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The VISAR Window Correction for Soda-lime Glass under Shock Conditions

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Introduction

Soda-lime glass is a potential VISAR window for shock wave experiments. Any potential VISAR window must be characterized to determine the effect of the shock induced change in the window's index of refraction on the VISAR velocity record. This paper outlines the results of twelve shock wave experiments with soda-lime glass as a VISAR window performed at 1.45 GPa, 2.0 GPa, 2.5 GPa and 3.0 GPa. All shots were symmetric impacts, therefore the particle velocity was known independent of the VISAR data. The shock induced change in the index of refraction was determined by comparing the VISAR velocity record to the known particle velocity.

Experimental Setup and Procedure

Each experiment consisted of a soda-lime glass sample impacting a soda-lime glass target containing an aluminum vapor-deposited VISAR mirror. An optical fiber was used to shine light through the target to the mirror and transmit the reflected light back to the VISAR. A trigger pin was used to turn on the laser and trigger the oscilloscopes and an impact pin was used to measure the time of impact for diagnostic purposes. Appendix A lists the experimental details.

Results

The soda-lime glass samples were characterized by measurements of sound speed, density and, in most experiments, flatness. The average sound speed of the samples was 5.853 mm/μs, ranging from 5.801 mm/μs to 5.925 mm/μs. The average density of the samples was 2.502 g/cm^3, ranging from 2.488 g/cm^3 to 2.509 g/cm^3. These variations indicate that the uniformity of the glass from batch to batch may differ, however no apparent correlations between the sample characteristics and the resulting window correction factors were seen.

The window correction factors from all twelve experiments are shown in Figure 1. The average correction factor is 1.144. The range of correction factors of 1.136 to 1.154 is within 1% of the average. Appendix B lists the data used in these calculations.

Approximate Stress	# of Shots	Average Correction
1.45 GPa	3	1.152
2.0 GPa	5	1.141
2.5 GPa	1	1.151
3.0 GPa	3	1.140

In a typical VISAR experiment, the velocity record is accurate to 1%. The uncertainty in the velocity record combined with an uncertainty in the measured projectile velocity results in an

uncertainty in the correction factor greater than 1%. This places all the calculated results within the range uncertainty.

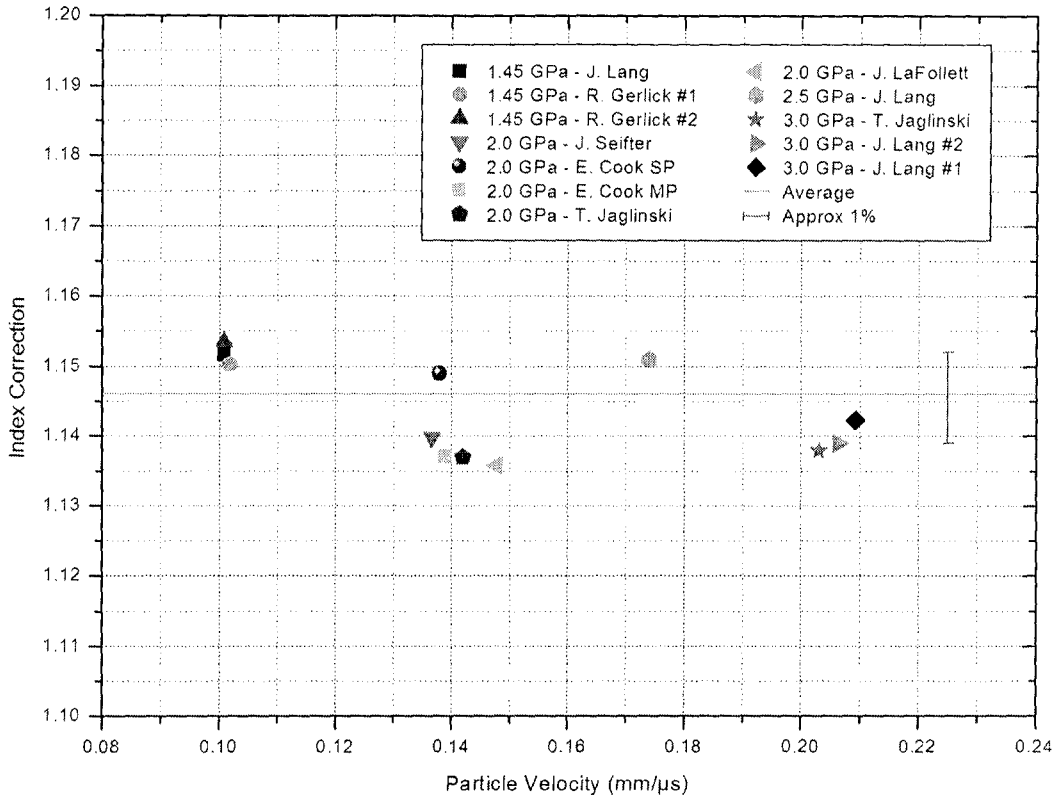

Figure 1 – Window correction factors for all twelve experiments

Conclusion and Comments

The results of these experiments suggest that soda-lime glass can be used as a reliable VISAR window, after ensuring that the samples used are consistent with the characterization given above.

Eryn Cook, Rob Gerlick, Tim Jaglinski, Jon LaFollett, John Lang and Jason Seifter performed the above experiments with the assistance of the scientists and engineers at ISP. Thanks to Kurt Zimmerman, Kent Perkins and Nate Arganbright for their assistance in performing these experiments and to Eryn Cook and Tim Jaglinski for assisting in the preparation of this report.

Appendix A: Experimental Setup and Sample Characterization

All twelve experiments were built using a transmitted wave configuration or an impact wave configuration, shown in Figures 2 and 3 respectively. The velocity profile was measured at the aluminum vapor-deposited VISAR mirror. In the transmitted wave configuration, the impact wave is slightly perturbed as is it transmitted through the glass before it reaches the mirror. In the impact wave configuration the mirror is deposited on the front surface, allowing the VISAR to record the unperturbed impact wave.

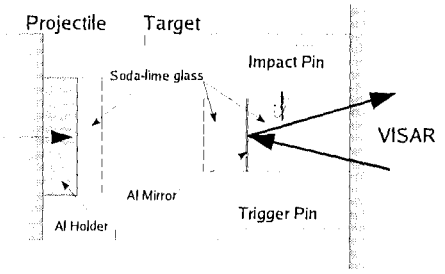

Figure 2 - Transmitted wave configuration

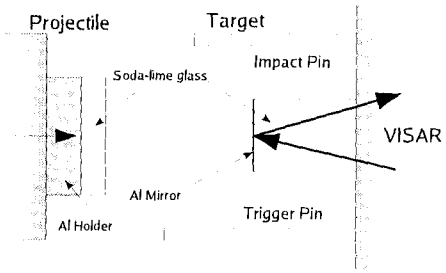

Figure 3 - Impact wave configuration

1.45 GPa Shots

In these three shots, a 1" x 0.25" soda-lime glass sample was mounted on a 2.5" projectile to be impacted into a 0.75" x 0.5" soda-lime glass sample. The 0.75" x 0.5" sample was composed of a 0.75" x 0.125" front window and a 0.75" x 0.375" VISAR window epoxied together. An aluminum mirror was vapor deposited on the VISAR window before the samples were epoxied together. All three experiments were transmitted wave configurations.

- Sample Characterization
  - John Lang's Shot (July 7, 2006):

Property	Impactor	Front Window	VISAR Window
Rough Dimensions	1" x 0.25"	0.75" x 0.125"	0.75" x 0.375"
Thickness at center [mm]	5.756	3.073	9.474
Sound speed [mm/μs]	5.850	5.801	5.843
Density [g/cm^3]	2.502	2.507	2.502

  - Robert Gerlick's Shot #1 (July 24, 2006):

Property	Impactor	Front Window	VISAR Window
Rough Dimensions	1" x 0.25"	0.75" x 0.125"	0.75" x 0.375"
Thickness at center [mm]	5.756	3.078	9.545
Sound speed [mm/μs]	5.857	5.861	5.853
Density [g/cm^3]	2.501	2.503	2.500

  - Robert Gerlick's Shot #2 (Aug 14, 2006):

Property	Impactor	Front Window	VISAR Window
Rough Dimensions	1" x 0.25"	0.75" x 0.125"	0.75" x 0.375"
Thickness at center [mm]	5.759	3.078	9.466
Sound speed [mm/μs]	5.864	5.880	5.864
Density [g/cm^3]	2.502	2.504	2.501

- Experimental Parameters:
  - Desired Stress = 1.45 GPa
  - Desired Velocity of Projectile = 0.2 mm/μs
  - Gas Gun: 2.5"

2.0 GPa Shots

The first experiment at this impact stress was conducted by Jon LaFollett with a slightly different experimental configuration. A 1.25" x 0.5" soda-lime glass sample was impacted into a 1.25" x 0.5" soda-lime glass target. An aluminum mirror was vapor deposited on the impact surface of the target. This experiment was built in the impact wave configuration.

The second, third and fourth experiments at this impact stress was conducted by Jason Seifter, Tim Jaglinski and Eryn Cook, respectively. They used the same experimental configuration as was used in the 1.45 GPa shots.

The fifth experiment at this impact stress was conducted by Eryn Cook using the multi-point VISAR. A 1.25" x 0.25" soda-lime glass sample was mounted on a 2.5" projectile to be impacted into a 1.25" x 0.5" soda-lime glass target. The four VISAR beams measured the particle velocities on the vertices of a square of side length 0.75". The average of the velocities of the four points is reported here. This experiment measured the impact wave.

- Sample Characterization
  - Jon LaFollett's Shot (June 29, 2005):

Property	**Impactor**	**VISAR Window**
Rough Dimensions	1.25" x 0.5"	1.25" x 0.5"
Thickness at center [mm]	12.182	12.169
Sound speed [mm/μs]	5.810	5.850
Density [g/cm^3]	2.490	2.488

  - Jason Seifter's Shot (June 30, 2006):

Property	**Impactor**	**Front Window**	**VISAR Window**
Rough Dimensions	1" x 0.25"	0.75" x 0.125"	0.75" x 0.375"
Thickness at center [mm]	5.759	3.077	9.449
Sound speed [mm/μs]	5.877	5.861	5.832
Density [g/cm^3]	2.501	2.505	2.501

  - Tim Jaglinski's Shot (Oct 19, 2006):

Property	**Impactor**	**Front Window**	**VISAR Window**
Rough Dimensions	1" x 0.25"	0.75" x 0.125"	0.75" x 0.375"
Thickness at center [mm]	5.782	3.082	9.464
Sound speed [mm/μs]	5.835	5.925	5.833
Density [g/cm^3]	2.502	2.506	2.500

- Eryn Cook's SP Shot (Dec 20, 2006):

Property	Impactor	Front Window	VISAR Window
Rough Dimensions	1" x 0.25"	0.75" x 0.125"	0.75" x 0.375"
Thickness at center [mm]	5.772	3.081	9.451
Sound speed [mm/μs]	5.830	5.925	5.834
Density [g/cm^3]	2.502	2.505	2.501

- Eryn Cook's MP Shot (Jan 18, 2007):

Property	Impactor	VISAR Window
Rough Dimensions	1.25" x 0.25"	1.25" x 0.5"
Thickness at center [mm]	5.743	12.170
Sound speed [mm/μs]	5.860	5.851
Density [g/cm^3]	2.499	2.509

- Experimental Parameters:
  - Desired Stress = 2.0 GPa
  - Desired Velocity of Projectile = 0.276 mm/μs
  - Gas Gun: 4" (LaFollett, Seifter), 2.5" (Cook, Jaglinski)

2.5 GPa Shot

In this shot, a 1" x 0.25" soda-lime glass sample was mounted on a projectile to be impacted into a 0.75" x 0.375" soda-lime glass sample. An aluminum mirror was vapor deposited on the impact surface of the target sample. John Lang built this experiment in the impact wave configuration.

- Sample Characterization:
  - John Lang's Shot (May 29, 2007):

Property	Impactor	VISAR Window
Rough Dimensions	1" x 0.25"	0.75" x 0.375"
Thickness at center [mm]	5.763	9.441
Sound speed [mm/μs]	5.856	5.845
Density [g/cm^3]	2.500	2.506

- Experimental Parameters:
  - Desired Stress = 2.5 GPa
  - Desired Velocity of Projectile = 0.3449 mm/μs
  - Gas Gun: 2.5"

3.0 GPa Shots

The first two shots at this impact stress were conducted by John Lang and used the same experimental configuration as was used in the 2.5 GPa shot.

The third experiment at this impact stress was conducted by Tim Jaglinski, using the same experimental configuration as was used in the 1.45 GPa shots.

- Sample Characterization
  - John Lang's Shot #1 (July 26, 2006):

Property	**Impactor**	**VISAR Window**
Rough Dimensions	1" x 0.25"	0.75" x 0.375"
Thickness at center [mm]	5.758	9.441
Sound speed [mm/μs]	5.864	5.848
Density [g/cm^3]	2.502	2.501

  - John Lang's Shot #2 (Aug 2, 2006):

Property	**Impactor**	**VISAR Window**
Rough Dimensions	1" x 0.25"	0.75" x 0.375"
Thickness at center [mm]	5.738	9.450
Sound speed [mm/μs]	5.867	5.851
Density [g/cm^3]	2.502	2.508

  - Tim Jaglinski's Shot (Oct 6, 2006):

Property	**Impactor**	**Front Window**	**VISAR Window**
Rough Dimensions	1" x 0.25"	0.75" x 0.125"	0.75" x 0.375"
Thickness at center [mm]	5.771	3.076	9.453
Sound speed [mm/μs]	5.814	5.859	5.834
Density [g/cm^3]	2.502	2.501	2.502

- Experimental Parameters:
  - Desired Stress = 3.0 GPa
  - Desired Velocity of Projectile = 0.414 mm/μs
  - Gas Gun: 4”

Appendix B: VISAR Data and Calculations

The particle velocities in each shot were determined by analyzing the VISAR data with the velocity interferometer equation[1,2]:

$$v\left(t-\tfrac{1}{2}\tau\right)=\frac{\lambda_0 F(t)}{2\tau\left(1+\frac{\Delta v}{v_0}\right)(1+\delta)}$$

The window correction was calculated using the following relation,

$$1+\frac{\Delta v}{v_0}=\frac{v_p}{u_p}$$

where v_p is the particle velocity measured by the VISAR without the correction and u_p is the expected particle velocity.[3] For a symmetric impact, the particle velocity is one-half the projectile velocity. The impact stress was calculated from the Hugoniot for soda-lime glass:

$$\sigma=\rho_0 c u_p \approx 14.6 u_p$$

Shot	Impact Stress [GPa]	Projectile Velocity [mm/μs]	Particle Velocity (calc): u_p [mm/μs]	Particle Velocity (meas): v_p [mm/μs]	Window Correction $(1+\Delta v/v_0)$
1.45 GPa R. Gerlick #2	1.46	0.202	0.101	0.116	1.154
1.45 GPa J. Lang	1.46	0.202	0.101	0.116	1.152
1.45 GPa R. Gerlick #1	1.48	0.204	0.102	0.117	1.150
2.0 GPa J. Seifter	1.98	0.273	0.137	0.156	1.145
2.0 GPa E. Cook SP	1.99	0.275	0.138	0.158	1.149
2.0 GPa E. Cook MP	2.01	0.277	0.139	0.158	1.137
2.0 GPa T. Jaglinski	2.05	0.283	0.142	0.161	1.137
2.0 GPa J. LaFollett	2.14	0.296	0.148	0.168	1.136
2.5 GPa J. Lang	2.52	0.348	0.174	0.200	1.151
3.0 GPa T. Jaglinski	2.94	0.406	0.203	0.231	1.138
3.0 GPa J. Lang #2	2.99	0.413	0.206	0.235	1.139
3.0 GPa J. Lang #1	3.03	0.418	0.209	0.239	1.142

References

1. Barker and Hollenbach, JAP 43, 4669 (1972)
2. Barker and Schuler, JAP 45, 3692 (1974)
3. Dandekar, JAP 84, 6614 (1998)