# Quantitative Visualization of Cascading Dynamic Crack Bifurcations in Soda-Lime Silicate Glass

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**Abstract.** In this research, evolution of highly transient full-field stress gradient fields is visualized and quantified in rectangular and tapered soda-lime silicate glass (SLSG) plate geometries. Controlled experiments are carried out to generate single and multiple (cascading) crack bifurcations in wedge-loaded specimens. The method of Digital Gradient Sensing (DGS) along with ultrahigh speed photography is adopted to map crack tip fields during 'mile-a-second' crack growth events. The measurements are subsequently analyzed to extract fracture parameters - crack speed, mixed-mode stress intensity factors, high order terms - and identify a few notable precursors at crack branching events.

**Possible Sessions**

7. Dynamic Behavior of Materials, 2. Fatigue & Fracture, 12. Optical and DIC Techniques

**Introduction**

Dynamic crack growth in ultralow-toughness materials such as soda-lime silicate glass (SLSG) often involves unprovoked crack branching events which are yet to be fully explained. The lack of optical tools for measuring mechanical quantities in the whole field at sufficiently high spatial and temporal resolutions to decipher highly localized deformations when cracks grow in excess of mile-a-second speed has resulted in this knowledge gap. The full-field method of Digital Gradient Sensing (DGS) used in conjunction with ultrahigh-speed photography has recently overcome some of these limitations allowing visualization and quantification of fracture parameters associated with different phases of crack growth in SLSG [1,2]. Exploiting this, in this work crack tip fields are mapped during controlled single and multiple crack growth events with the goal of identifying fracture mechanics-based precursors of crack branch formation.

**Experimental Setup**

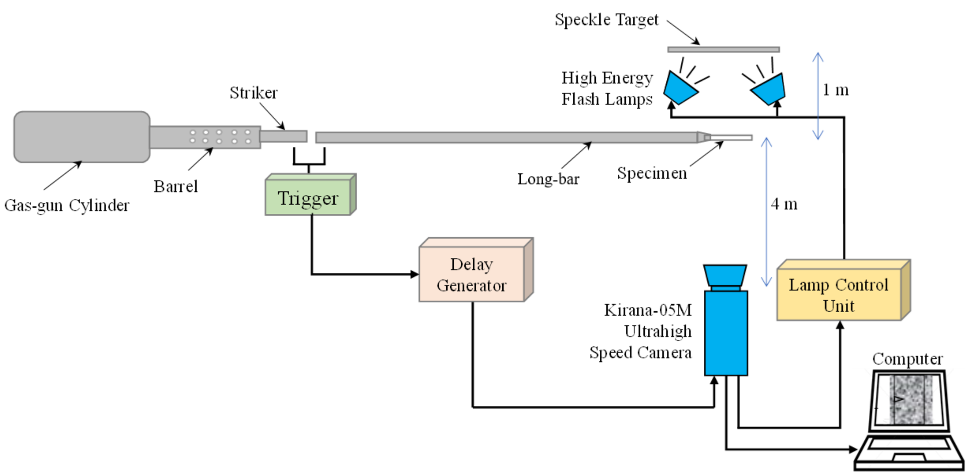


Fig. 1: Schematic of the experimental setup used to carryout DGS measurements on SLSG specimen using ultrahigh-speed photography and a long-bar impactor apparatus.

The schematic of the experimental setup shown in Fig. 1 consists of a gas-gun to launch a striker rod to axially impact a long-rod and set off a 1-D stress wave transmitted to the specimen via a snuggly fitted tapered end of a free-standing V-notched SLSG plate. A Kirana ultrahigh speed camera capable of recording events at up to 5M frames per second is focused on a target plane decorated with random speckles and situated behind the transparent specimen. The impact event triggers the camera, flash lamps and the computer to photograph stationary speckles as the crack initiates, propagates and branches in the specimen under stress wave loading.

## Results

Using the experimental setup described above, fracture experiments are carried out on notched SLSG specimens with a rectangular as well as tapered geometries. The differing geometries are considered to examine potential far-field wave reflection effects on crack branching behavior. The recorded speckle images in the deformed state are subsequently correlated with the one recorded before the arrival of stress waves. The resulting pseudo-speckle displacement fields are converted into angular deflections of light rays in the whole field by knowing the distance between the specimen and the speckle target. By knowing the elasto-optical constant of glass, the angular deflection fields are converted into spatial gradients of $(\sigma_x + \sigma_y)$ (see, [3]) in two orthogonal planes and visualized. An example of angular deflections in the x-z plane (z being is the optical axis and x-, y-axes denote the planar coordinates) are shown in Fig. 2 as colored contours:

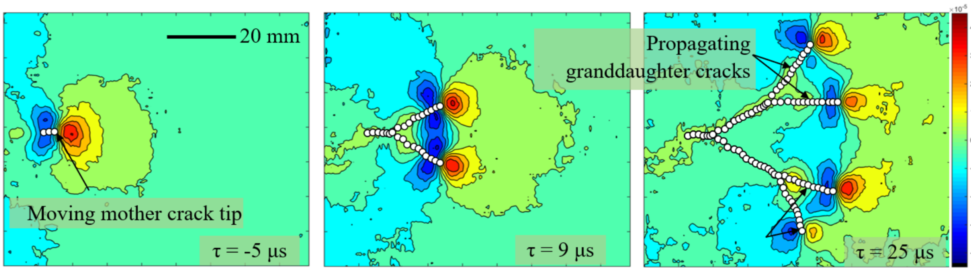


Fig. 2: Contours of angular deflections of light rays in the x-z plane in a square SLSG plate at different time instants (τ=0 is when the first crack bifurcation occurs) from DGS.

The two orthogonal stress gradient fields are subsequently analyzed using over-deterministic least-squares error minimization using elasto-dynamic crack tip field descriptions to extract temporal histories of mixed-mode stress intensity factors (SIFs) and a few higher order terms (HoT) during the crack growth and branching events. The crack tip velocity (V) histories are also estimated during the event. Based on multiple crack branching events that occur in each SLSG geometry and the corresponding SIFs, HoT and V, crack branching precursors that occur consistently across all branching events are identified.

## Conclusions

Early conclusions of this continuing research include a distinct drop in crack velocity, doubling of the effective stress intensity factor relative to the one at crack initiation, and a noticeable kink in the data history of a high-order coefficient are identified as precursors of impending macroscale branching events. A comparative examination of single vs cascading branching events in different specimen shapes are also being looked into for the role HoT play on these complex events.

## References

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[3] C. Periasamy and H. V. Tippur, Applied Optics, Vol. 51, (2012), p. 2088-2097.