HGC Window Prototyping - July Testing Series

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As part of the prototyping process for the SoLID Heavy Gas Cherenkov detector (HGC), a suitable material for the entrance window must be found. The HGC will be filled with gas at a pressure of approximately 1.5 atm, or 22.0 psi (that is, 0.5 atm or 7.35 psi over-pressure), 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). In this series of trials, a miniature version of the HGC window is tested with 5 different material configurations.

1 Procedure

Due to warping of the frame in previous tests on the scaled down window, which consisted of a steel base plate and acrylic flange, an entirely new prototype has been constructed. This prototype has the same dimensions as the previous prototype (35.6 by 28 cm), with the following improvements: Both base plate and flange have been constructed from steel; The flange incorporated the new gripping arrangement for the wire and o-ring (detailed below); Over the course of these trials, all corners expected to contact the window material have been beveled at 45° and then smoothed with a file. Fig. 1 shows the cross-section of the flange.

The original flange to be used in these tests was 1/4" in thickness. However, after the second test it was deemed necessary to make a new flange with a thickness of 3/8", and a larger inner radius on the corners. The schematics for each flange are shown in Fig. 2.

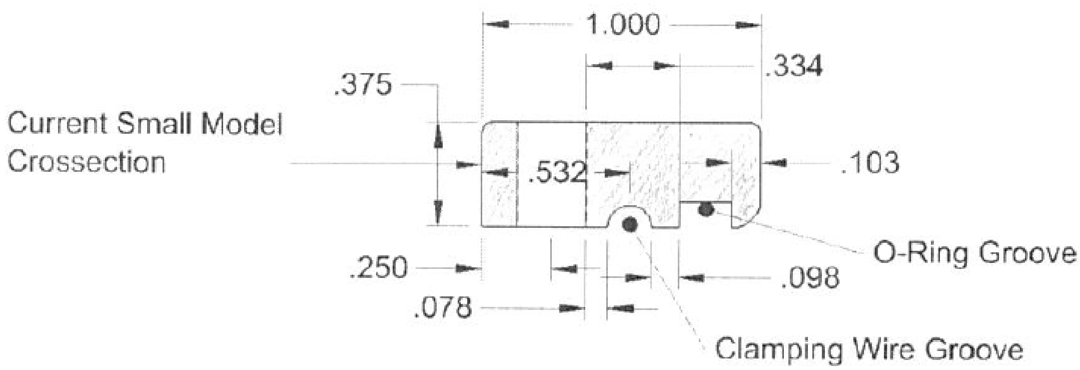

Figure 1: Cross-section schematic of window flange. All units are shown in inches. These specifications are based on design principles from Mapes and Leonhardt [2], and safety guidelines from FNAL [1].

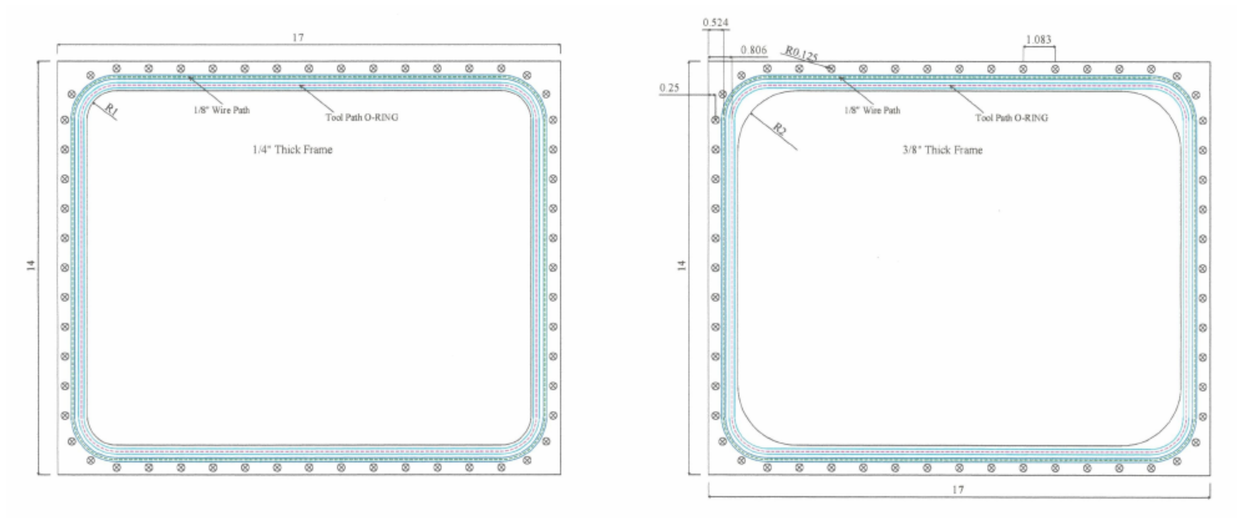

Figure 2: Schematic diagrams of the 1/4” (left) and 3/8” (right) window flange. The radius R1=1” was found to be too small according the FNAL guidelines [1], so was increased to R2=2”.

Based on results of prior tests, in which the clamping wire was placed outside of the bolts, the wire has been moved to be inside the bolts, consistent with the BNL thin window report [2]. The hypothesis is that the previous windows failed due to too much force being placed on the bolts, where the material is weak. Placing the wire inside should allow the wire to take this force instead. Fig. 3.

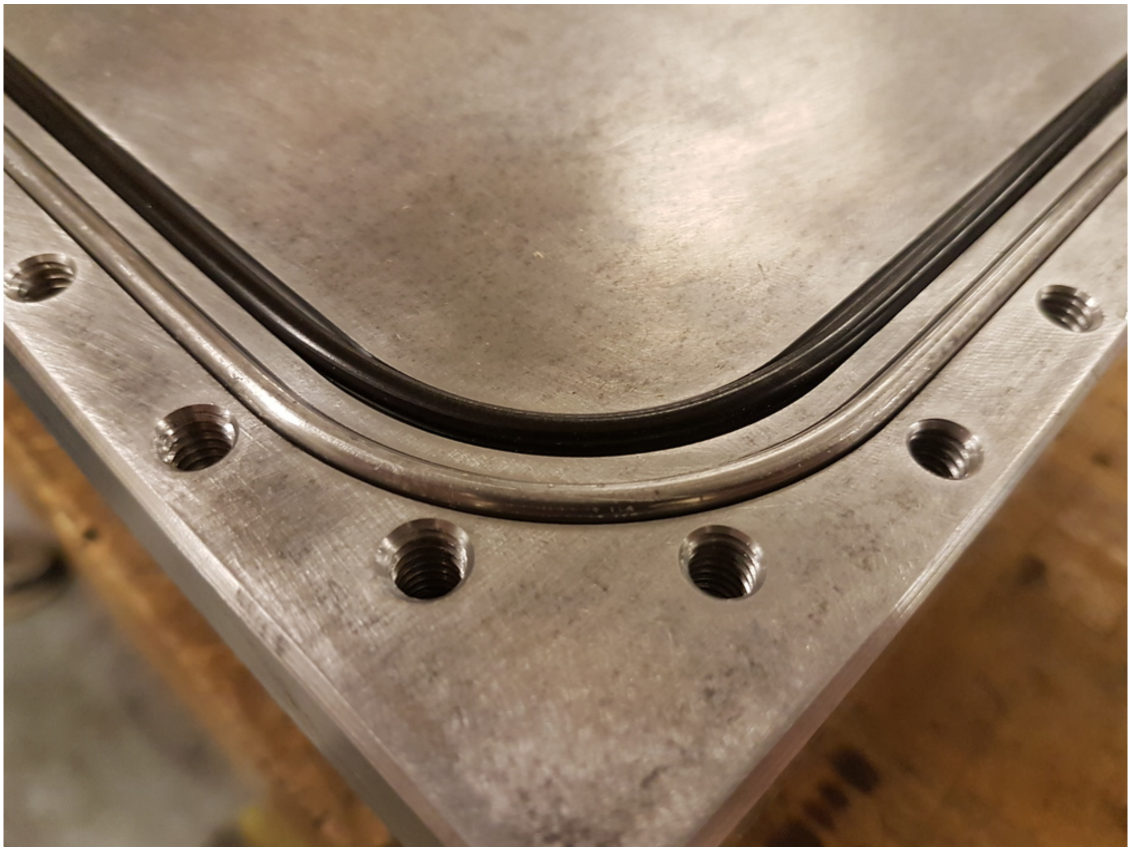

Figure 3: Close up of base plate edge, showing (from top to bottom), the O-ring, the clamping wire, and the bolt holes.

Each window in this series of tests was constructed from layers of Mylar (5 mil thickness), Kevlar (14 mil thickness) and LePage epoxy, in different configurations. The material was pre-stretched over a wooden frame. This was to eliminate the initial sharp increase in deflection noted in previous tests, assuming that that the pressure-deflection curve would start at the shallower slope, and give less deflection overall. A sheet-metal vice-grip was used to pull the material over the wooden frame under tension.

The details and variations between each trial are detailed in the following sections. Each window was inflated using a bicycle pump, measuring deflection at regular intervals in pressure. The pressure was increased until either the window experienced any form of failure, or a pressure of 60 psi was reached. At this point, further investigation was decided upon and conducted based on the results.

1.1 Mylar-Kevlar, Epoxy

The first test used one layer each of Mylar and Kevlar. The Kevlar was adhered to the Mylar using the adhesive backing included with the Kevlar. This layer was stretched over the wooden frame and stapled in place. The Kevlar was then coated with LePage epoxy and allowed to set. The material was then clamped into the window and cut from the wooden frame. The flange used in this test was 1/4” thick.

1.2 MKKM, Epoxy

The second test used two layers each of Mylar and Kevlar. Each layer of Kevlar was adhered to a layer of Mylar using the adhesive backing included with the Kevlar. The first layer was stretched over the wooden frame and stapled in place. The Kevlar was then coated with the epoxy and the second layer was stretched over it, while the epoxy was still wet. The two Kevlar layers were on the inside, with the Mylar on the outside. The epoxy was then allowed to set before the material was clamped into the window and cut from the wooden frame.

The 1/4” window flange was also altered for this test to give the inside edge a smoother radius. It was cut using a 45° bevel cutter, then filed to be smooth, to approximate the radius specified by the FNAL guidelines.

1.3 MKKM, Epoxy, Thicker Flange

The material for the third test was prepared by equivalent procedure to the second test. The primary difference is that the thickness of the window flange was increased by 50%, to 3/8”. This flange featured the same edge radiusing as in the second test, and an increased corner radius, as indicated by Fig. 2.

1.4 MKK, Thicker Flange

Based on results of the third test (see section), the fourth test omitted both the second layer of Mylar and the epoxy binding the Kevlar. For this test the first layer of Kevlar was adhered to the Mylar using the adhesive backing included with the Kevlar. The second layer was then adhered to the first layer of Kevlar, also using the included adhesive backing. This three layer material was then stretched over the wooden frame and stapled in place, before being clamped into the window, and cut out.

This test also used the 3/8” flange as in the third test, with one additional modification: The groove for the clamping wire was filed from the original rectangular cross section to a rounded one. This was done to remedy damage caused by the wire groove during the third test (see Section 2.3).

For this tests, the bolts were also tightened using a torque wrench. The bolts were torqued to 100 lb-in.

1.5 MKK, Thicker Flange, Construction Adhesive

The material for the fifth test was prepared by equivalent process to the fourth test. However before mounting to the window, LePage PL premium construction adhesive was applied to both the base plate, around the clamping wire, and to the wire groove in the flange. The material was then clamped into the window and left for 72 hours, to allow the adhesive to set, before being cut from the wooden frame.

This test used the same 3/8" flange as in the third and fourth tests, and the bolts were also torqued to 100 lb-in as in test four.

2 Results

The raw deflection data are summarized in Fig. 4. Fig. 5 shows the tension in the window material based on the approximation of the shape of the window as spherical, and that the tension is equal to the pressure times the radius of curvature.

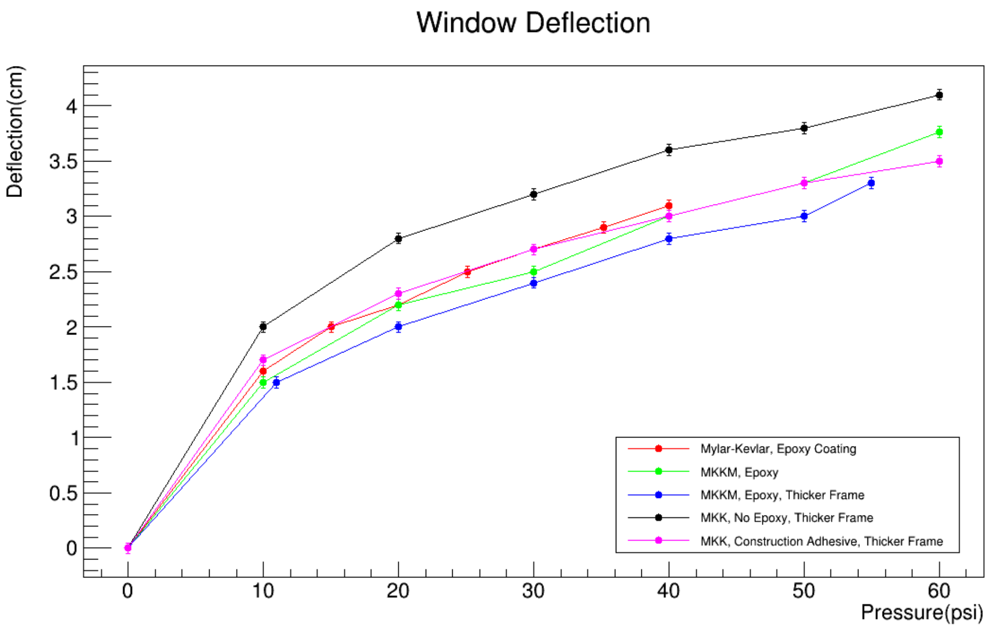

Figure 4: Raw deflection data of the five window tests.

These data indicate that the desired result of the pre-stretching was achieved; The shallower slope in the Deflection-Pressure plot sets in at a lower pressure, and the window bulges less overall. However, this has the undesirable side effect of increased tension in the window.

All windows in this series failed above 50 psi, versus the 35 psi failure point of the previous test using the acrylic flange. This indicates that the new clamp made a substantial improvement in gripping the window.

The results and extended procedures for each test are detailed in the following sections.

2.1 Mylar-Kevlar, Epoxy Coating

Between 40 and 45 psi, the window burst, ripping along three sides of the frame, as shown in Fig. 6. Fig. 7 shows the window after it was dismantled. It was hypothesized at this point that the window failed due to the sharp edge on the flange against the material. This edge of the flange was therefore radiused for the next test.

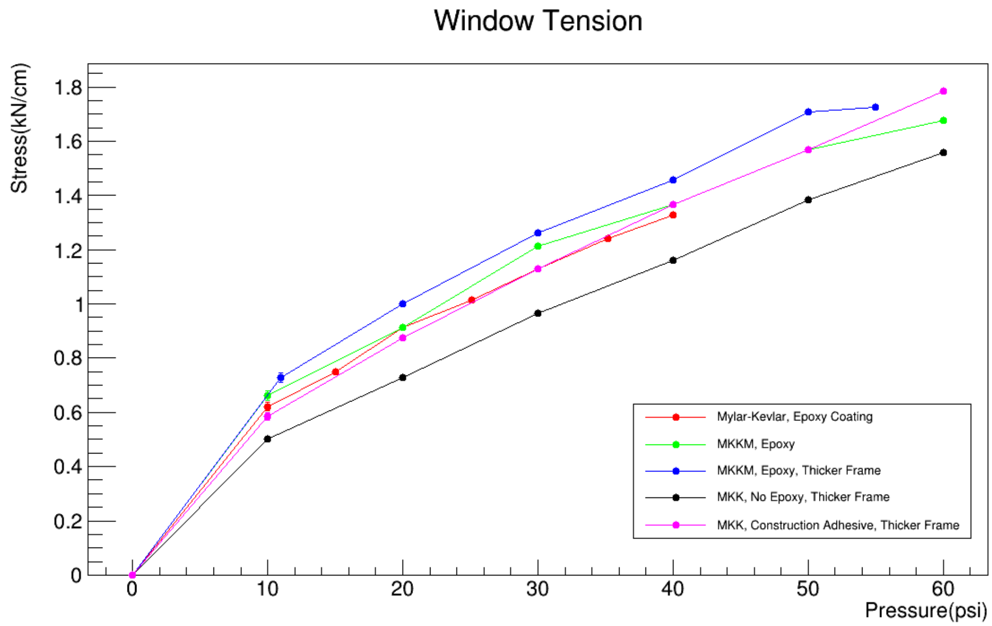

Figure 5: Tension in the material for each window.

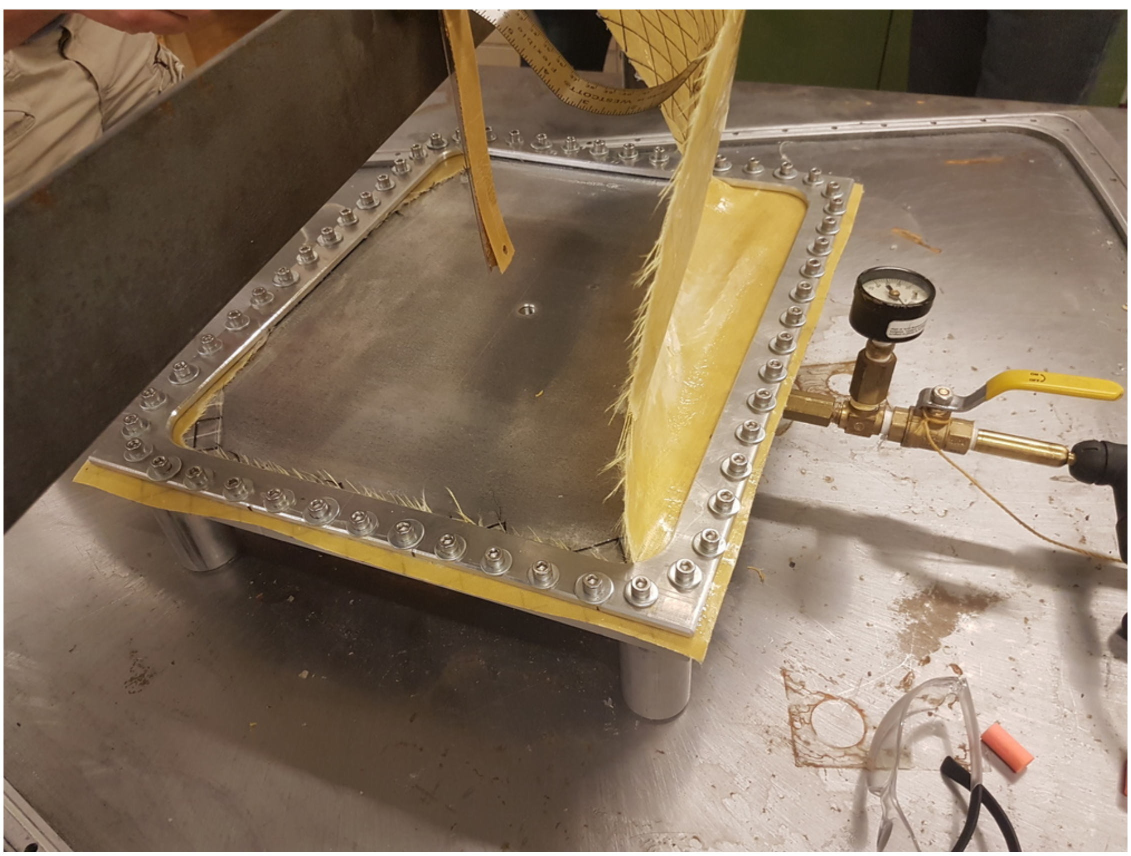

Figure 6: Mylar-Kevlar window after bursting during the first test.

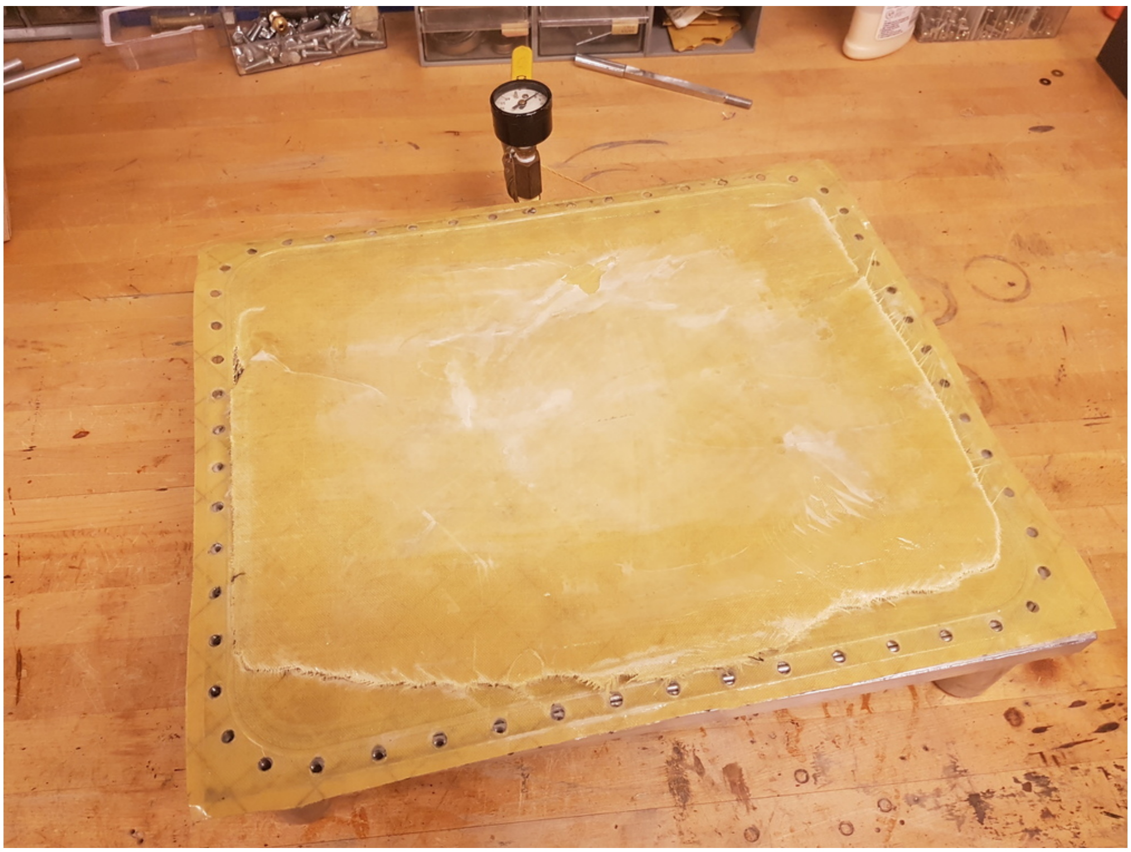

Figure 7: Mylar-Kevlar window after dis-assembly following the first test.

2.2 MKKM, Epoxy

During inflation, above 30 psi, the material layers began to separate around the edge, outside the window flange. The window reached a pressure of 60 psi with no obvious failure. The pressure decreased to 54 psi while the window expanded by an additional 4 mm.

The window was left at pressure for 30 minutes, after which the pressure had decreased to 25 psi. A spray-bottle with soapy water was used to check for leaking, but none was found. The window was re-inflated to 35 psi at which point air was found to be escaping between the material layers. Fig. 8 shows the separated layers, and the soap bubbles indicating the escaping air.

The bolts were tightened, and this appeared to stop the leaking as it was inflated again up to 52 psi, when the leaking resumed. Curiously, once the pressure dropped below approximately 30 psi the window appeared to stop leaking and maintain its pressure.

Fig. 9 shows a closeup of one of the edges of the window material after dis-assembly. It appears that the Kevlar layers were drawn inwards, while the Mylar remained mostly in place. As the Kevlar was drawn inward, the force was placed on the material near the bolts, leading to the tear visible here.

It was at this point hypothesized that the upward force of the inflated window was causing a prying action on the flange, weakening the grip on the material. It was then decided to use a thicker flange in order to reduce this effect and maintain grip strength.

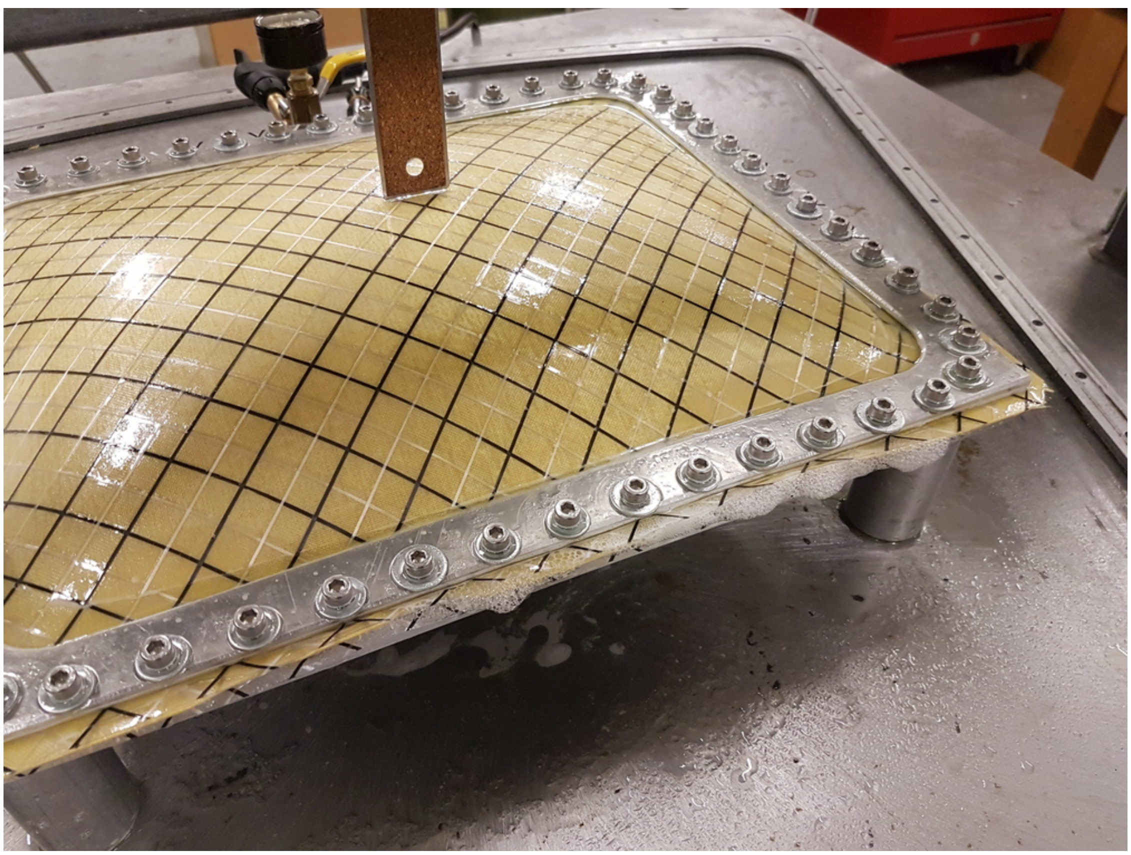

Figure 8: MKKM window after maximum pressure was reached. Soapy water was applied to the perimeter to make any leaks visible.

Figure 9: Closeup of tear in Kevlar layer of the MKKM window after dis-assembly following the second test. It is clear here that the Kevlar material slipped and tore along the bolt holes when under pressure.

2.3 MKKM, Epoxy, Thicker Flange

Between 50 and 60 psi, the same edge separation was observed as in the previous test. Fig. 10 shows the separation of the window layers. The window reached a pressure of 60 psi with no apparent failure. With the pump valve sealed, the pressure dropped to 58 psi as the window expanded an additional 2 mm.

The window was left at pressure for 30 minutes, after which the pressure had fallen to 50 psi, and the window expanded an additional 4 mm. Soapy water was sprayed around the circumference but no leaking was found.

The window was re-inflated to 60 psi and then left overnight. Over the next few hours the pressure dropped at a steady rate of less than 5 psi/hour. At some time between 19:00 and 20:00 (4 to 5 hours after inflating), the pressure in the window dropped to 23 psi, and then maintained that pressure for at least 12 hours.

At 09:00 of the next day, the window was re-inflated to 50 psi, and was found to be leaking around one of the bolts.

Fig. 11 shows the window material after dis-assembly. Despite the fact that this test appeared to be an improvement over the previous test, the damage to the Kevlar layer was much more extensive. Fig. 12 shows a closeup of the edge of the window at the top of Fig. 11. Once again, the two Mylar layers seem to have remained mostly in place while the Kevlar slid between them, tearing at the bolt holes.

Based on this damage, it was hypothesized that the friction and adhesive between the Mylar and Kevlar was not enough to hold the Kevlar in place. It was suggested that removing the top layer of Mylar might improve the grip by allowing the clamping wire to contact the Kevlar directly.

It was also noted after dis-assembly that the two layers of Kevlar, bound together by the epoxy, could be pulled apart (by hand) with significantly less force than the Mylar from the Kevlar, which were bound with the included adhesive. It was therefore decided to also forgo the epoxy in the next test.

Further damage was noted at the edge at the bottom of Fig. 11, as shown in Fig. 13. Here, the top layer of Mylar had been cut along the location of the wire groove. It was suggested that the wire groove in the flange had a sharp edge against the material, and so the groove was filed to be round for the next test.

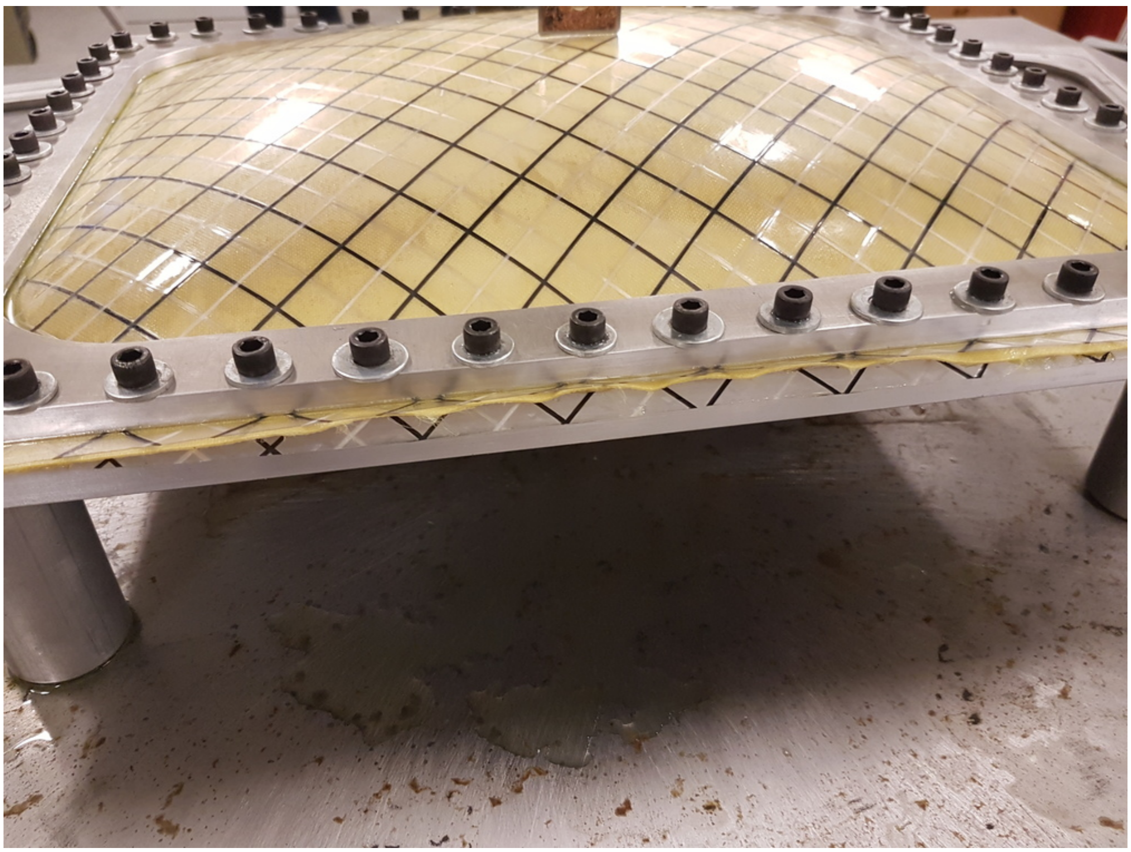

Figure 10: Separation of material layers in the MKKM window during the third test.

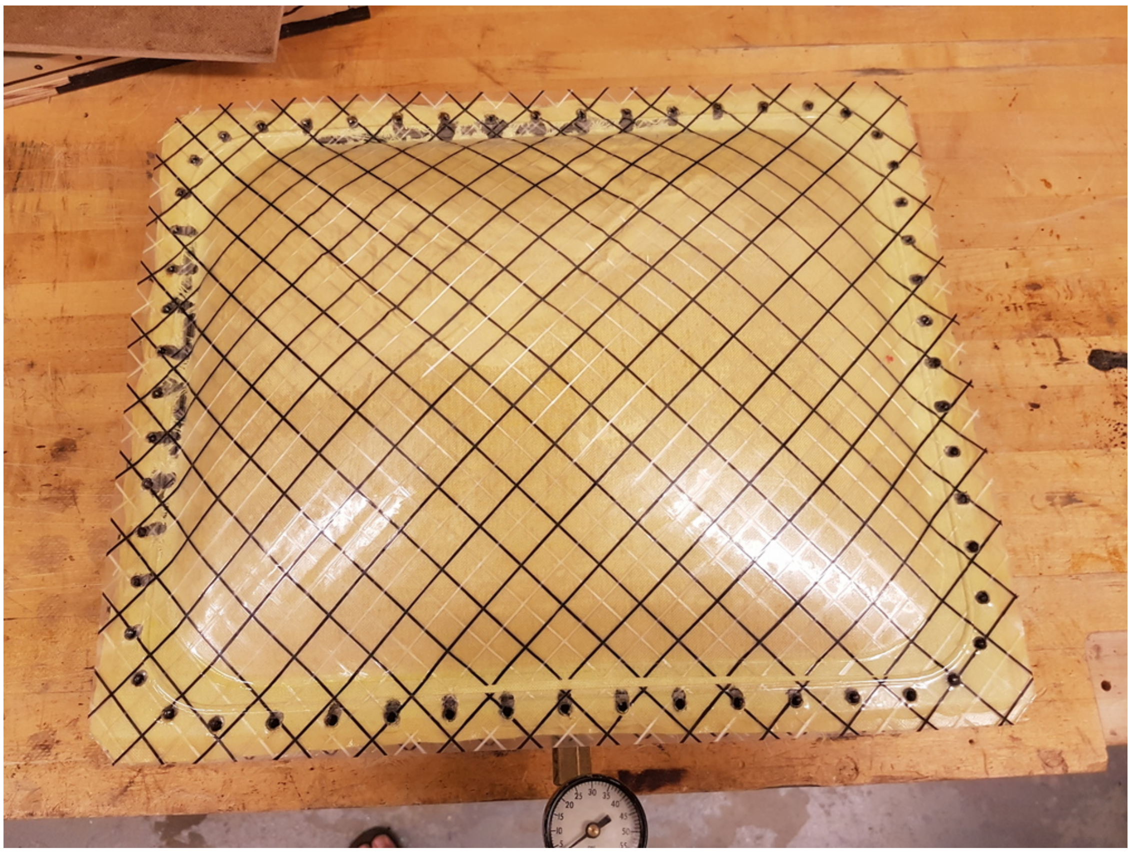

Figure 11: MKKM window after dis-assembly following the third test. Note the extensive tearing at the top and left.

Figure 12: Closeup detail of damage to the Kevlar layer in the MKKM window following the third test.

Figure 13: Closeup detail of damage to the top Mylar layer along the location of the wire groove, after the third test.

2.4 MKK, Thicker Flange

Once again, between 50 and 60 psi the edges of the material began the separate. After reaching 60 psi, the window was found to be leaking through one of the bolts and losing pressure. The bolt in question was the same bolt through which the window leaked in the previous test. The leak slowed as the pressure levelled at approximately 35 psi after a few (less than 10) minutes.

Since the test had already been deemed a failure, the opportunity was taken to perform a puncture test. A screwdriver was placed against the window and struck with a mallet. The screwdriver pierced the window, making only a small puncture, through which the window quickly, but steadily, deflated. There was no explosive burst.

The damage to the window material was similar to that seen in previous tests, though less extensive. Fig. 14 shows the only tear in the Kevlar layer after this test. The red dot shows the location of the bolt through which air was escaping. It was noted that this point lined up closely with the welded joint in the clamping wire.

Figure 14: Closeup of damage to the Kevlar layer after the fourth test. The red dot indicates the bolt hole which was found to be leaking while under pressure.

2.5 MKK, Thicker Flange, Construction Adhesive

In this final test, the window reached 60 psi without any issue. After closing the valve, the pressure slowly decreased by 5 psi total, while expanding an additional 3 mm. As this happened, the edges of the material began the separate, as in the previous tests. The pressure then dropped more rapidly to 50 psi, and a leak was found at one of the bolts.

It was decided then that nothing more could be learned from this window and it was dis-assembled. Similar damage to that found in the fourth test was found at one edge, as shown in Fig. 15.

Figure 15: Closeup of damage to the Kevlar layer after the fifth test.

3 Conclusions

This series of tests has several implications for the design of the HGC entrance window. First, the epoxy coating is not as helpful as previously thought. Furthermore, the second layer of Mylar on top may be more detrimental than helpful by lessening the friction between the clamp and the window.

The new clamp arrangement shows an overall improvement over the previous design. While the fifth test did ultimately fail, it was successful enough to warrant a full scale test using the same configuration.

References

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M. Mapes and W. J. Leonhardt, *Design of large aperture, low mass vacuum windows*, Journal of Vacuum Science Technology A: Vacuum, Surfaces, and Films 11, 1587 (1993); doi: http://dx.doi.org/10.1116/1.578509