

Considerations in Manufacturing Cemented Assemblies

Brandon Light
Optimax Systems, 6367 Dean Parkway, Ontario, NY USA

This paper will examine options in construction of cemented lens assemblies, and considerations for mechanical mounting and cement selection will be offered.

DESIGN OF CEMENTED LENS ASSEMBLIES

When designing an optical system, one design strategy may be to incorporate cemented lens assemblies¹. This involves cementing two or more lenses together to build a lens assembly. Strain in excess may cause delamination or fracture of the assembly elements². Accordingly, management of strain within the assembly represents the main challenge in employing cemented assemblies.

There are some inherent sources of strain in cemented assemblies. To provide achromatic performance, assemblies are made from spherical elements of crown and flint materials. Looking at an example achromat³, the coefficient of mean linear thermal expansion (CTE) for F2 is over 25% larger than SK11⁴. Looking at the ~80 - 100°C temperature range specified in standard thermal cycling^{5,6} one can expect to see differential expansion causing stress within the cemented assembly. Additionally, the cement itself shrinks as it cures, leading to deformation of the lens⁷ and degradation of system performance.

There are geometric considerations that can be made in the design stage to benefit the assembly process and the robustness of the cemented lens assembly. The stress from the above sources acts normal to the surface⁸. Highly curved interfaces experience a net force gradient as a function of included angle, with forces cancelling out or doubling at the edge of a hemispherical surface. Accordingly, highly curved interface surfaces should be avoided, and when necessary, choosing radii to create space for a layer of adhesive of uniform thickness at the interface is advised⁹.

Additionally, assembly stress can cause print-through, stress at the interface deforming the external surface. Elements of high aspect ratio (diameter/center thickness) elements are especially prone. Accordingly, lens designers suggest maximum diameters¹⁰ or avoiding thin lenses¹¹ to avoid print-through.

MECHANICAL CONSIDERATIONS

After choosing an optical design, consideration must be given to the physical layout of the elements. Accommodations are made for mounting, cleaning and manufacture of the cemented lens assembly.

Mounting Scheme

When discussing assembly process selection with the optical fabricator, having information about the planned mounting scheme for the cemented assembly available is beneficial. The fabricator can consider how the lens will be mounted when proposing an assembly method, and the fabricator can use the same datums used in mounting the cemented assembly as datums of the assembly process. Depending on the assembly method, there may need to be additional clearance space provided. More information on this can be found in the related Assembly Method Considerations for Cemented Assemblies Technical Note.

Practical Concerns

There are some practical concerns that may not be readily apparent. Avoid pockets at the interface when possible. These collect debris and prove hard to clean without exposing the cement interface to potentially damaging solvents. Figure 1 shows the condition to avoid.

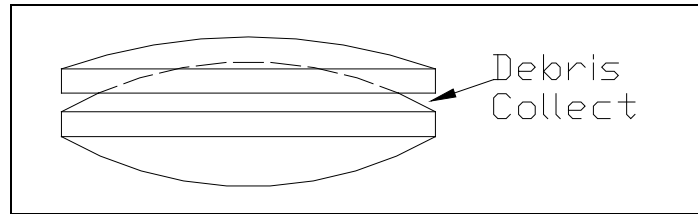


Figure 1 - Doublet with undesirable pocket at interface

Be sure there is some way to tell the external surfaces apart. When possible, use obvious physical indicators (visibly distinctly different external radii or edge thicknesses), and this is the most successful approach. There may be an unavoidable need for marked indication, an arrow or chevron drawn on the edge. For cemented lens assemblies with little edge thickness a different size bevel may serve as a guide.

CEMENT TYPES AND BACKGROUND

The optical cements currently used at Optimax are synthetic polymers falling into one of three categories: thermosetting, catalyst, photopolymer. All of these work in a similar manner, differing only by method and time of curing.

Thermosetting is the oldest form of synthetic optical cement, and heating induces polymerization. The assembly must be held immobile and heated to 100°C for an inconvenient 16 hours, a potentially stress inducing process from thermal swell and contraction¹². Additionally, shrinkage due to volatile solvent evaporation can run up to 20%, aggravating the stressed condition¹³.

Catalyst cement involves adding a cobalt/organic or peroxide catalyst to the thermosetting cement to lower cure temperature¹⁴. The assembly needs be heated to only 70°C, but the assembly must be still held immobile for 3 hours. Room temperature cure over a period of days is possible¹⁵, removing the risk of thermal stress. With shrinkage initially at ~10%¹⁶, stress related to shrinkage is an issue. Improved cements have reduced shrinkage relative to early values.

For both thermosetting and catalyst cements, curing begins upon mixing. The cement is pliable for about 15 minutes (pot life), after which the assembled elements cannot be repositioned relative to each other¹⁷.

Photopolymer cements represented the biggest leap forward. Polymerization is activated by ultraviolet light, and polymerization begins instantaneously with irradiation. The elements may be handled or repositioned and cement wiped away with an acetone wipe until cured. Photopolymer cements also do not release volatile solvents, so there is little or no shrinkage¹⁸. Full curing takes less than an hour, and the assembly can be moved from the assembly fixture after a 10 – 20 second exposure¹⁹. Cure times do need to be adjusted based on UV transmission of the material, scaling in proportion to transmission.

SELECTING AN OPTICAL CEMENT

Cements must be transparent in the spectral region of interest, have good adhesion characteristics, have acceptable shrinkages and be robust in the environment of use²⁰. Below are some considerations when selecting cements with respect to these functions.

Mechanically speaking, the thermosetting and catalyst cements are stronger²¹ than the photopolymer cements, resulting in a more rigid bond. The rigidity may produce strain and distort the surfaces if the assembly is stressed in mounting.

The temperature range of use for the assembly must be considered in assembly selection. The CTE should be close to the materials to prevent thermal stress. The cement must not soften within the range of use to prevent elements from moving out of position. Additionally, the cement must not outgas, causing

shrinkage and potential redeposition of evaporate on the optical surfaces²².

Refractive index of cements fall into the 1.48 - 1.58 range. While promoters to raise index are available, they can have a terrible effect on pot life. An antireflective coating can be applied to one side of the interface to mitigate Fresnel reflection losses, but as the difference between material and cement index grows so will losses. For example, if one component of the doublet is $n=1.8$ and the cement is $n=1.5$, the reflection from the glass/cement interface will be nearly 1%. If this is unacceptable, an AR coating will need to be designed that is optimized for glass/cement rather than a glass/air interface.

While refractive effects of the cement layer can be neglected²³, the transmission characteristics cannot. The cement needs to transmit in the wavelength range of use for the assembly, and any transmission loss must be accounted for in the design. Figure 2 shows a sample transmission curve for a representative photopolymer cement. Additionally, when planning to use photopolymer cements, at least one of the materials to be cemented must transmit at the curing wavelength of the cement.

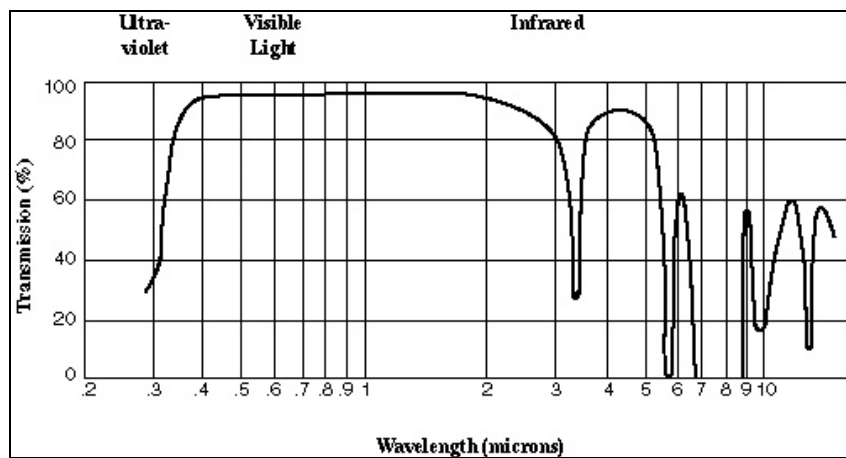


Figure 2 - Transmission curve for Norland 61 cement (norlandprod.com)

The cement must not be so viscous as to not wet the surface properly yet it must be capable of maintaining some thickness and uniformity²⁴. The pH of the cement must be considered to prevent chemical attack. The cement also must not be hazardous to the assembler, nor the chemicals used to remove it.

Cement Selection As A Tool For Managing Assembly-Related Stress

The curing process must produce only manageable distortion. Distortion stems from the curing process as detailed earlier, and while some design steps can be taken to mitigate it, the risk remains. Cure uniformity and the pace at which curing occurs has the biggest influence²⁵ in the assembly process. Heating rates in thermosetting cements, choosing to heat at all for catalyst cements, or how UV light is applied to photopolymer cements²⁶ are all examples of stress mitigation tools the fabricator may employ.

Cement choice can help here too. At strongly curved cemented interfaces, the incident UV cure radiation may preferentially pass through center, possibly not getting to the edge at all, and cause a differential rate of curing across the aperture. Radial stress can result, and choosing a catalyst cement cured at room temperature may be a better option. For robust elements with a strong difference in CTE, choosing a photopolymer cement over a thermosetting cement would be a sensible option. The rapid cure and lack of heat would prevent thermal stress from accumulating. For thin elements, a catalyst cement mixed to a high cement to catalyst ratio (slows cure rate) put through a slow, room temperature cure (minimal thermal stress) with ample overflow of cement (offsets shrinkage) could minimize assembly-related stress. For demanding applications, the cement and curing conditions should be specified on the drawing following a successful simulation with modern finite element modeling tools.

WORKING WITH OPTICAL CEMENT

The cementing process begins with preparing the selected cement according to manufacturer instruction. This could involve adding a catalyst, stirring or removing trapped gasses or water by outgassing under vacuum. The cement is applied to the cleaned cement interface, and the layer is worked down to desired thickness by rolling the two elements together about the interface. Excess cement is cleared away using a solvent dampened wipe. The assembler now checks the assembly for cement fringes, interferometric indication of thickness variation or tilt in the cement layer²⁷. Cement fringes look like a bullseye pattern, either centered (thickness variation) or decentered (tilt). The assembler also checks for bubbles or voids in the layer, adjusting the assembly as needed.

Once the cement is applied the elements are positioned using one of the alignment methods discussed in the related Assembly Method Considerations for Cemented Assemblies Technical Note. When using catalyst cement the alignment must be performed swiftly before the cement becomes sufficiently set. Once the elements are positioned the cement is cured. After curing, positional accuracy of the elements is checked, and the assembly is checked for distortion due to cementing. If all is well the assembly is ready to go. If not, the assembly is taken apart by soaking in solvent, a risky, time consuming endeavor. Once apart, the parts are cleaned and checked for staining, and the assembly process is repeated.

CONCLUSIONS

- Managing Assembly-related stress is key to specifying cemented assemblies. Areas of focus include:
 - Lens design geometry (Keep interface curvatures mild, avoid thin elements)
 - Lens material selection (CTE mismatch)
 - Cement selection (Cure uniformity and the pace at which curing occurs)
- Declare the mounting scheme. It will help in assembly process selection.
- Optical cement has one function: hold the assembly together without changing optical performance.

¹ R. Kingslake, *Lens Design Fundamentals*, Pg 4, Academic Press, New York City, 1978

² A. Clements, *Selection of Optical Adhesives*, Pg 15 - 16, College of Optical Sciences, Presented at University of Arizona on December 12, 2006

³ W. Smith, *Modern Lens Design*, Pg 115-118, McGraw Hill, New York City, 2005

⁴ Both values from Schott Glass Catalogue, 1978

⁵ MIL-A-3920B, *Adhesive, Optical, Thermosetting*, US Govt., 1974

⁶ MIL-STD-810A, *Environmental Test Methods for Aerospace and Ground Equipment*, US Govt., 1964

⁷ R.E. Fischer, B. Tadic-Galeb, P. Yoder, *Optical System Design*, Pg 501, McGraw Hill, New York City, 2008

⁸ Summers Optical, *The Bonding of Optical Elements – Techniques and Troubleshooting*, Pg 5, emsdiasum.com, 2008

⁹ Summers Optical, *Bond Failures – Causes and Remedies*, Pg 2, emsdiasum.com, 2008

¹⁰ R. Kingslake, *Lens Design Fundamentals*, Pg 4, Academic Press, New York City, 1978

¹¹ R.E. Fischer, B. Tadic-Galeb, P. Yoder, *Optical System Design*, Pg 501, McGraw Hill, New York City, 2008

¹² J. Maygar, "History and potential for optical bonding agents in the visible", *Passive Materials for Optical Elements*, G. Wilkerson editor, Vol. 1535, Pg 55, SPIE, Bellingham, WA, 1991

¹³ Ibid

¹⁴ H.H. Karow, *Fabrication Methods For Precision Optics*, Pg 226, John Wiley & Sons, New York City, 1993

¹⁵ Ibid, Pg 228

¹⁶ Ibid

¹⁷ Ibid, Pg 226

¹⁸ Ibid, Pg 228

¹⁹ Ibid, Pg 229

²⁰ P. Yoder, *Mounting Lenses In Optical Instrumentation*, Pg 9, SPIE, Bellingham, WA, 1995

²¹ Comparison of vendor-supplied mechanical properties data: Catalyst cement Summers M-62 vs Photopolymer Norland 61

-
- ²² A. Clements, *Selection of Optical Adhesives*, Pg 4, College of Optical Sciences, Presented at University of Arizona on December 12, 2006
- ²³ R. Kingslake, *Lens Design Fundamentals*, Pg 4, Academic Press, New York City, 1978
- ²⁴ A. Clements, *Selection of Optical Adhesives*, Pg 3, College of Optical Sciences, Presented at University of Arizona on December 12, 2006
- ²⁵ Summers Optical, *The Bonding of Optical Elements – Techniques and Troubleshooting*, Pg 6, emsdiasum.com, 2008
- ²⁶ D. Green, "Minimizing cement strain while cementing thin lenses using ultraviolet light", *Adhesives Engineering*, E. Norland & K. Liechti editors, Vol 1999, Pg 22-24, SPIE, Bellingham, WA, 1993
- ²⁷ G Sharma and G Dimri, "Interferometric Countercheck In Precision Cementing", *Applied Optics*, Vol 22, Pg 1132-1133, OSA, Washington DC, 1983