Heavy Gas Cherenkov Detector: Window Material Pressure Test

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As part of the prototyping process for the SoLID Heavy Gas Cherenkov detector (HGC), we are seeking a suitable material for the entrance window. The HGC will be filled with gas at a pressure of approximately 1.5 *atm*, or 22.05 *psi* (that is, 0.5 *atm* or 7.35 *psi* overpressure), and must fit in the SoLID assembly at Jefferson Lab Hall A. As such the material must not only withstand the pressure difference, but do so with minimal bulging (no more than approximately 10 *cm*).

1 Mylar/Kevlar Window Test

1.1 Procedure

We have acquired Mylar and Kevlar samples from Challenge Sailcloth [1]. The Mylar has a thickness of 5 *mil* and is crosshatched with strands of carbon fiber and fiber glass. The Kevlar has a thickness of 12 *mil* and comes with an adhesive backing, which we have used to bind the layers. We have tested a single layer of Kevlar over a single layer of Mylar. Tests with two layers of Kevlar are pending. We cut and mounted the material over a prototype window frame, as in the design for the HGC. The schematic for the window is shown in Fig. 1 [1]. The window was then fixed to a steel plate with an O-ring to provide an airtight seal. A precision depth-gauge was mounted above the window to measure the height of the bulging. Air was pumped through a hole in the under side of the plate using a bicycle pump attached to a pressure gauge and valve. Fig. 2 shows the setup from prior tests, where the same procedure was used.

Measurements were taken by closing the valve at desired pressure values, and then waiting 10 seconds before measuring the bulge height (as the material continued to stretch slowly even after the valve was closed). We also performed a “soak test” by leaving the window pressurized for several hours, to test the material’s ability to hold pressure over an extended period of time.

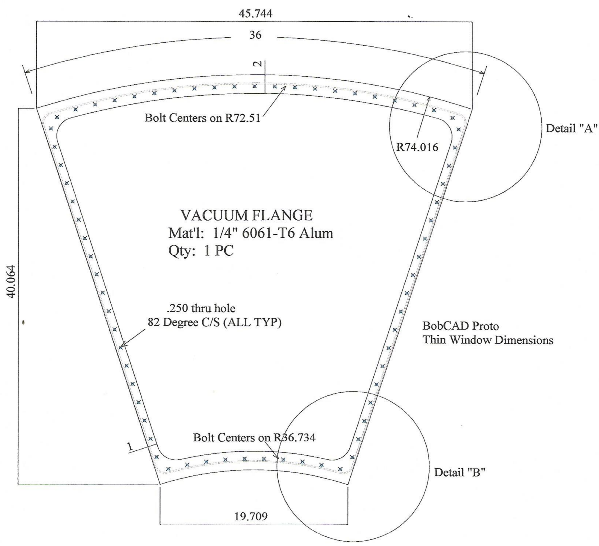

Figure 1: Schematic diagram of the HGC detector window.

1.2 Results

Air was pumped in until the pressure gauge read 7 *psi*, at which point the material had bulged to a height of 2.174". The height of the bulge versus the pressure is shown in Fig. 3 by the black points.

We then left the window over night with the valve closed to observe any changes in pressure and height over time. Over a 24 hour period, the material stretched an additional 260 *mil*, with no measurable decrease in pressure.

At this point we deflated the window to see how well the material would return to its original shape. The material returned to nearly its original state, with slightly more slack than before. We then began inflating the window again, following the same procedure as before, continuing past 7 *psi*. The results are displayed in Fig. 3 by the red points. Gauge readings were here noted to be slowly dropping after sealing the valve, where before they would slowly rise.

The data in Fig. 3 shows that after being inflated for the first time, the material had become stretched, and stretched more easily upon further inflation. The difference in height on the second inflation is approximately 0.4" at low pressure, decreasing to 0.3" at 7 *psi*.

While pumping between 8 and 10 *psi* we noted creaking noises coming from the window. After passing 10 *psi* a portion of the material tore and slipped out of the flange causing the window to burst. The aftermath at the point of failure is shown in Fig. 4. The point of failure was very close to where the mylar-tedlar window failed on the same frame [4].

1.3 Summary and Conclusions

The bulging in this material does not satisfy the requirements for the HGC. However it is a substantial improvement over the previously tested Mylar-Tedlar, which bulged to 6.1" at 8 *psi*, compared to 2.6" at the same pressure for this material. As such we will soon repeat these tests with a second layer of Kevlar.

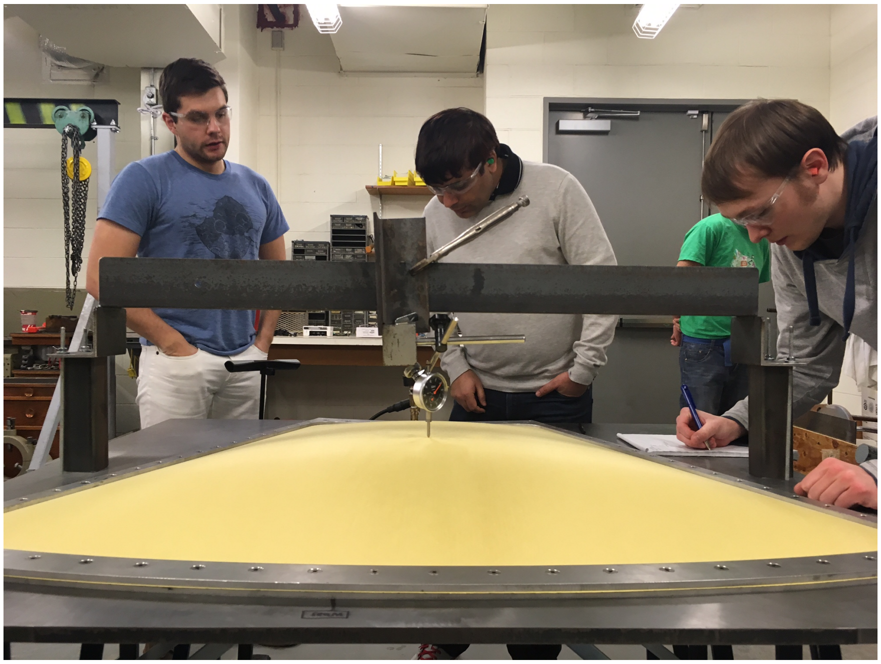

Figure 2: Photograph of experimental setup.

Inspection of the material and flange after the failure occurred indicates that the point of failure was where the bolts passed through the material. We suspect that as the material pulled through the clamping wire in the flange, the tension started being placed on these bolts. This indicates a flaw in the design of the flange. It is unlikely to be coincidence that both windows failed at the same point on the flange, so there is some particular flaw at this point. Inspection of this area showed no obvious anomalies.

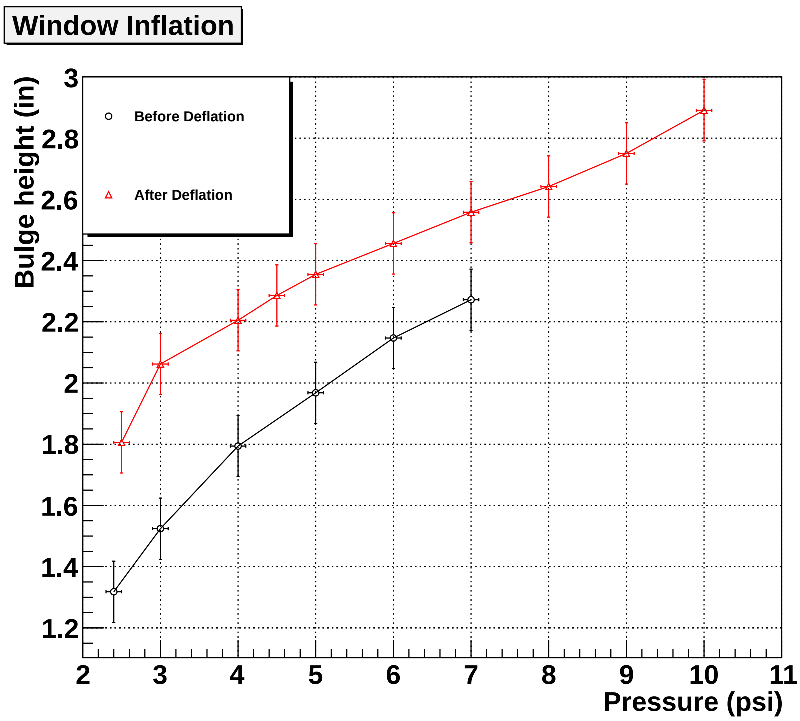

Figure 3: Graph showing height of the bulge in the window versus pressure both before and after deflating the window.

Figure 4: Photo showing the window after it failed.

2 Tensile Strength Testing

2.1 Estimated Strength Required

To approximate the maximum tension required by the design of the HGC, we look at a single, unit width strip of material, under uniform force (per unit length) normal to its surface, fixed at the ends. See Fig. 5. The assumed shape in this instance is a circular arc, with a radius related to the height of the bulge, h, and width of the window, w, by:

$$r = \frac{w^2}{8h} + \frac{h}{2} \tag{1}$$

Then under a pressure, P, the tension is:

$$T = Pr \tag{2}$$

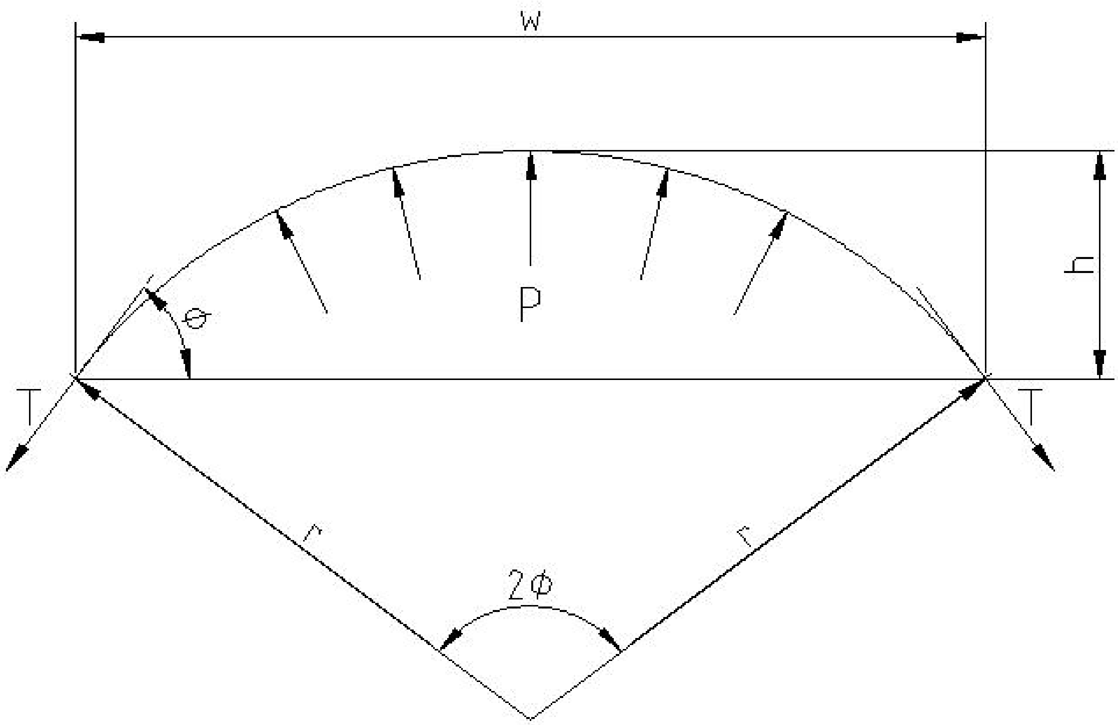

Figure 5: Force diagram of a strip of window material of unit width, under equal load per unit length, normal to surface. This approximates the window under pressure.

Thus, if we interpret w as the overall width of the window, 45.744", and assume our ideal circumstances, $h < 1''$ and $P = 14\ psi$, then the tension in the window is approximately 3700 lb/in, or approximately 6.5 kN/cm. However allowing up to 3" requires only approximately 2.2 kN/cm.

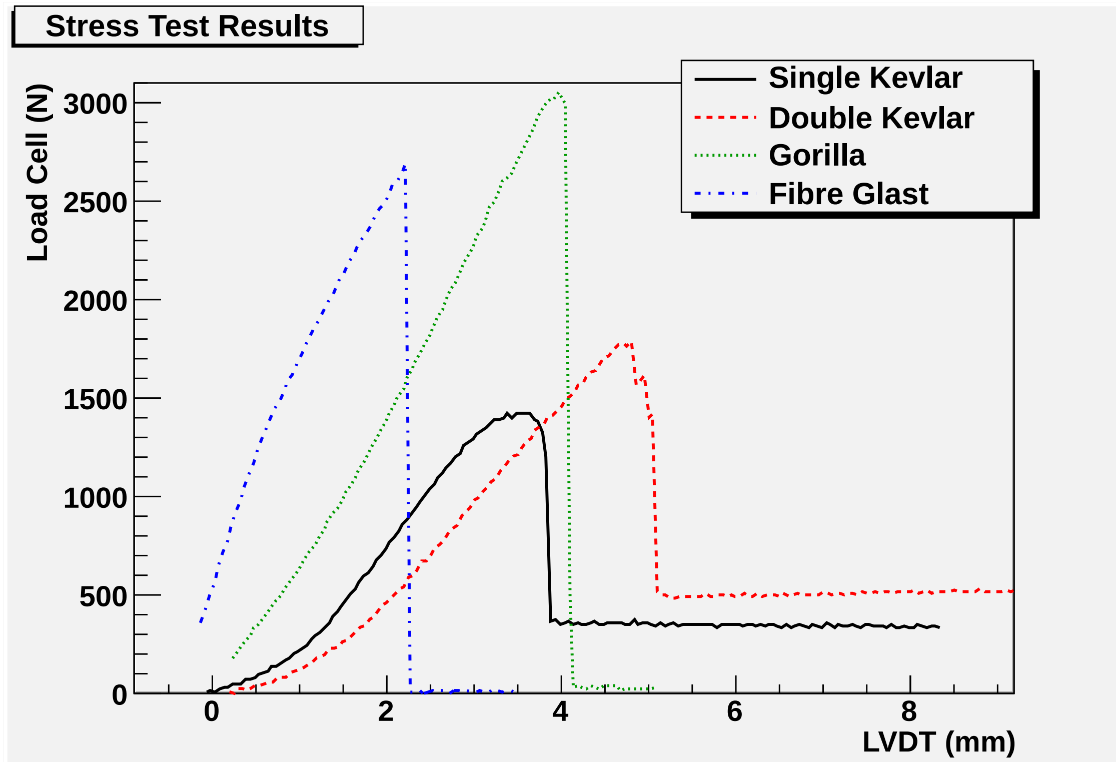

Figure 6: Results from stress test for four different configurations of Kevlar-mylar. The horizontal axis represents the distance the material has stretched. The vertical axis represents the tension in the sample.

2.2 Procedure

We use a stress testing machine to test the tensile strength of four different configurations of Kevlar-mylar: A single layer of each (the "single Kevlar" sample), two layers of Kevlar and one of Mylar (the "double Kevlar" sample), one layer of each bound with Gorilla Epoxy [3], and one layer of each bound with Fibre Glast epoxy (2000 epoxy resin, 2020 epoxy cure) [2]. The samples are cut to the specifications of the machine, and are 1.3 cm wide at the narrowest. This means they must tolerate a tension of at least 8.45 kN to meet our ideal requirements, or at absolute minimum 2.9 kN.

[PLACEHOLDER FOR TENSILE STRESS MACHINE SPECIFICATIONS].

2.3 Results

The results are shown in Fig. 6. The failure point of each sample can be seen in this figure as the sudden drop in tension. These failures occurred at approximately: 1.4 kN for the single Kevlar, 1.5 kN for the double Kevlar, 3 kN for the Gorilla Glue, and 2.6 kN for the epoxy.

We also note the state of the samples after the failure. See Fig. 7. The single and double layer samples tore apart, leaving frayed strands of Kevlar at the ends. The epoxy sample snapped more cleanly at the failure point. The Gorilla glue sample snapped at the failure point, but remained attached by a few threads of Kevlar.

Figure 7: Stress test samples after testing. From top to bottom: Single layer, double layer, Gorilla Glue, epoxy.

2.4 Summary and Conclusions

We see that the highest performing sample in terms of maximum stress is the Gorilla Glue sample. This sample failed at approximately 3 kN. This does not meet our ideal requirements, but does fall within tolerance for a 3" bulge.

The highest performing sample in terms of stretching is the epoxy sample. However we note that this sample is more brittle and less flexible than the others, and may be more prone to failure if used in the window, due to curvature.

Curiously, doubling the layers of material had minimal effect on the maximum tension, and appears to stretch more, which is counter-intuitive.

While none of these samples meet our ideal requirements (and only one meets the requirements for a 3" tolerance), we can see that there are substantial benefits the treating the material with epoxy.

References

[1] Challenge Sailcloth, Inc. 711 W 17th St, Cosa Mesa, CA 92627-4345. 949-722-7448

[2] Fibre Glast Developments Corporation. 385 Carr Drive, Brookeville, OH 45309. 800-383-8984

[3] Gorilla Glue, Inc. 4550 Red Bank Rd, Cincinnati, OH 45227. +1 513-271-3300

[4] Evans, R. S., et al. Heavy Gas Cherenkov Detector: Window Material Pressure Test, *Unpublished* (2016).