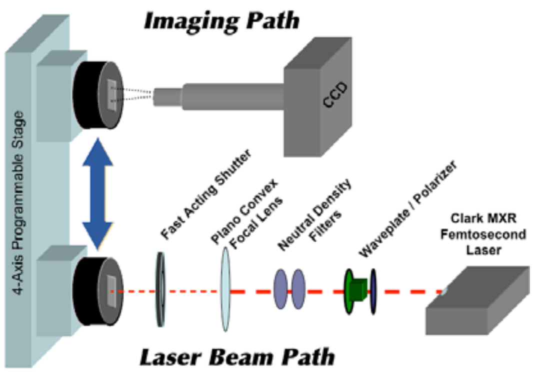

Figure 1 - Femtosecond laser aided serial sectioning schematic setup.

The machining step of the laser aided serial sectioning process uses a Clark-MXR CPA-2001® femtosecond laser to ablate material. Femtosecond lasers have been developed to achieve ultra-short laser pulse durations, on the order of femtoseconds (1 fs. = 10^{-15} s). These ultra-short pulses produce ablation events that are qualitatively different than long pulse (nanosecond or picosecond) or continuous pulse lasers. Specifically, in femtosecond lasers, the localized heating event is insignificant[1] and collateral damage is minimal[2]. Furthermore, the ultra-short pulse duration provides high focused intensity (>10^{18} W/cm^2) permitting for direct ablation of most materials. The limited amount of material damage results in optically viewable surface qualities, and therefore machining and imaging outside of a vacuum chamber. The high repetition rate (1000 Hz) of the femtosecond laser allows for rapid pulse deposition and fast material removal rates. These high pulse intensities combined with high pulse repetition rates permit tomographic analysis of material volumes in the mm^3 to cm^3 range.

Table 1 - Removal rates, characteristics and volumes for different serial sectioning techniques.

	Mechanical Serial Sectioning	Focused Ion Beam	Femtosecond Laser (Potential)
Slice thickness	0.1 - 2.7 μm	5nm - 100nm	20nm - 150nm
Slice rate	5 - 20 /h	300-500/12 h	>3000 /h
Material removal rate	200 $\mu m^3/s$	0.5 $\mu m^3/s$	1 - 10 μm^3/pulse 10^{12} $\mu m^3/s$
Max sample volume	1.0 x 0.7 x 1.2 mm	50 x 50 x 50μm	> 10 cm^3

The femtosecond laser serial sectioning technique utilizes a three-axis stage, a fast acting shutter, and an optical CCD imaging setup, schematically shown in Figure 1. The laser machining parameters may be adjusted to address different materials systems and has been demonstrated with imaging a nickel base superalloy dendrite solidification front and a lanthanum modified gear steel system. These different metallic materials systems have similar ablations rates, well characterized ablation fluences, and ablation events which occur with similar mechanistic pathways[3]. As noted in Table 1, the femtosecond laser can be optimized to work with many different materials systems by varying laser fluence and the number of machining steps between imaging. The machining flexibility with the laser process allows imaging of different materials systems with features having a wide range of lengthscales. Compared with other serial sectioning methods, such as mechanical and focused ion beam (F.I.B.), femtosecond laser aided serial sectioning has the capacity for larger sample volumes and faster material removal rates.

IDL reconstructions of the series of optical images obtained through the femtosecond laser serial sectioning routine have been created. These reconstructions rely on the use of numerous image processing algorithms in order to produce binary images. These algorithms include: segmentation routines aiding in edge detection, and localized region growing for precipitate thresholding. These reconstructions require no image alignment because of the sample fixture and the precision of the three-axis stage. An auto-focusing routine has been incorporated into the image acquisition system, which not only ensures focusing as material is removed, but also provides removal rates and depth data for every slice taken.

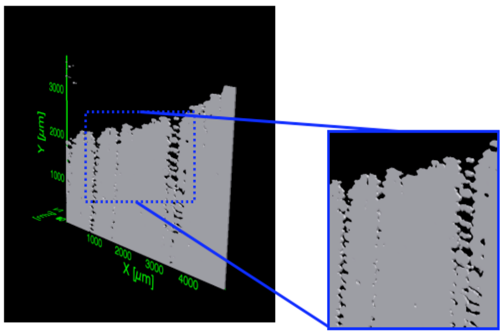

Figure 2 – Preliminary IDL reconstruction of dendrites visible from the solidification front in a Nickel base

References

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