Effects of Dynamic Strength in the Velocity History of a Rippled Shock from A Perturbed Bimaterial Interface

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Research question: Can shocks produced from perturbed bimaterial interfaces be used to estimate dynamic strength using laser velocimetry measurements and if so, what is the optimum sample geometry?

Abstract:

The objective of this research is to perform careful simulations and experimental measurements of propagation of perturbed shock waves in bimetallic samples to estimate dynamic strength. Relationships derived from hydrocode simulations will determine optimum experimental geometries that can be used to carry out experiments in these geometries to validate direct numerical simulations of the tests. The findings will further our understandings of dynamic strength effects on the evolution of hydrodynamic instabilities in solids and potentially lead to a new technique to evaluate dynamic strength of solids under extreme loading conditions. Results has potential applications to design better ballistic armor and protection systems.

Background

The evolution of the amplitude of rippled (perturbed) shock fronts can be related to dynamic strength of a material [1].
Producing rippled shocks in metallic samples via flyer plate impacts can be complicated due to low impact velocities as compared to shock wave speeds [1,2].
A framework to produce rippled shocks reliably in metallic samples is needed to measure dynamic strength reliably.

Method:

° Research carried out in Spring '20 evaluated several sample configurations and the optimal for this purpose was a Cu rippled sample with an electroplated Nickel layer (see Fig. 1)
° The sample geometry was optimized to maximize the strength signature, given by differences in time of arrival and particle velocity along the shock front. (See Fig. 2 and Fig. 3)
° An electroplating process was researched to place a Ni layer on top of the Cu perturbation.
° The Ni layer will be impacted by a W flyer plate at 700m/s and the velocity history at a peak and valley of the perturbed front will be measured with Photon Doppler Velocimetry (PDV).
° When data is collected, the comparation of velocities should provide an indication of the magnitude of strength as compared to values used in the simulations and interpolations (See Fig. 3).

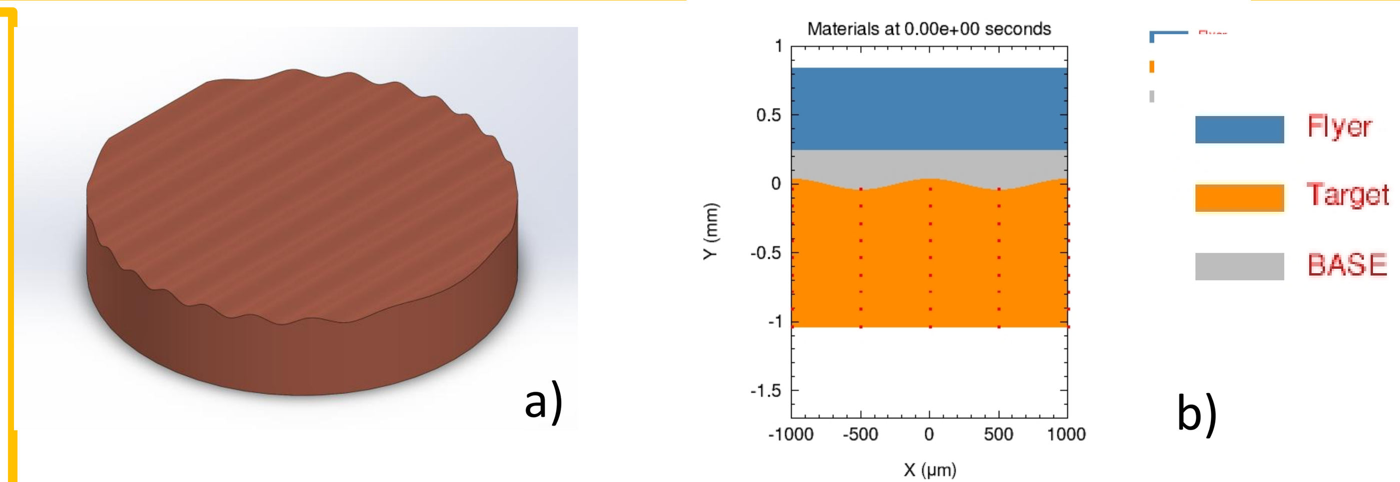

Figure 1: a) Geometry of copper sample with surface perturbation. b) Updated multimaterial setup .

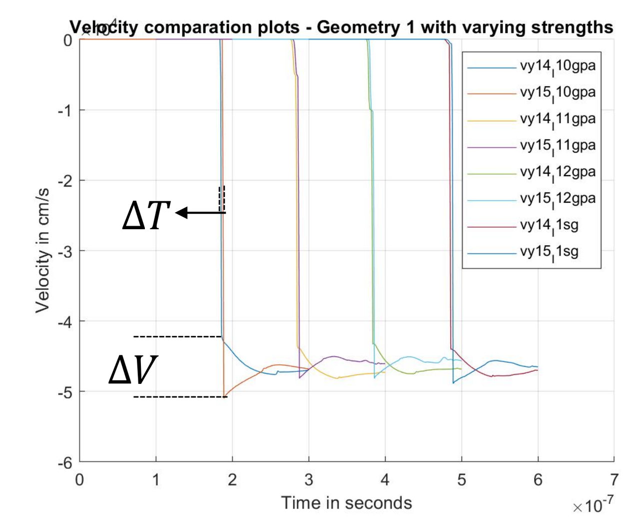

Figure 2: Velocity comparation plots

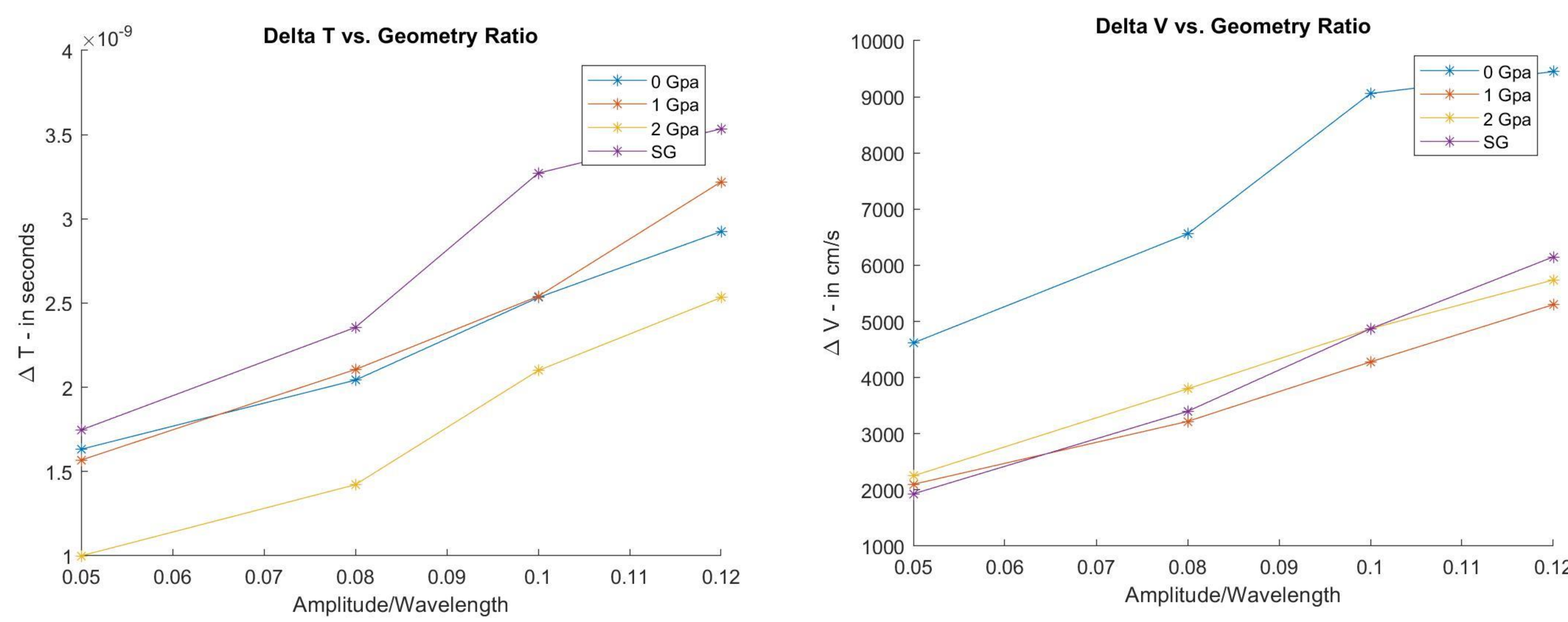

Figure 3: a) Difference in Times with respect to geometric ratio b) Difference in Velocities with respect to perturbation aspect ratio

Results:

° Simulations indicated that Ni was a good choice to be the base material as W sound speed is too close to Cu, so the shock arrives almost flat, while Ni has a faster wave speed than Cu, which is desirable.
° Calculations determined that the effective Amplitude/wavelength ratio of the perturbation is 0.0374, even though this ratio for the Cu sample is 0.1 due to the difference in sound speed of Ni and Cu an effective ratio must be calculated, which is the amplitude after the shockwave passes the rippled perturbation.
° From Hydrocode simulations the difference in breakout times and particle velocities where calculated and plotted with respect to the geometric ratio, this helps us understand the relationship between the two variables and to choose the perturbation geometry ratio to fabricate the sample.
° Results from using elastic-perfectly plastic models (1 and 2 GPa) and a strength model (Steinberg-Guinan or SG [3]) indicate there is a possibility to identify the type of strength model required (See Fig. 3b and Fig. 4).

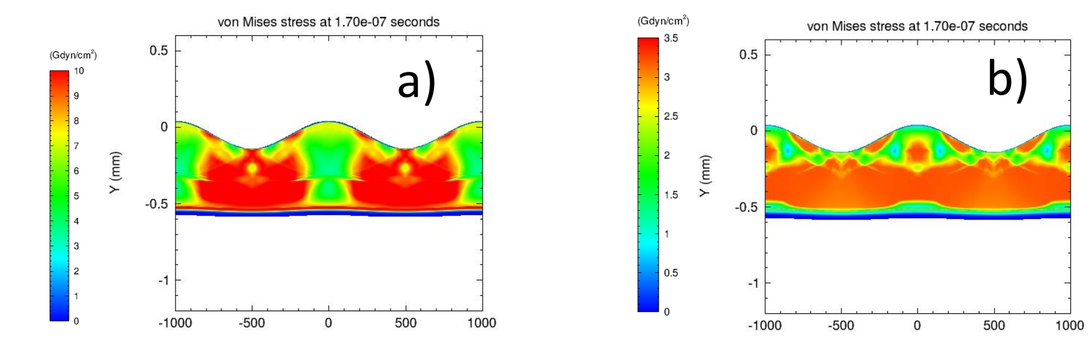

Figure 4: von Mises stress at 170 ns after impact for a) Elastic-perfectly plastic model with Sy=1 GPa. B) Steinberg-Guinan model with constants for Cu [3]

Conclusion:

- Copper sample cross section was updated to include precise cut at the initial peak to ensure correct positioning of PDV probes.
- A geometric ratio of 0.1 was found to be optimal to measure velocities at the peaks and valleys of the breakout shock.
- Figures 3 and 4 show how sensitive the experiment is to changes in aspect ratio of the perturbation and the strength model

Future Work:

- The gas gun at Dr. Peralta's Lab will be used to run experiments with the updated setup (See Fig. 1)
- Electroplate Nickel layer to Copper sample, produce jig to ensure only top layer of Copper sample is electroplated and ensure electrical contact to sample.
- Develop a technique to evaluate dynamic strength of solids from the velocimetry measurement.

References:

[1] Opie, S., Loomis, E., Peralta, P., et al (2017). Strength and Viscosity Effects on Perturbed Shock Front Stability in Metals. Physical Review Letters, 118(19).
[2] Peralta, P., Loomis, E., Chen, Y., Brown, A., McDonald, R., Krishnan, K. and Lim, H. (2015). Grain orientation effects on dynamic strength of FCC multicrystals at low shock pressures: a hydrodynamic instability study. Philosophical Magazine Letters, 95(2), pp.67-76.
[3] Meyers, Marc A. 1994. Dynamic Behavior of Materials. New York: Wiley.

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