Exploring New Glass Technology for the Glazing of Papyri

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TABLE OF CONTENTS

Proceedings of the 28th International Congress of Papyrology, Barcelona 2016
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1. Introduction

There is a general consensus that papyrus is best handled, exhibited, and stored between sheets of a transparent rigid material such as glass; however, debates remain as to the very best material for glazing. Managers and conservators of papyrus collections strive to use a material that is strong, lightweight, and withstands moderate handling and travel. Historically, soda-lime glass has been used, with acrylic being more recently favored in some institutions. The use of damaging materials such as cellulose nitrate, cellulose acetate, and static-laden polyester films are also found in collections.[1] There has been much advancement in the field of glass manufacture in recent years, influenced by the need for a light-weight, scratch-resistant, and unbreakable glass for the manufacture of watches, cell phones, PCs, and tablets. Brands of high-quality alkali-aluminosilicate glass such as Corning Gorilla Glass, Asahi Dragontrail, and Schott Xensation, are a key part of the electronic devices we use every day. The application of glass proven to be extraordinarily stable is worth exploring for use in glazing papyri. These new glass products are created using a high ion exchange (HIE) fusion process, which produces glass with extremely high impact and bending strength as well as scratch and crack resistance, while keeping the sheets thinner, lighter, and clearer than traditional panes of glass.[2] With a particular focus on Gorilla Glass, this article will explore how new types of glass may be successfully employed in the housing of papyri, including economic feasibility and an investigation of how it handles under stress in a variety of environments.

At the University of Michigan (U-M), with a collection of well over 18,000 fragments, one has to be very economical about how papyri are housed. It is not possible to glaze every fragment. There is not enough space, time, or resources to accomplish such an overwhelming task. Generally, papyrologists will separate fragments of interest from the hundreds within boxes for conservation treatment. Each of these fragments is a potential treasure, but housing them after treatment and cataloging is a challenge. A solution at U-M is to house fragments in folders within clamshell boxes in a temperature and humidity-controlled vault (fig. 1), in which 100% cotton blotter paper that has a slight texture to the surface is adhered to 20-point folder stock and the fragment is placed within. The texture keeps the papyrus from sliding within the folder. If there are multiple fragments associated with an inventory number, each fragment is placed in its own acid-free tissue folder, which is held within the larger folder. Glazing is designated for items that are handled frequently for scholarship and tours, displayed in exhibits, or going on loan. In general, U-M fragments have been glazed with annealed soda-lime glass, also referred to as float or window glass. The edges are lightly sanded, and the glass distributor provides sheets that contain no bubbles, flaws, or scratches. The edges of the glass sandwich are sealed with Filmoplast SH, which is a white linen tape. When fragments are glazed at U-M, the papyrus is anchored to the glass using tiny strips of

[1] Leach and Tait (2000) 245.
[2] Technical details and videos on Corning fusion manufacturing process: https://www.corning.com/gorillaglass/worldwide/en/technology/how-it-s-made.html

glassine, which is pre-coated with dextrin adhesive and can be remoistened with water, but this material is now difficult to acquire. More frequently, people use lightweight Japanese paper and wheat starch paste for anchoring papyrus to the glass. Most glazed items are stored vertically in the vault so that there is no weight resting on the fragments. For larger pieces that need to be stored horizontally, no more than a few are stacked. The largest challenge is housing oversized pieces. The majority of U-M's oversized papyri are currently glazed with acrylic. Some pieces are in special aluminum frames to keep them from torqueing, but the acrylic still presents problems to be discussed further, especially at this large size (fig. 2).[3]

2. Historic overview

There is a multitude of different materials historically used for glazing papyri. Many pieces collected in the 19th century, especially those in the British Museum collections, were mounted onto paper or board with a sheet of glass placed on top and bound along the edges with strips of leather or tape. Papyri were sometimes lined with linen as well. When fragments had writing on both sides, they were sandwiched between two sheets of glass. Regular window glass is still the most widely acceptable material for mounting papyri. Nitrocellulose film was used occasionally to back fragments. These fragments completely blackened and disintegrated and there is nothing that can be done to save them. They were essentially cooked by the off-gassing chemicals the way we see old movie film disintegrating at rapid rates. Fragments that were backed with gelatin film have deteriorated but remain comparatively stable. Wood and paper-based board backings are prone to warp and distort, damaging the papyrus. The only board that may be safe to use as a backing is Tycore honeycomb board (also known as Hexamount), but this obviously cannot be used with pieces that are double-sided. Laminated glass, such as safety glass, is much too heavy to be realistic. When regular glass breaks, it is held in place by the binding tape along the edges, so although laminated glass seems less prone to breaking, it is overkill. Last, Mylar (also known as Melinex or polyester film) is much too flexible and holds a tremendous amount of static –a problem that will also be explored further in this article.

There are about a half-dozen articles specifically written about 20th and 21st century papyrus housing methods, such as that at the Brooklyn Museum, Yale, and Princeton, which all use acrylic sheeting.[4] In Princeton's case, the housing also uses Stabiltex, which is a polyester multifilament textile, and Mylar. Papyrus fragments were stored in a different plastic material called Vinylite at the University of California, Berkeley (UCB) several decades ago. UCB provided some images of the damage done from their collections being housed in Vinylite, which is similar to Mylar (fig. 3). Vinylite is thin and flexible, and studies show that it is full of static. The intentions were excellent at UCB: since they are located right over an active earthquake fault, they did not want to use glass. Fragments were housed in Vinylite with the greatest care decades ago. But the static and flexibility of the material broke down the papyrus, turning it to dust. In the 1990s, UCB conservators worked with scientists in the university's microelectronics facility to find a system that would allow for safely opening the Vinylite enclosures. They ultimately worked with a company called Ion Systems, which supplied the air ionization system installed at the microelectronics facility at UCB. After careful measurements, static was proven to be the main cause of the harm done to the papyri in Vinylite.[5] They ended up using an air ionizer when opening the Vinylite housings to mitigate further damage (fig. 4). This worked well for them, and it is now an important piece

[3] Kaye (2015) 1-3.
[4] Owen (1993) 36-40; Noack (1986) 61-73; Stanley (1994) 49-55.
[5] Steinman (1997) 3B.6.1-5.

of equipment to have on hand when working with plastic housing materials in a papyrus collection. The ionizer is mounted about 30 to 40 cm away from the item, operated at a low fan speed, and both sides of the package are then neutralized as it sits on the work surface.

3. The use of acrylic

Due to its popularity, acrylic must be addressed further. It is a highly desirable and frequently discussed material that many people turn to for the housing of papyrus. There are many different grades and types of acrylic, but the most reputable company in the US is Tru Vue, which makes glazing products that are used by conservators and museum professionals and has conducted a lot of testing and scientific research to support the validity of their products.[6] One of their specialties is Optium Museum Acrylic, which is a conservation-grade glazing that incorporates a UV-blocking layer, along with an optical coating that allows for excellent light transmission and no reflection. It is also manufactured to be anti-static. In the past, acrylic often yellowed and discolored over time, and the thickness did not allow for the best visibility. Tru Vue prides itself in lessening the reflection that bounces off the surface, as well as creating a surface that is no longer easily scratched. The regular Optium Acrylic nonmuseum variety does not protect against UV, but papyrus collections are rarely exposed to UV light for long periods of time and exhibit cases are often built with UV filtering capabilities. In the search for a potentially safe acrylic for papyrus, Tru Vue's StaticShield looks the most desirable, and one that is chosen by colleagues working with papyrus collections. It is hard to find anything wrong with this product, as it claims to be more anti-static than glass, scratch-resistant, shatter resistant, and cleans like glass. But what raises concern is the proprietary coating engineered for static control. Whenever there is a coating that cannot be readily identified, one must consider whether its components can leach out over time, especially since it will be in direct contact with the papyrus. Tru Vue's glazing was not designed with direct contact in mind –in general when artwork is framed there is a window mat or spacers between the artwork and the glazing. This is a consideration when thinking of materials to use for glazing papyri, which will be touching the glazing material directly.

If acrylic remains the material of choice, at least the data shows that the anti-static properties of StaticShield hold up for long-lasting protection, and it also proves to be abrasion resistant, another strong plus. But no matter how many great properties a piece of acrylic may display, a major downside is its flexibility. This property may make it less prone to breaking, but when it comes to the papyri being supported between sheets of acrylic the flexing can cause real damage. The oversized items at U-M that are housed in unframed acrylic readily flex, resulting in risk whenever handled (fig. 5). Even when handled with care, grabbing the piece from one end will inevitably flex the entire package, potentially causing breaks or at the very least putting undue stress on the papyrus that is anchored on the acrylic. Additionally, some oversized items at U-M are mounted on foam board lined with fabric, with a sheet of acrylic resting on top of the papyrus. The static from the acrylic has caused small fibers to break off and scatter, some of which likely contain ink. Although pricier and newer varieties of acrylic may have improved working abilities, the higher quality choices are not always what people purchase outside the conservation community, due to budget constraints or lack of knowledge about all the choices available on the market. Concerns over coatings and the expansion and contraction of acrylic with fluctuations in humidity and temperature must still be considered. The papyrus at U-M is kept in a temperature-controlled storage vault, but the room where people use the collections has variable conditions and at times the temperature has risen to

[6] Please refer to Tru Vue's company website for in-depth studies and options: http://tru-vue.com

26ºC at a higher humidity than is appropriate for papyrus, so stability of the glazing material is a big concern. Acrylic sheets have an expansion allowance of 1.6 to 6 mm depending on temperature and humidity.[7] In addition, acrylic is more expensive than glass. Not many people are aware that acrylic is petroleum based, so it is susceptible to oil price spikes. As with gasoline, when the cost of a barrel of oil goes up, so does the price of acrylic.

4. The use of soda-lime glass

Aside from the popularity of acrylic, attention must turn back to soda-lime glass, because it is still used in the majority of papyrus collections today. The glass starts out as a mixture of very fine powders, including limestone, silica sand, and soda ash. The raw materials are very inexpensive, keeping it the most cost-effective option. Annealed soda-lime glass is used at U-M. When glass is annealed, it is slowly cooled to relieve internal stresses. When not annealed, glass is more likely to crack when exposed to temperature changes. Annealed glass will break off into large, sharp shards, which obviously poses safety risks. Another soda-lime glass variety to consider is chemically strengthened. As described by a representative at the glass distributor Abrisa Technologies, annealed glass is not the same as chemically strengthened. Most float glass is considered annealed glass. Chemical strengthening of glass requires that the glass be placed into a chemical bath for a prescribed amount of time, and the compression of the top layers of the glass is thus changed, making it stronger and more scratch resistant. Another popular glass variety used in the conservation community is borosilicate glass. This glass is commonly known for its use in laboratory glassware as well as Pyrex products. Glass chemist Otto Schott developed this glass to withstand sudden, uneven temperature shifts without shattering. This quality was obtained when Schott included boron in the glass recipe, which was later perfected by Corning scientists. Boron moderates vibrations that can cause shattering by making the distance between atoms in the glass almost identical, resulting in nearly zero net movement of the glass atoms.[8] With so little expansion, the glass does not break. Most notably, it is used to replace deteriorated glass in the conservation of daguerreotypes because it is physically stable, chemically inert, highly transparent, and has been tested in the conservation field as a component of accelerated aging packages for decades.[9] It is proven to be at least twice as stable as regular soda-lime glass, and can be ordered in varying thicknesses. A downside is that unlike soda-lime glass, it cannot be cut by hand and the cost is more significant.

With so many choices, debate over the best choice remains. Several years ago, on a discussion list for papyrologists, experts argued over the use of glass versus Perspex (acrylic).[10] Some of the most respected papyrus conservators in the world, including Bridget Leach, Myriam Krutzsch, and Leyla Lau-Lamb, responded with their complete support for the use of glass. In her response and numerous publications, Bridget Leach emphasizes that glass is preferred precisely because it requires such great care to handle. She explains that in her observations at the British Museum, glass has cracked or broken but the papyrus remained relatively unharmed because the glass takes the impact of the vibration and damage involved, not the papyrus.[11] To date, papyrus conservators have not published accounts on trouble with ink offsetting from papyrus onto glass. It is a very inert, smooth surface with no

[7] Tru Vue's Acrylic Collection Facts and Specifications: http://tru-vue.com/2016/01/acrylic-collection-facts-and-specifications/
[8] Corning Museum of Glass - All About Glass: https://www.cmog.org/article/finding-right-recipe-borosilicate-glass
[9] Bulat (2009) 151.
[10] Bulow-Jacobsen (2014).
[11] Leach (2005) 195.

risk of abrasion or static. Glass is very easy to clean with plain water and a paper towel, so no chemicals or special solutions are required. It may be breakable, but history shows that even when it cracks, the harm to the papyrus remains minimal because the damage is contained by the support of the second sheet and the binding at the edges. These items should be handled with the greatest care in the first place, so handling glass carefully is not an unreasonable request.

The main disadvantage is the microenvironment that is created between the two sheets, which can be seen manifesting in salt blooms. Papyrus contains salt deposits from being buried and exposed to soil at archaeological sites. The source of salt in the soil largely stems from the limestone and clays that lie beneath the desert sand. The composition of the salt is the same as simple table salt, and extensive research has shown that it does not harm the papyrus. If the bloom greatly disrupts legibility, it can simply be cleaned away from the glass with water or a little ethanol and water mixture, and the piece can be re-glazed again. Removing salt efflorescence must be considered carefully, however, because the salt may be an inherent part of the history of the papyrus, potentially revealing clues as to its origin and use.[12] It is important to note that more recently the conservator Jörg Graf produced a study, which indicates that the seemingly inert components of soda-lime glass may not be as inert as we think, depending on provenance and composition. His analysis indicates that a combination of fluctuating humidity, minerals in the glass surface, and minerals within the papyrus fragment result in float glass corrosion. Graf explains that the white bloom we often observe under the glass may arise from chloride ions in the papyrus reacting to the sodium ions in the glass, thus leading to glass corrosion.[13] Graf concludes that further investigation is needed, as observation with an electron microscope showed no significant surface changes took place where the bloom was observed.[14] He also aims to analyze borosilicate glass and whether it is conducive to bloom.

5. New glass technology

Along with the many pros and cons to consider with the more traditional glazing materials, it is time to consider new glass technology. Corning has always been a leader in glass manufacturing in the United States, and when cell phones and tablets took over the world, they observed that regular glass was not succeeding as a screen material. A tougher and more light-weight glass was required for portable electronics, so using glass technology they developed in the 1960s as inspiration, in 2006 Corning scientists started developing a glass that was damage resistant with a pristine surface quality and free of environmentally harmful materials such as arsenic, lead, and antimony. Corning uses a fusion-draw process that enables them to make the glass extremely thin, so grinding and polishing is not required, which are steps that can introduce flaws that weaken the glass matrix. The alkali-aluminosilicate sheet glass they developed, which they named Gorilla Glass, is ideal for the touch technology used in sleek electronic devices. There is a deep layer of high compressive stress created through an ion-exchange process, which is a type of chemical strengthening or tempering. Large ions are stuffed into the glass surface, creating a state of compression. The compression acts as a sort of ‘armor’, making the glass extremely tough and damage resistant. There have been five generations of Gorilla Glass to date, with each generation becoming thinner. It can be produced at a thinness of 0.4 mm. Gorilla Glass is by no means damage proof if subjected to enough abuse, but it is better at surviving real-world events. The

[12] Neate (2011) 153.
[13] Graf (2016) 51.
[14] Graf (2016) 51.

larger chemically strengthened depth in the Gorilla Glass prevents the damage from extending far into the matrix when compared to soda-lime glass. Illustrations provided by Corning in their product information sheets demonstrate the way damage is suppressed in Gorilla Glass.[15] For example, the comparison of a scratch test applied to the two kinds of glass clearly demonstrate how scratches are visible to the naked eye in soda-lime but nearly invisible in Gorilla Glass. Corning also created a Gorilla Glass variety that is antimicrobial, but one must remain wary of the coating they use. The coating is not meant to last longer than the lifespan of a typical device, which is really not long at all, seeing as people cycle through their devices every few years. Corning developed an easy-to-clean coating as well, but again, it is not clear how stable it is or what goes into it that may potentially harm a papyrus fragment in direct contact with the surface. Another consideration is that haze is a problem with soda-lime glass as it ages, and regular non-coated Gorilla Glass is not immune to haze, but still out-performs soda-lime glass.[16]

A small collection of samples from a few glass distributors were obtained for experimentation, including samples obtained directly from Corning, the manufacturer. Corning's business director of emerging innovations, Hank Dunnenberger, provided samples of Gorilla Glass-1 in various thicknesses including some oversized pieces. While the clarity and lightness of the largest pieces are unparalleled, they were very flexible. The large pieces used for experimentation were 1 mm in thickness, which was the thickest available for the largest sheets. Fig. 6 illustrates two 1 mm pieces placed together, which still remain flexible. It is strong, but the flexibility is a problem with papyrus unless the piece is single-sided and mounted on a stiff board such as Tycore, which is the most dimensionally stable of any fiber based mounting board. Another solution is to build trays out of Tycore and then place the papyrus glazed in Gorilla Glass in the tray for handling. But it remains a challenge if a papyrus has writing on both sides and would require careful support to turn it over. Acrylic has the same flexibility problem, so the downside is shared between the two materials. A frame is another potential solution for increasing stability, such as the aluminum frames used at U-M for oversized pieces glazed with acrylic. Apart from flexibility, another downside to Gorilla Glass is that Corning is unable to provide any information or test results on the longevity of aluminosilicate glass, as there are no artificial aging tests completed to date. Personal consultation with glass scientists shows confidence that the aging will directly parallel other trusted varieties of glass due to the fact that it contains no harmful ingredients; however, this has not been technically proven when it comes to aluminosilicate glass. There is a lack of urgency to prove longevity, likely due to the short life spans of electronic devices where it is used most. Despite some of the unknowns, the conservation department at the University of Chicago Library recently put Gorilla Glass to use for one of their papyrus fragments. The Gorilla Glass they ordered was 1.1 mm thick and from McMaster Carr.[17] Personal communication with Ann Lindsey, head of conservation, shows a high level of satisfaction with the material. While there was some worry about the thin glass torqueing, it did not show any movement with two layers taped together. Patti Gibbons, head of collections management in special collections at the University of Chicago, stated: «So far, I, too, think the papyrus glass is a nice solution. It looks wonderful, it is lightweight, and easy to handle. The older glass is much thicker and gives me 'crash anxiety' where I worry about handling accidents where someone would accidentally drop and shatter the glass and harm

[15] Gorilla Glass 2 product information sheet: http://www.valleydesign.com/Datasheets/Corning-Gorilla-glass.pdf
[16] Please refer to Corning's company website for more information on Gorilla Glass: https://www.corning.com/gorillaglass/worldwide/en/technology/technology-overview.html
[17] McMaster-Carr Gorilla Glass size and price list: https://www.mcmaster.com/#gorilla-glass/=16wbnuq

the papyrus fragment». The Library of Congress has also started to put Gorilla Glass to use for their small papyrus collection, and personal communication with conservator Yasmeen Kahn has also resulted in positive feedback for the housing of small fragments.

6. Conclusion

Pros and cons run through all three materials as seen in fig. 7. The workability of Gorilla Glass with papyrus proved to be satisfying overall; however, for the time being soda-lime glass will be kept in use at U-M due largely to budgetary restrictions. It is worth pursuing the idea of using Gorilla Glass for special cases, groups of items that are handled frequently, and oversized items, despite the flexibility of large pieces. The ease of handling, stability in different climates, easy cleaning, and light weight in storage would make Gorilla Glass a joy in a papyrus collection. The fact that there is little to no concern over scratches and the optical clarity is extremely sharp is also appealing when thinking of users' needs. But if Gorilla Glass is too expensive, at least conservators and papyrologists can generally be confident about the dimensional stability and impermeability of the more affordable glass options, still making glass a safe choice for years to come. In the end, the reality of Gorilla Glass comes down to cost. A cost comparison for each type of glass can be found in fig. 8. The high cost of several of these options is likely to be prohibitive in many institutions. Perhaps if grant money is obtained for a housing project, the choices can broaden. Anyone can appreciate the rarity and awe-inspiring survival of papyrus, and proposing to use a material for its housing that can withstand the stresses of use even better than any material encountered to date does not seem too much to ask. The industries that are beginning to request Gorilla Glass are expanding rapidly.[18] As it starts to be used for more products in the world, the cost of Gorilla Glass is also likely to decrease, making it the material of choice for glazing papyri, bringing the ancient and modern to a unique crossroads.

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[18] Gorilla Glass was recently in the headlines for use in the automotive industry: http://mashable.com/2017/01/05/corning-gorilla-automotive-glass-ces/#L6JZhtwSnOqZ

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Plates

Fig. 1. Clamshell boxes housing papyri on shelves in the vault at the University of Michigan. ©Marieka Kaye. University of Michigan.

Fig. 2. Papyrus fragment glazed with annealed soda-lime glass. ©Marieka Kaye. University of Michigan.

Fig. 3. University of California Berkeley, old housing using Vinylite. ©Center for the Tebtunis Papyri,The Bancroft Library, University of California, Berkeley.

Fig. 4. Air ionizer used to reduce static when opening plastic based-housings. ©University of Michigan.

Fig. 5. Flexing of acrylic glazing. ©Marieka Kaye. University of Michigan.

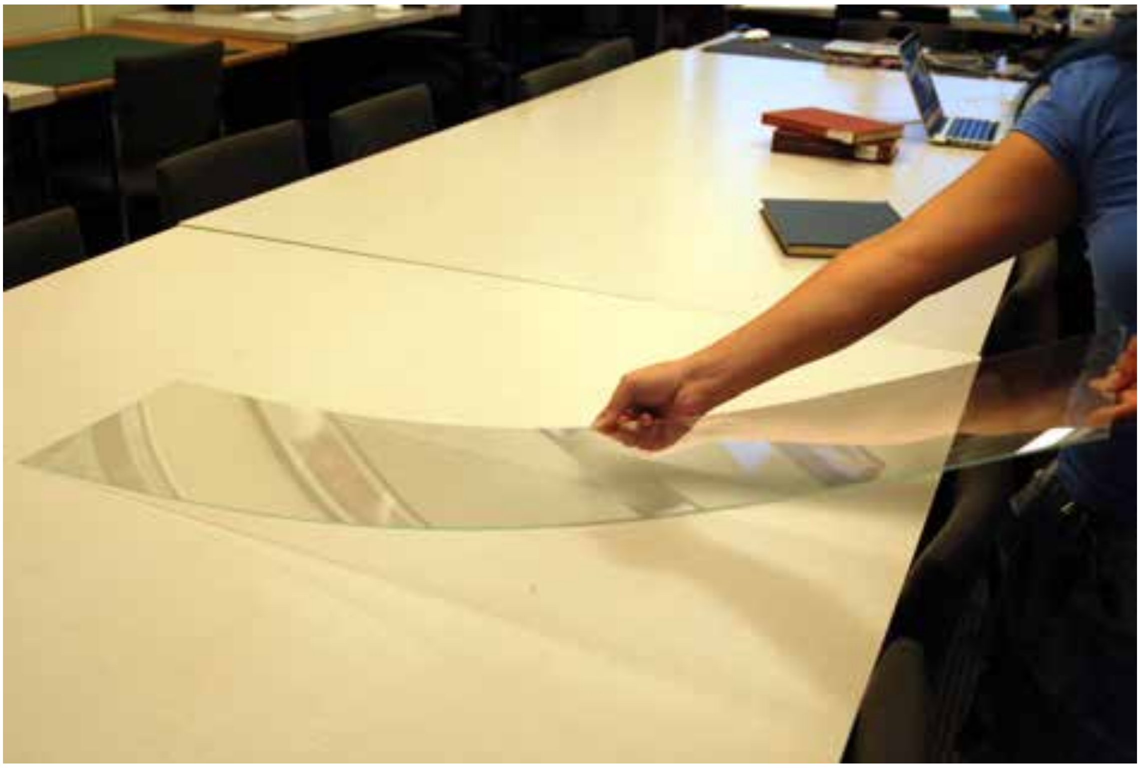

Fig. 6. Flexing two pieces of 1 mm thick Gorilla Glass sandwiched together. ©Marieka Kaye. University of Michigan.

Gorilla Glass	Soda-lime Glass	Acrylic
Nearly unbreakable	Can break & damage papyrus	Shatter-proof
Easy care & scratch-resistant	Easy care & scratch-resistant	Requires special cleaner & soft cloth; easily scratched
Lightweight, thin, flexible	Heavy, thin, inflexible	Lightweight, thick, flexible
Optically clear with no discoloration over time	Green tint; color distortion with extra thickness or coatings	Clear but can yellow over time
Nonporous & impermeable	Nonporous & impermeable	Permeable to gas, including water vapor
Most expensive	Cheap	Expensive
Easy transport	Difficult transport	Easy transport
Non-flammable	Non-flammable	Flammable
No size fluctuations	Negligible size fluctuations	Expands & contracts due to temp & humidity

Fig. 7. Pros and cons of soda-lime, acrylic, and Gorilla Glass.

Type	Size	Cost
Annealed (heat strengthened) soda-lime glass	8 x10", 1.1 mm	$8.61
Chemically strengthened soda-lime glass	8x10", 1.1 mm	$9.97
Tru Vue StaticShield acrylic	8 x10", 3 mm (thinnest available)	$14
Borosilicate glass	8 x 10", 1.1 mm	$20.40
Gorilla Glass	8 x 10", 1.6 mm	$25.55

Fig. 8. Cost comparison of available glazing materials.