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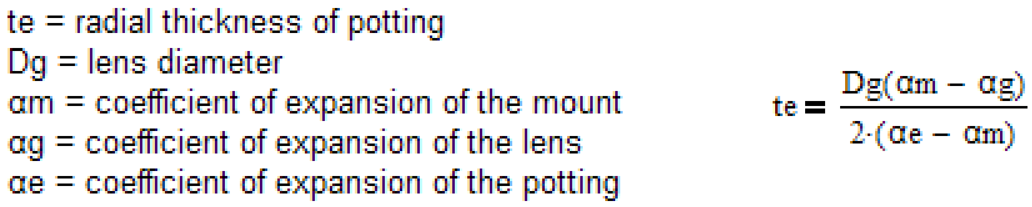
Synopsis of a Technical Paper

Report Chosen:
K.A. Miller “Non-Athermal Potting of Optics” in Proc. Optomechanical Design and Engineering SPIE Vol 3786 July 1999 pp. 506-514

Summary of Paper:

Kirk Miller's report on “Non-Athermal Potting of Optics” focuses on the risks of designing elastomeric lens mounts without fully athermalized bond gaps. An athermalized bond gap is a design that matches the lens and bond gap dimensions to the CTE (coefficient of thermal expansion) of the materials. This design produces a theoretical stress free mounting of a lens, over changes in temperature where the CTE remains linear. In many cases a fully athermalized bond gap is not practical or feasible, designs that have very tight size or weight constraints may not accommodate fully athermalized designs. Miller uses finite element analysis to compare Bayar's[i] athermalized potting gap calculation (figure 1) results to smaller bond gaps. The finite element analysis was performed on three different lens types: Convex-Concave, Convex-Convex, Concave-Concave. The lens material, elastomeric adhesive and barrel material were all kept the same for comparison. Each one of these lenses were analyzed with the athermal lens condition and 1/2, 1/8, and 1/16 the athermalized bond gap.



te = radial thickness of potting
Dg = lens diameter
αm = coefficient of expansion of the mount
αg = coefficient of expansion of the lens
αe = coefficient of expansion of the potting

$$te = \frac{Dg(\alpha m - \alpha g)}{2\cdot(\alpha e - \alpha m)}$$

Figure 1: Bayar's Athermalized bond gap equation.

For the configurations that Miller tested the analysis follows basic logic. When the ideal bond gap is cut in half the imparted stress from temperature is approximately doubled. Depending on the maximum stress you are willing to allow in the lens, rules of thumb can be created based on the finite element results. Using a maximum stress less than 500 pounds per square inch results in a set of possible “Rules of Thumb”. Stiff geometry lenses would be considered (Convex-Convex and Concave-Concave) any shape where the thermal force vector goes straight through the glass. Stiff lenses could possibly allow down to an 1/8 of the athermalized bond gap to be used. Lenses that are of a less stiff geometrical shape like a convex-concave lens (where there is an air gap in the line of force) could possibly use down to a 1/4 of the athermalized design.

Comparison to Other Papers:

Most other papers on athermalization focus on designing stress free bond gaps and improving Bayar's[i] original equations to account for Poisson's Ratio, or Young's Modulus. The uniqueness of this paper comes from the fact that it is acknowledged that the theoretical optimal bond gap is not always feasible. Knowing the tradeoffs between stress free and slightly stressed can greatly simplify a design. Miller focuses mostly on empirical finite element testing and less on derivations of the principle formulas.

Audience:

The audience of this paper is directed to engineers directly engaged in similar designs. The language and terminology is very mechanical and the paper rarely delves into the optical. The finite element analysis is based on Raytheon internal code that is not accessible to engineers outside of Raytheon. Miller describes his process and setup in sufficient detail, that the same analysis could easily be duplicated with Ansys, Nastran or any other finite element analysis package commercially available.

Applications:

In many design cases fully athermalized bond gaps are not feasible due to size or weight constraints. Soldier portable optical systems like weapon sights, night vision goggles or laser range finders have extremely tight size and weight requirements while maintaining extremely large temperature range requirements. Applying the type of analysis described in Millers paper would create a good staring point for an Optomechanical lens system design. The rules of thumb themselves would not negate the need for a finite element analysis but may cut down on subsequent design iterations. Minimizing bond gap thicknesses can also lead to greater lens stiffness reducing system jitter and bore-sight effects from large elastomeric mounts. Typically stiffer elastomers or epoxies are used in these applications. Further work would need to be done to evaluate if epoxies like 3M 2216 or elastomers like Summers Optical MilBond would follow the same trends for rules of thumb.

Recommendations for further work:

Miller recommended evaluating different lens sizes and mounting materials for future work. In addition further work should be done analyzing the trade-offs between non-athermalized lens design and the effects of stress induced birefringence. The optical degradation from the birefringence imparted in the lens may be the limiting factor in the design not the fracture stress of the lens. In addition to the effects of birefringence many optical systems are designed to take into account the focus shift created from index of refraction changes over temperature. The finite element models should be run to solve for displacement (prescription changes) in the lens due to the stress induced from the mounting scheme. Radially induced stresses could alter the prescription of the lens and affect performance.

More mounting designs should be evaluated for comparison to three designs analyzed in the pa Analysis of more mounting techniques may add insight to the phenomena. Alternate lens materials for example BK7 for the visible, ZnSe or Sapphire for the dual band should be evaluated. Silastic-E was the elastomer bond evaluated. In many cases Silastic-E does not have the strength required for sealing or rigid bore-sight applications. Higher strength bonds like 3M 2216 and Summers Milbond should be evaluated. More mounting substrates should be evaluated, although 6061-T6 aluminum was a good starting point other engineering materials like magnesium or stainless steel may provide different results.

Many of the systems that would use this work like soldier portable sighting systems have external lenses that have pressure requirements as well thermal requirements. The combination of effects from the lens pressure and the thermal stress could drive the allotment of thermal stress down even further. The design of mounting schemes of external pressure lenses with military environmental requirements in itself would make a good paper.

Summary:

In summary Millers work on comparing Bayar's athermalized lens equation to finite element analysis of non-athermalized design highlights a flexibility in lens bond thickness not previously published elsewhere. By juggling allowable lens stress versus bond thickness, smaller more compact systems can be designed that will still perform over wide temperature ranges. Practicing engineers should consider using Miller's rules of thumb when size or other system constraints prevent full bond athermalization. Further work is necessary though to ensure that the knowingly induced stress does not effect optical performance to much by means of birefringence or distortion of the lens surfaces. This paper is very limited in its analysis base, provides a very good starting point for a lot more lens mounting design optimization work using over all lens cell size and weight as the optimization factor instead of lens stress.

i M. Bayar “Lens Barrel Optomechanical Design Principles” in Opt. Eng 20:181. 1981