Applications of data mining techniques to exit surface damage growth on fused silica optics

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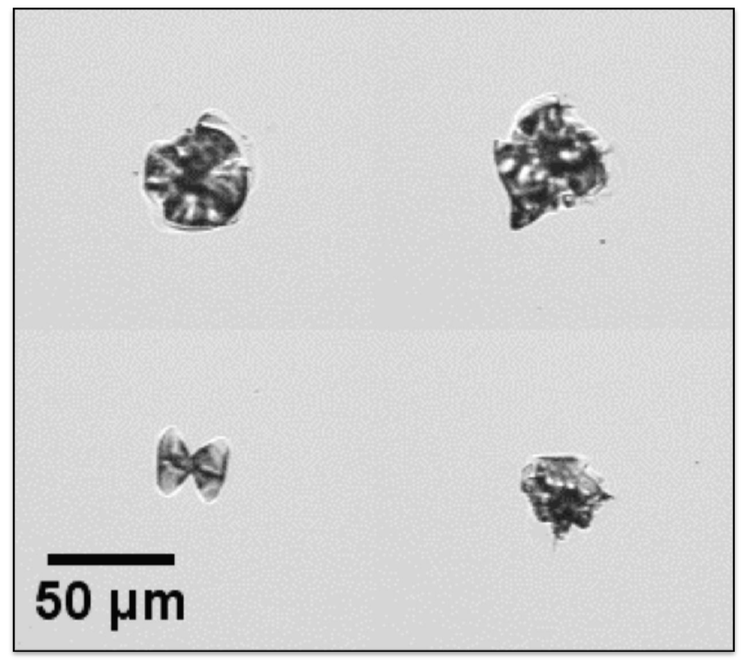
Understanding and forecasting the rate at which laser-induced damage sites grow when exposed to subsequent laser pulses is of interests both as a case study laser-matter interactions as well as of use to efficient management of ICF class lasers. We employ a clustering algorithm to explore the multi-parameter growth space and expose average growth trends. This approach identifies sites likely to exhibit growth rates outside the norm (outliers, or fast growing sites) which significantly enhance the accuracy of predictive models over those based on average growth behaviors. In a follow up work, we use Monte-Carlo simulations based on Weibull growth rate distributions to model the evolution of a population of damage sites. The accuracy of the model is compared against experimental observations over multiple laser shots. In addition, we compare the model it to a machine learning (classification) technique which independently predicts site evolution from patterns extracted directly from the data.

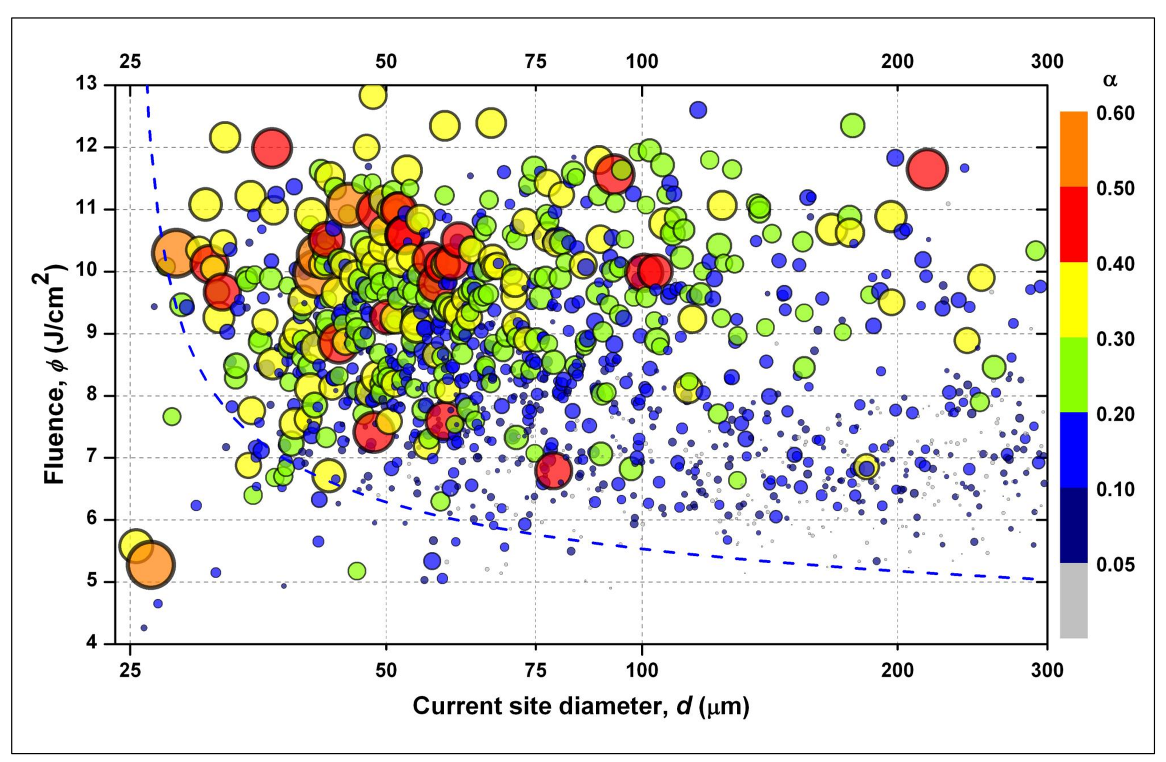
Introduction

Laser-induced damage on the exit surface of fused silica optics is a topic of considerable interest for large aperture, high-power laser systems such as the National Ignition Facility (NIF). We conduct a series of experiments to understand the damage initiation and growth on the surface of fused silica. We initiate damage sites at a predefined size and grow them using multiple exposures with 351-nm, 5 ns FIT laser pulses. Individual site diameters are then measured using a robotic microscope under various illuminations with ~1 µm resolution. The single shot growth rate, α (dimensionless) is defined based on the expectation[1] of exponential growth between two consecutive shots, i.e., $\alpha=\ln(d_n/d_{n-1})$, where d_n and d_{n-1} (in µm) are the effective circular diameters of a site before and after the nth shot, respectively.

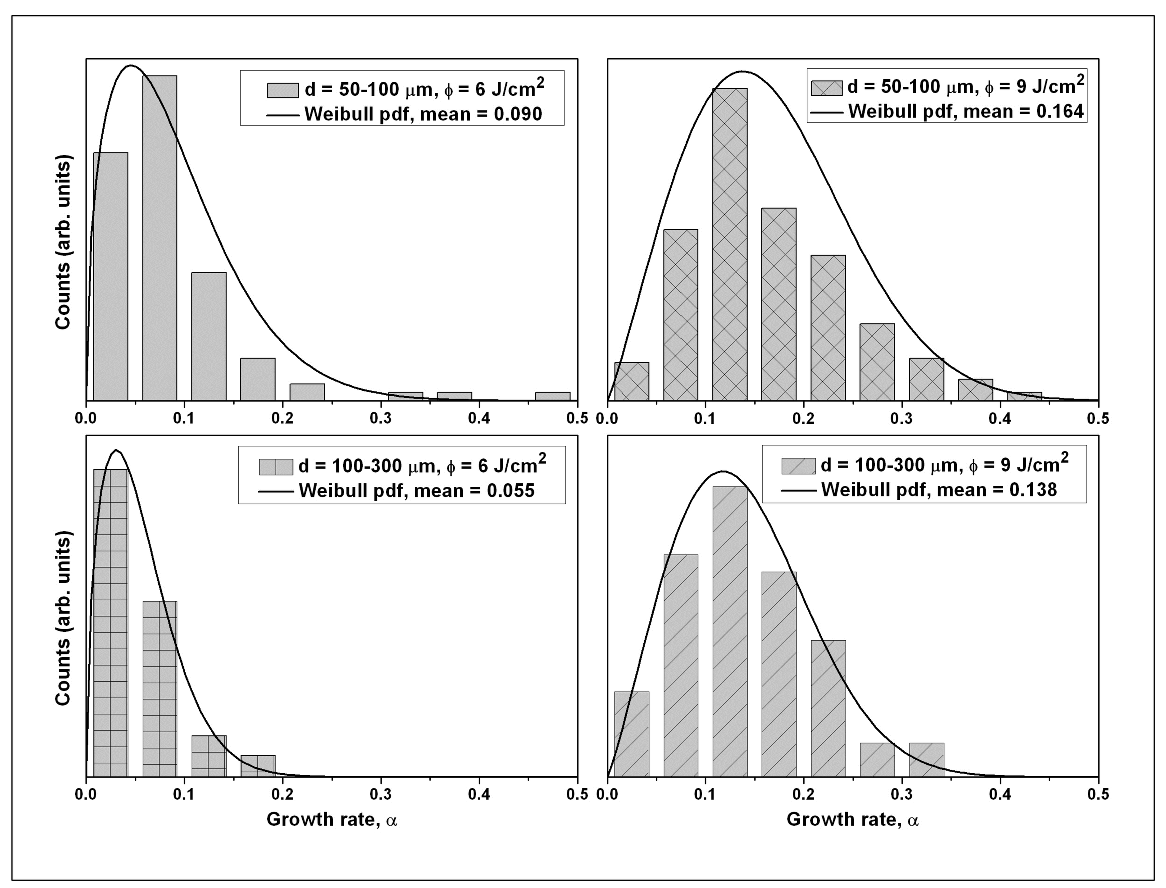


Typical optical micrographs of as-initiated damage sites on the exit surface of fused silica optics

Results



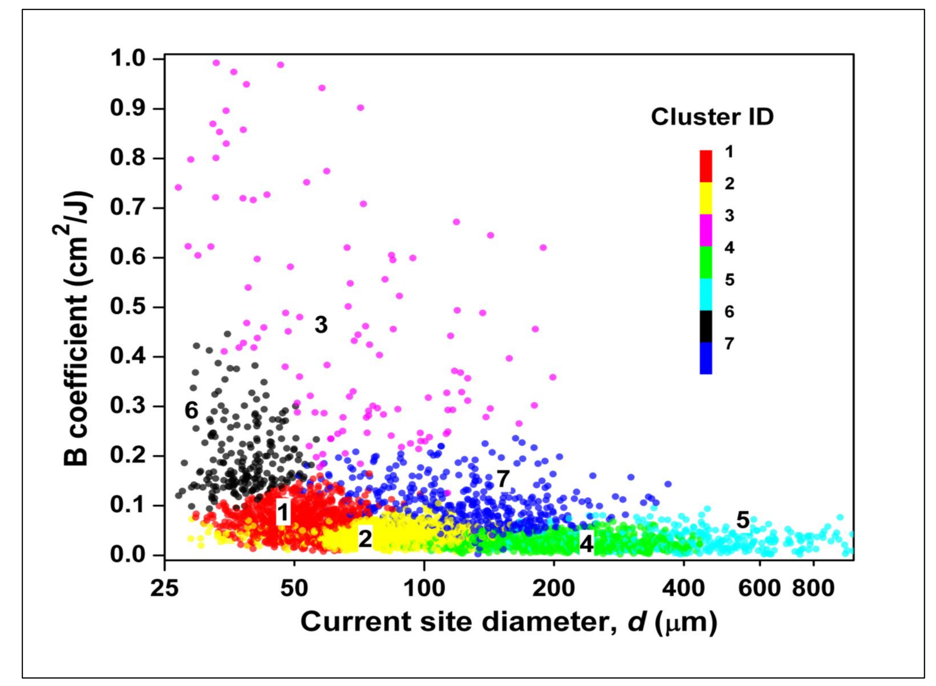
Visualization of measured single shot growth rates in the (ϕ, d) parameter space. The size (and color map) of each bubble is proportional to the single shot growth rate α.



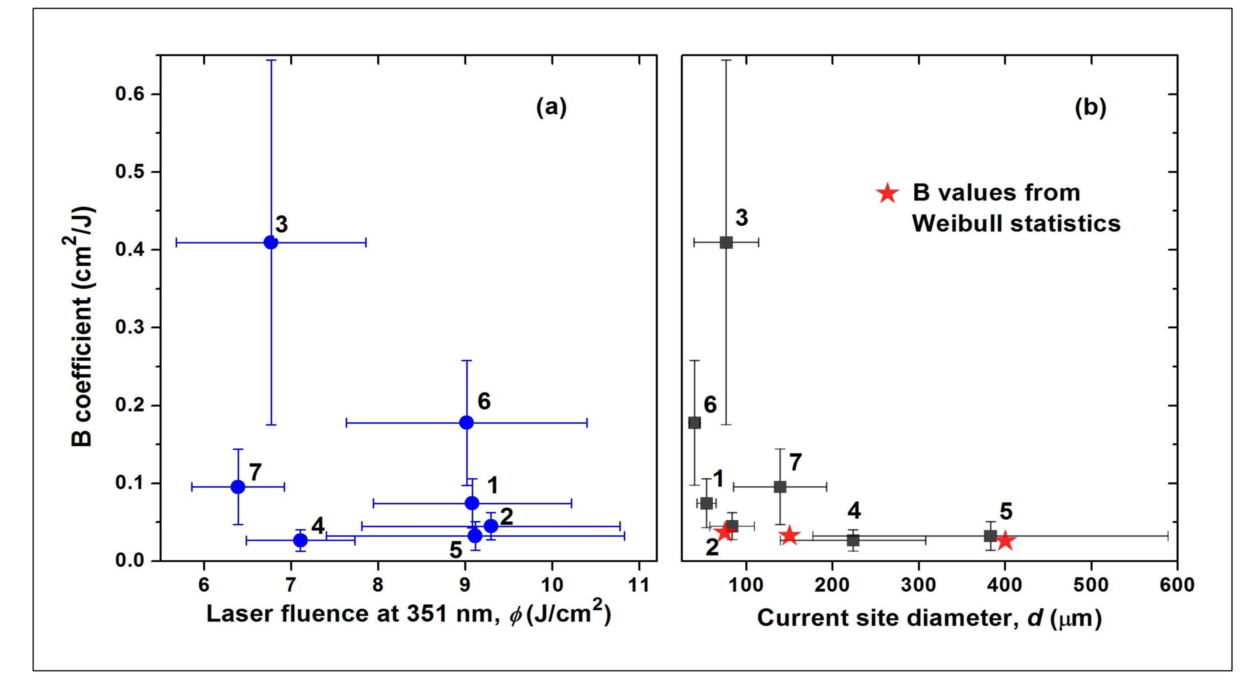
Measured growth rate distributions under narrowly constrained experimental conditions and Weibull distribution fits[2,3] to the data (parameters are size and fluence dependent).

Growth trends and outlier detection using clustering algorithms

We use three input parameters to cluster instances of non-zero α values: 1) current site diameter, d, 2) laser fluence, ϕ, and 3) rate of increase in growth rate, B coefficient, as $<\alpha>/(\phi - \phi_{th})$. Here ϕ_{th} is the growth fluence threshold [2,3].

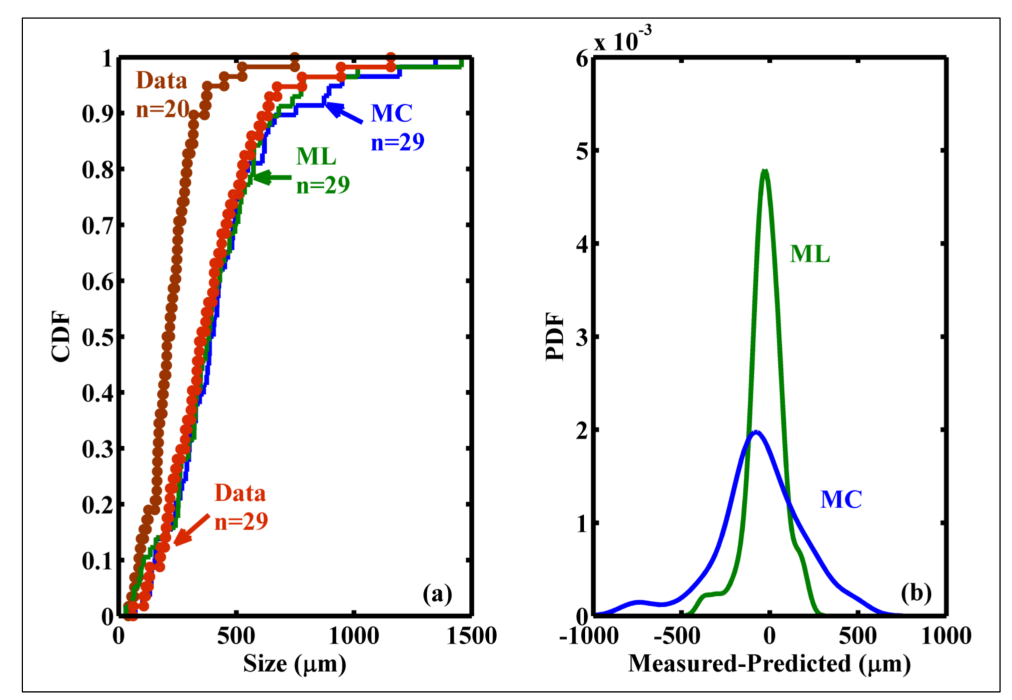


Visualization of seven clusters in (B, d) parameter space obtained using an expectation-maximization clustering algorithm with three input parameters.



Clusters statistics for each of the seven clusters: (a) B coefficient vs. laser fluence, ϕ and (b) B coefficient vs. current site diameter, d. The data labels represent the cluster IDs.

Model comparison for future damage site size predictions



We have shown that both Monte-Carlo simulation and supervised machine learning can accurately reproduce the evolution of a population of damage sites over 10 or more laser shots, depending on the size range[4].

(a) Initial and final cumulative size distribution (CDF) and (b) the probability size density (PDF) for site specific error (measured-predicted) using Monte-Carlo (MC) simulation vs. supervised machine learning (ML).

References

1. Negres et al., Growth behavior of laser-induced damage on fused silica optics under UV, ns laser irradiation, Opt. Express 18, 19966 (2010).
2. Negres et al., Probability of growth of small damage sites on the exit surface of fused silica optics, Opt. Express 20, 13030 (2012).
3. Negres et al., Exploration of the multi-parameter space of nanosecond-laser damage growth in fused silica optics, Appl. Opt. 50, D12 (2011).
4. Liao et al., Predictive modeling techniques for nanosecond-laser damage growth in fused silica optics, Opt. Express 20, 15569 (2012).

Discussion

We used a clustering approach to expose average growth trends and identify sites likely to exhibit growth rates outside the norm. The ability to identify which sites are likely to grow abnormally fast in advance of the manifestation of such behavior will significantly enhance the accuracy of predictive operational models over those based on average growth behaviors. The Monte-Carlo technique is more flexible in terms of applying to different data sets (since there is an implicit understanding on the depending variables), but it is less accurate than the classifier. However, the classifier technique require stronger oversight in developing the truth data. In addition, we have also shown that machine learning can be a powerful predictive technique as well as an important tool to increase our understanding of the growth process[4].

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